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INSIDE

JAPANESE VIEW TOWARDS THE ITER EDA

by M. Yoshikawa, Executive Director, JAERI

Japan views the ITER as the most instrumental element of its own and worldwide fusion programmes with the objective to proceed to the next step where technological feasibility of fusion energy is to be demonstrated. It intends to contribute to the advancement of the ITER process by dedicating its capability and experiences to the ITER Engineering Design Activities (EDA) and by inviting the EDA design centre to the Naka Fusion Research Establishment of the Japan Atomic Energy Research Institute (JAERI). Due budgetary requests are now in process.

Japan invites EDA

The Naka/Tokai/Hitachi area is unique in that it combines major efforts of Japan in research and technical development in both fusion and fission fields. We hope, and expect, that it could contribute to most efficient implementation of the EDA. Major institutions located in this area include Tokai and Naka Establishments of JAERI, Tokai Works of Power Reactor and Nuclear Fuel Development Corporation (PNC), and many industrial works and laboratories including Hitachi's.

Appreciation of the CDA progress and hope for further collaboration

Finally, we would like to express our appreciation and congratulations to all participants to the ITER Conceptual Design Activities, especially to the ITER Design Team, for achieving a technically feasible and consistent design of ITER. It is our hope that those achievements and experiences will be most effectively exploited in the future ITER activity now being discussed among the four Parties.

LONG-TERM R&D PLANS REVIEWED BY ISTAC

by N. Pozniakov, ISTAC Secretary

The sixth official meeting of ISTAC was held in Vienna on 12-14 September. The discussion was centred around the long-term physics and technology R&D plans worked out by the IMC. The ISTAC's final appraisal of the conceptual design will be made at the end of November when the Committee will meet for the last time during the CDA. By that time a complete draft of the ITER Conceptual Design Report will have been provided by the IMC.

Long-Term Physics R&D and need of its co-ordination

The IMC had prepared a comprehensive programme for ITER physics R&D in the period 1991-92 and beyond, which the ISTAC found to be responsive to its previous recommendations. Specific comments were made on some tasks that appear to be critical, on balancing of high- and lower-priority tasks and on the applicability of the physics R&D contributions offered by small experiments. Because of the "voluntary" nature of ITER Physics R&D, the Committee emphasized that special attention should be given to its co-ordination. Also the ISTAC noted that the IMC had developed a programme of Plasma Diagnostic R&D. This programme is planned to be supported by ITER-specific funding, which is a part of Technology R&D funds.

ISTAC Meeting. From left to right:
Prof. F. Troyon, Dr. P. Rebut, Dr. D. Sweetman,
Dr. E. Salpietro (reporting), Acad. B. Kadomtsev (ISTAC Chairman),
Dr. N. Pozniakov (ISTAC Secretary) and Dr. M. Tanaka

ITER as a centerpiece of a larger world fusion programme

Addressing ITER activities in a broader sense, the ISTAC stated that "*in addition to the physics issues identified in the long-term R&D plan that can be investigated on existing facilities, it is necessary that the ITER Parties begin planning for other physics facilities that will be needed to continue scientific progress during the decade required to construct ITER and bring it into operaion. Following the successful strategy of the past, ITER should be seen as the centerpiece of a larger world programme that includes these other facilities and prepares the way for Demonstration Reactors.*"

ISTAC supported the IMC Long-Term Technology R&D Plan providing a mission-oriented approach essential to produce the technology data base necessary for the decision to proceed to the ITER construction. Among the high-priority tasks, the Committee re-emphasized the central importance of the divertor problem, and noted that the success of ITER is also critically dependent on magnets. Given the potential advantage of the development of fusion as an energy source from an environmental and safety viewpoint, the ISTAC reinforced its earlier recommendation that emphasis be placed on low activation materials in the blanket testing programme. In this regard, the Committee also noted the key role of R&D in the area of ITER fuel cycle and tritium processing system.

Existing facilities could be made available for execution of Technology R&D Plan

Discussion of the implementation of the proposed Long-Term Technology R&D resulted in a general and positive view of the Committee members that "*a technically feasible Technology R&D Plan can be executed by task-sharing among the four Parties.*" The ISTAC noted that for the most of the scalable model tests, which it deemed to be critical, the existing facilities of the four Parties could be made available with reasonable modifications.

LONG-TERM PHYSICS R&D PLANNING

by F. Engelmann

Over the last year, a long-term Physics R&D Programme was prepared by the ITER Physics Group. This Programme takes the ITER-related Physics R&D activity ongoing in 1989-1990 as a starting point and is to provide the data base necessary for supporting the decision to start ITER construction. It should be carried out in parallel with the ITER engineering design in the years 1991-1995.

Framework Programme in 1991-95

For the full period 1991-1995 a framework programme was established which, in contrast for the 1989-1990 programme, covers all Physics R&D needs. Priority areas are:

- power and particle exhaust physics (i.e., the combined fields of plasma edge physics, plasma-wall interaction and impurity behaviour);
- disruption characterization and control;
- stationary operation in regimes with low energy transport (in particular in the H-mode);
- collective effects caused by a fast ion population.

In fact, the most crucial problems, to validate the ITER design concept and complete the physics data base required for starting ITER construction, in practical terms, are:

- the demonstration, in experiments prototypical for ITER, that operation with a cold divertor plasma ($T_e \lesssim 30$eV) is possible, that the peak heat flux onto the divertor plate can be kept below 10 MW/m^2, and that helium exhaust conditions corresponding to a fractional burnup larger than 3% can be ensured;
- a characterization of disruptions which allows specification of the consequences for the plasma facing components, and demonstration that the number of disruptions can be reduced to a level yielding an acceptable lifetime of these components;
- the confirmation that steady operation in a regime with low energy transport (in particular in the H-mode) and satisfactory plasma purity is possible under ITER condition, as well as the capability to predict energy confinement for this mode in ITER with satisfactory accuracy;
- insurance that the presence of an appreciable population of fast ions does not jeopardize plasma performance in ITER.

Further areas covered by the Programme are plasma heating and fuelling, long-pulse operation (including non-inductive current drive) and optimization of discharge startup and shutdown, as well as plasma diagnostics.

An overall assessment of the potential coverage of the R&D needs laid down in the framework programme led to the conclusion that this is satisfactory. There is redundancy in serveral areas, but concentration of efforts on some critical areas will be necessary to obtain all the information needed in time. The R&D work will have to combine experiments, theoretical analysis and modelling; in particular, systematic model development and validation, as a basis for extrapolation to ITER, is required.

Programme 1991-92 (and beyond)

An ITER-related R&D programme for the years 1991 and 1992 (but extending beyond as far as possible) is presently being developed from the framework programme 1991-1995. It is based on a detailed description of the R&D needs for ITER and the associated time schedules which were provided to the fusion programmes of the ITER Parties. The programme covers five areas and is subdivided in 22 tasks, supplemented by subtasks where appropriate for a clear definition of the problems (Table I). Ten of these tasks (marked by bold numbers in Table I) address the crucial questions listed above and therefore have been classified as high-priority tasks. The other tasks are concerned with the optimization of ITER operation, including in a few areas (power and particle exhaust; fuelling; non-inductive current drive) alternative and/or innovative schemes, the development of which may extend beyond the end of ITER design.

The coverage of the programme by the contributions which have been offered by the research institutions of the ITER Parties is generally good. However, studies of the edge plasma in ITER-relevant divertor configurations and operating conditions will be intensified only from 1992 on. Further improvement of the diagnostics for the edge plasma is needed. Work on the validation and development of models for the plasma edge as well as the characterization of candidate materials for plasma-facing surfaces (low and high Z) needs to be enhanced. The validation of theoretical predictions on the effects caused by a population of fast ions requires specific attention. The diagnostic means to characterize such a population must be improved. As far as operational issues are concerned, large-scale experiments on non-inductive current drive by fast waves will only be done in 1993 and later, and work on fast (emergency) shutdown is not yet planned.

Diagnostics

A special process was adopted for developing an R&D programme for plasma diagnostics. The activity will have to be closely related to ITER design, to a technology oriented R&D activity on nuclear properties of materials and components, as well as to the Physics R&D programme being undertaken at many tokamaks worldwide. It will draw on information arising from these programmes in evolving the R&D requirements.

TABLE I. PHYSICS R&D TASKS DURING 1991-1992 AND BEYOND
(Priority Tasks are referred to in bold)

No.	Task Description, with subcategories where appropriate
1.	POWER AND PARTICLE EXHAUST PHYSICS
1.1	Experimental exploration in hydrogenic background plasmas of the characteristics of the scrape-off layer, divertor plasma and divertor target power load, as well as validation and development of models.
	a) Poloidal and toroidal dependence of divertor power load and temperature
	b) Impact of divertor geometry variation
	c) Hot spots on plasma-facing components
	d) Impact of auxiliary heating and current drive on the edge plasma
	e) Impact of fuelling
	f) Characterization and control of ELMs (and other edge transients)
1.2	Impurity radiation and tansport in the bulk, scrape-off layer and divertor plasma
	a) Powerfully radiating plasma edge
1.3	Exhaust of helium and hydrogenic species
1.4	Active control and optimization of divertor and startup limiter conditions
1.5	Characterization and tests of plasma-facing materials
	a) Wall conditioning methods
	b) Wall conditioning between discharges
1.6	Alternative divertor target concepts
2.	DISRUPTION CONTROL AND OPERATIONAL LIMITS
2.1	Characterization and statisctics of disruptions
	a) Characterization and minimization of disruption-produced runaway electrons
	b) Characterization of disruption with soft current quench

2.2 Characterization of vertical displacement events (VDEs) and plasma motion during disruptions

2.3 Disruption avoidance and control
- a) Reliable identification of pre-disruptive state

2.4 Characterization and control of beta-limiting phenomena
- a) Impact of profile effects on the beta limit
- b) Steady-state pressure and current profiles in inductive operation
- c) Impact of the m=1 (sawtooth) and other MHD modes on high beta operation
- d) Impact of the presence of fast ion population on high beta operation

2.5 Density limit

3. ENHANCED CONFINEMENT

3.1 Steady-state operation with enhanced confinement
- a) Improvement of global energy confinement scalings
- b) Plasma particle transport
- c) Momentum transport

3.2 Control of MHD activity

3.3 Identification of transport mechanisms relevant in tokamak plasma
- a) Identification of plasma turbulence and correlation with transport

4. OPTIMIZATION OF OPERATIONAL SCENARIO AND LONG-PULSE OPERATION

4.1 Long-pulse operational experience
- a) Bootstrap current
- b) Lower hybrid wave injection and current drive in large tokamaks
- c) Fast-wave current drive efficiency
- d) Electron cyclotron current drive efficiency
- e) Neutral beam current drive
- f) Advanced non-inductive current drive techniques

4.2 Optimization of startup
- a) Lower hybrid wave current rampup and/or rampup assist

4.3 Optimization of shutdown and development of rapid shutdown techniques, with and without soft disruptions

4.4 Heating physics: heating and control of energetic ions by ion cyclotron waves

4.5 Fuelling physics: pellet ablation model
- a) Fuelling by the injection of compact toroids

5. PHYSICS OF A BURNING PLASMA

5.1 Transport of and energy transfer to the plasma from fast ions (single particle effects)
- a) Fast ion losses induced by the ripple of the toroidal field

5.2 Collective effects due to a fast ion population

5.3 Properties of DT plasma and of alpha-particle heating

LONG-TERM TECHNOLOGY R&D MEETING

by C.A. Flanagan, ITER Systems Group

Experts from the Parties meet with the Project

Invited experts from each Party met with the joint work team at Garching (referred to here below as the Project) from August 27 through August 31, 1990, to review the ITER Long-Term Technology Research and Development (R&D) Plan. This plan was developed by the Project to identify the R&D essential to produce the technology data base necessary for the decision to proceed to the ITER construction and to provide the basis for the actual construction of ITER.

The elements of the plan are presented in nine different areas: Magnets, Containment Structures, Assembly and Maintenance, Heating and Current Drive, Plasma Facing Components, Blanket, Fuel Cycle, Structural Materials, and Diagnostics. In each of these nine areas, information is presented on the key technical issues, the results to be achieved and the associated milestones, the detailed specifications of each task, the facility needs, and the cost.

The plan focuses on the R&D necessary to support a decision to be taken by the end of 1995 to start construction; where appropriate the plan includes an indication of the required R&D follow-up. For planning purposes it was assumed that the Engineering Design Activities begin at the beginning of 1991 and a Construction Activity would begin in 1996.

Objectives of the meeting

The objectives of the meeting were the following:

- to present the elements of the plan,
- to solicit feedback and comments on the suggested tasks, milestones, and costs in each design area, and
- to obtain advice from the experts in three particular areas:

  1. balance of R&D tasks and the resources allocated,
  2. major Scalable Model Testing, including possible manner of conducting the tasks and common facility (or facilities) to be used, and
  3. R&D tasks to be implemented urgently in 1991 of the EDA phase.

General findings

The experts concluded that the overall technology programme, as modified by the findings, is reasonable for implementation beginning in 1991 to produce by 1995 the technology readiness necessary for the Parties' decisions on ITER construction and to provide the data base for the construction of ITER.

The overall cost balance among the major task categories was deemed appropriate. However, the Project was requested to re-examine the cost profile year-by-year to assure that the annualized costs are the most reasonable. The Project was also requested to evaluate how to include contingency considerations in the R&D programme.

The experts indicated that, from a technical point of view, the optimal situation is to have a smooth flow from the Engineering Design Activities (EDA) to the Construction Activity. The split of the Project into separate activities (EDA and Construction) for planning of R&D is artificial and introduces additional difficulties into the overall planning of the programmatic needs. The experts suggested that consideration be given by policy makers to reflect in the planning the accompanying

1) needed preparation for construction,
2) needed long-lead equipment prototype orders, etc., and
3) the continuing R&D during the Construction Activity.

Specific recommendations

A number of specific comments were provided by the experts to improve the overall plan. A few key suggestions are the following.

1) The programme plan should clarify how it is relying on the present ongoing national programmes since many important R&D elements of these ongoing R&D programmes are being relied upon by the ITER R&D programme.
2) The critical path in the schedule of tasks should be developed and made explicit in the plan.
3) In the magnet area, because of tight schedules for completion of the Model Coil Tests and also in order to reduce the risks associated with the R&D work, it was suggested by the experts that two facilities - one for the Central Solenoid (CS) Model testing and one for TF Coil Model testing - should be considered rather than a single model coil test facility.
4) In the containment structures and assembly and maintenance areas, the need for and the timing of a full-scale mock-up/prototype should be re-examined with the recommendation that the integrated testing should occur later after detailed design has been completed. The experts recommended that the Project should also evaluate the cost-benefit of centralized versus distributed efforts.
5) In the neutral beam area, the timing for tasks for the accelerator proof-of-principle test should be re-examined.
6) In the blanket area, the plan to accomplish the needs by 1995 appears feasible, but optimistic. The experts indicated that the overall plan for the blanket for 'large' module testing requires parallel, well managed and co-ordinated efforts on design, manufacturing development, and research.
7) The erosion disruption response task for the divertor needs urgent attention and should be emphasized.

The Project will finalize the plan during the present Joint Work Session taking into consideration the findings of this meeting, submit it for review and approval by the ISTAC and ITER Council respectively, and then issue the plan.

ITER COUNCIL AD HOC GROUP ADDRESSES TECHNOLOGY R&D TASK-SHARING ISSUES

by V.A. Chuyanov, Chairman, ITER Council Ad Hoc Group of Experts

Purpose of the IC ad hoc group of experts

In order to avoid a delay in initiating ITER EDA following the completion of an EDA agreement, and also recognizing the need to include in this agreement some specific arrangements for timely beginning of those R&D tasks which determine the EDA schedule, the ITER Council appointed at its meeting in July 1990 an ad hoc group of experts (GOE) to start an analysis of how the most critical R&D tasks could be shared among the four Parties. The Council Members, on behalf of their Parties, nominated the following persons in the group: R.Toschi (EC), S.Shimamoto (Japan), V.Chuyanov (USSR) - Chairman, and G.Logan (USA).

The members of the GOE took part in the discussions of the Specialists' Meeting on Technology R&D, previously arranged by the IMC, at Garching on 27-31 August 1990. The GOE then continued its work through 4 September, producing several important conclusions.

A number of tasks should be started at the outset of the EDA

First of all, regarding the approach to organization of the initial work of the EDA, the ad hoc GOE concluded that the earlier assumption that only a very small number of critical R&D tasks would have to be initiated at the very beginning of the five-year EDA was inadequate. Their analysis showed that if the EDA duration is to be limited to five years, a one-year delay in initiation of technology R&D would make practically each task time-critical, thus jeopardizing the schedule for choosing among design options and beginning licensing procedures. The GOE agreed with most of the IMC plans for tasks that should be started in the first year of EDA.

The IMC had estimated that the total cost of these tasks in 1991, assuming beginning of EDA with full intensity in January, would be of the order of $100 million and would imply further commitments during the remainder of the EDA of the order of $500 million. The GOE viewed the organization of R&D of that scale as demanding a functioning Central Team and the permanent Director in place from the very beginning of the EDA.

Technically feasible task-sharing favourably seen

Secondly, the ad hoc group came to a unanimous opinion that the existing diversity of the Parties' fusion programmes permits technically feasible and efficient task sharing of the ITER EDA Technology R&D among the four Parties. Technical considerations result in diminishing of the number of possible options and make the problem solvable. About 70% of tasks could be shared by the Parties agreeing on the pure technical background. Sharing of the remaining 30% of tasks would require negotiations among the Parties.

Thirdly, the members of the ad hoc group came to a common understanding that, at this stage, it is better not to spend efforts to produce better definitions of tasks than those given in the IMC Technology R&D Plan. More detail definitions can only be worked out in the process of future interaction between the Central Team and the Home Teams. At the same time, the group believes that the definitions of tasks produced by the IMC are sufficient for initiation of these tasks in 1991. In the opinion of the ad hoc group, the EDA agreement should only define the main directions and the general scope of work for each Party, while the detailed task agreements should be worked out later, during the first months of the EDA.

As a result of its work, the ad hoc group generated lists of major common test facilities, scalable models and component development works to be started in 1991, and made suggestions on possible sharing of these tasks. The results of the ad hoc group meeting were delivered to the Parties' Quadripartite Exploratory Discussions (QED) Working Party and to the ISTAC. They were positively accepted by both. The Working Party suggested further refinements be made to the listing. The Working Party also used the GOE's analysis as a basis for reconsideration of the approach to organization of the initial work of the EDA. The ISTAC was led to conclude that "a technically feasible Technology R&D Plan can be executed by task-sharing among the four Parties."

Ad hoc group will continue its efforts

The results of the ad hoc GOE were reviewed by the ITER Council in Washington on October 8 - 10. Acknowledging organizational problems of the prompt initiation of R&D, the Council decided to continue the effort of the ad hoc group with the goal of reducing the list of priority tasks and associated commitments basing the schedular needs on a revised schedule to be developed by the IMC. This new conceptual schedule will be based on the assumption of a gradual startup in 1991 and will likely require somewhat more than five years for EDA completion.

AN H-MODE DATA BASE FOR ITER

by D.E. Post, Head, Physics Project Unit, ITER

Energy confinement is one of the most important physics issues for ITER

One of the most important physics issues for ITER is energy confinement. It is essential that ITER have sufficient energy confinement to achieve the plasma performance necessary to meet its goals. In practical terms, the requirement for adequate energy confinement translates primarily into requirements for the plasma current, size, and configuration. The general tendency is that energy confinement improves with increasing plasma current and size.

The initial requirements for a plasma current for ITER were set with the expectation that ITER would be able to operate in the H-mode (High-mode), an optimized confinement regime originally discovered on the ASDEX tokamak [1] and since then used routinely on most tokamaks with a poloidal divertor. ITER is designed with a poloidal divertor which aids high quality H-mode operation. The level of energy confinement with the H-mode is roughly two times the level with the L-mode (Low-mode) usually produced with operation without a divertor.

L-mode data base was created in 1988

To set quantitative requirements for ITER, it is necessary to be able to predict the energy confinement time that can be achieved in ITER. The H-mode data in early 1988 was too incomplete to allow the development of a confinement scaling based on H-mode data. There was extensive, but fragmentary, data available for L-mode confinement, and many scalings had been developed. In 1988, the ITER physics group collected a data base of the latest L-mode data from all of the large tokamak experiments (≈1800 datapoints from ≈10 tokamaks) and produced two new scalings for L-mode confinement [2]. The H-mode data available at that time showed general agreement with these new L-mode scalings if the L-mode scalings were multiplied by a factor of ≈2 to 2.2.

Effort to collect H-mode data base

However, using a factor of 2 times an L-mode scaling is inadequate if we are to have confidence in our ability to predict the energy confinement in ITER with H-mode operation. The physics of the two confinement regimes appears to be somewhat different, and there is no a priori reason that the L and H modes should have the same scaling with the plasma parameters. The plasma profiles, fluctuation levels, electric fields, MHD activity, etc. are different between the two modes. Therefore, an effort was launched involving the experimental teams of the five largest divertor experiments (JET, DIII-D, ASDEX, JFT-2M, and PDX/PBX-M) to collect a data base of the existing H-mode data and to produce a scaling for the H-mode. The effort was co-ordinated by J.G. Cordey of JET and involved J.P. Christiansen, K. Thomsen, and A. Tanga from JET, J. DeBoo, D. Schissel, and T. Taylor from DIII-D, O. Kardaun, F. Wagner, and F. Ryter from ASDEX, S.M. Kaye from PDX and PBX-M, Y. Miura, N. Suzuki, M. Mori, T. Matsuda, H. Tamai, T. Takizuka, S.-I. Itoh, and K. Itoh from JFT-2M.

The group held three meetings at JET in 1989 and 1990 to co-ordinate their work. During these meetings, the group defined the type of data that should be collected, and agreed on a common format for the data. This was necessary because the H-mode exhibits more complicated behaviour than the L-mode. Each experimental group selected, validated and compiled the data from their experiments using the commonly agreed selection criteria and format.

The groups then combined the data from all of the experiments into a single data base. A preliminary check on the consistency of the data was done and in a number of cases turned up inconsistencies and inaccuracies in the data and data anlaysis techniques. The activity thus has had important feedback to the experimental teams, leading to a revalidation of the data.

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[1] F. Wagner, et al, Phys.Rev.Lett **49** (1983) 1408.

[2] P. Yushmanov, et al, "Scalings for Tokamak Energy Confinement", Nuclear Fusion **30**, 1990.

The iterated combined data base became available by September 1, 1990. Approximately 2000 observations from about 1000 discharges were collected. A "standard dataset" of about 1200 observations was selected for analysis. Because of the complex features of the H-mode, including a variety of MHD modes at the plasma edge, changes in the plasma edge conditions, etc., 75 variables for each observation were used to characterize the data in sufficient detail (compared to ≈20 variables per observation for the ITER L-mode data basa).

1200 observations analyzed

Several preliminary scalings were developed from the initial analysis of the ITER H-mode data base for two categories of plasma edge behaviour, and for two different functional forms of the fit. They predict that the H-mode confinement time for ITER will be ≈5 s for ignited conditions, which would provide some margin over the required confinement time of ≈4 s.

Preliminary H-mode scalings

The preliminary H-mode scalings have a different dependence on plasma parameters than the L-mode scalings. The dependence on plasma current is similar, but the size scaling is stronger than for the L-mode scalings ($\tau_E \approx L^{1.8}$ compared to $\tau_E \approx L^{1.2\text{-}1.5}$, where L is proportional to the plasma minor or major radius). The magnetic field scaling is not well determined, and new experiments are being done to resolve the issue. The results of the scaling analysis performed were reported at the IAEA meeting in Washington, D.C., on October 4, 1990 as part of the ITER papers at that meeting.

The activity on H-mode energy confinement is essential to develop a credible physics basis for ITER, and is also beneficial in enhancing research in the international fusion programme. Analysis of the H-mode data base after it is released to scientists in the ITER Parties' organizations is expected to result in additional insight into H-mode transport, just as happened after the ITER L-mode data base was released in late 1988.

Collection of H-mode data is being continued

Collection of H-mode data is ongoing and specific experiments are being performed to resolve some of the uncertainties in the present H-mode data base. The H-mode data base collection will therefore continue under the ITER umbrella during the Engineering Design Activity (1991-1995). Such an activity, whereby ITER provides a focus for and facilitates the co-operation of experiments in the fusion programmes of the ITER Parties, is a very useful and important function of the ITER collaboration. In this way, collaborative research among experiments which would normally be difficult or impossible due to non-technical obstacles can be performed.

DIVERTOR REMOTE MAINTENANCE DESIGN PROGRESS AND R&D

by T. Honda, Head, ITER Assembly & Maintenance Design Unit

Importance of divertor handling

All components of ITER are classified according to their requirements for maintenance. This classification is based on the need for scheduled and/or unscheduled maintenance, by likelihood of replacement, and by the impact of the maintenance procedure on operation and overall device availability. The divertor plate is assigned to Class 1 components that are known to require frequent scheduled maintenance.

Maintenance of the divertor will be accomplished through the use of in-vessel transporters, fitted with remote manipulator, handling fixtures, and special purpose tools to minimize the replacement time and thus maximize reactor availability.

Divertor replacement is the most critical remote maintenance issue which require heavy component handling (1.5 ton), with high positioning accuracy (2-5 mm), in high gamma radiation environment ($3x10^6$ rad/hr).

Two main concepts for the transporters are being developed in detail: articulated boom and in-vessel vehicle. In the articulated boom concept, the manipulator is fixed to the end of a cantilevered structure which is deployed toroidally to position within the vessel. Kernforschungszentrum Karlsruhe (KFK) has started fabrication of a prototype of articulated boom. For the in-vessel vehicle concept (Fig. 1), a transporter travels inside the vacuum vessel on a toroidally deployed rail.

Design concept of in-vessel transporter

The rail-mounted vehicle type maintenance system is expected to have higher mechanical stability and higher mobility in maintenance operations than the articulated boom type maintenance system. Working through two midplane horizontal ports, the vehicle will travel on the toroidally deployed rail inside the vessel to the required position for the removal of the desired divertor plate and deliver it to a material transfer station located at 90 degree to the entrance port.

The following are the main design features of the system.

1) This system has a pair of semi-circular rails in the opposite side container.
2) The semi-circular rail is a simpler structure and has no actuator or drive units.
3) The semi-circular rail is deployed passively using a deploying mechanism and vehicle.
4) Two semi-circular rails are connected to form a complete circular rail, which is rigidly supported at four maintenance ports. Thereby the system is very stable.
5) The vehicle, provided with a telescoping manipulator, moves along the rail and replaces divertor plates.
6) A manipulator for replacing armor tiles can be attached to the vehicle.

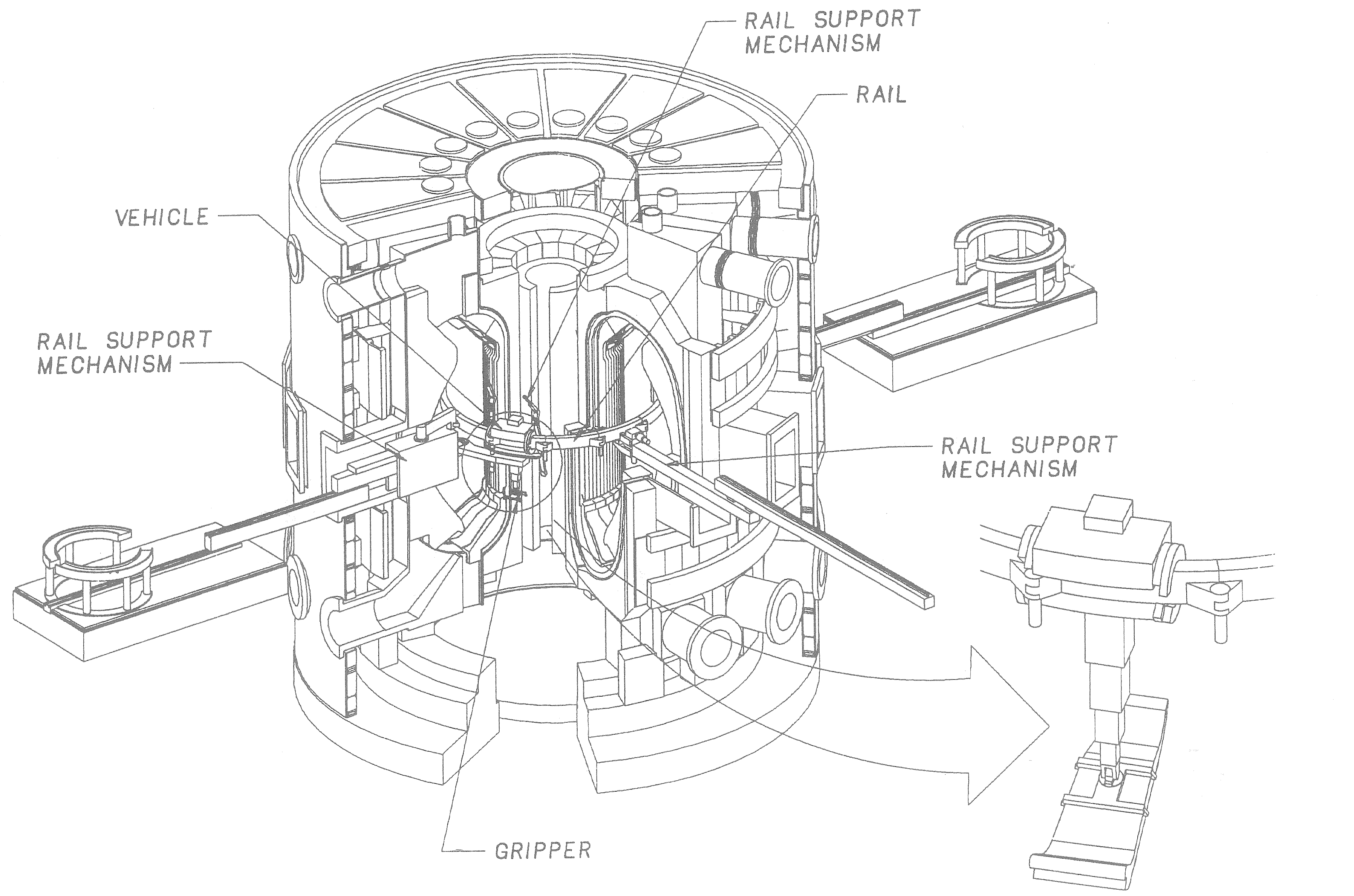


Fig. 1. In-vessel handling by vehicle

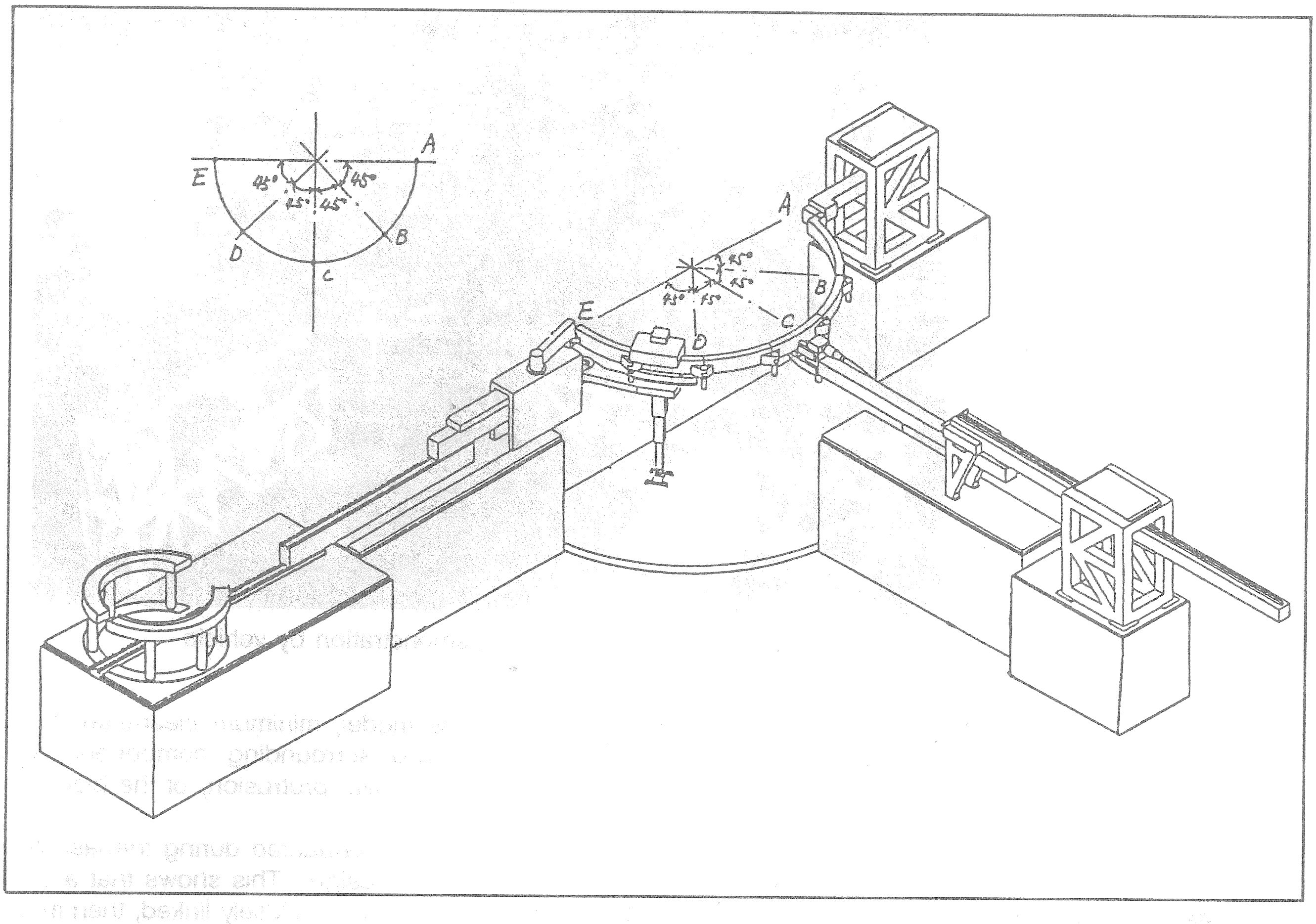


Fig. 2. 1/5 scale model of vehicle

To confirm feasibility of these concepts and to provide the data base for more detailed design of reactor and maintenance equipment, a 1/5 scale model of this system has been fabricated and tested by JAERI as one of the activities of ITER-related short-term R&D (Fig. 2,3 and 4). The following test operations were performed.

1) Deploying the rail into the torus and extracting it.
2) Moving the vehicle along the rail.
3) Swinging and telescoping the manipulator.
4) Feeding a cable simultaneously with movements of the vehicle.
5) The maximum deflection of the rail was 1.3 mm when the weight of the vehicle (30 kg) was loaded on the supported semi-circular rail (Fig. 2).

The results were successful and demonstrated that the rail is stable, simple and reliable.

In this model, a winding mechanism for rail storage and a two-step slide arm were adopted (Fig. 4). This concept is used also for the ITER design in order to minimize the impact on the reactor building by the length of a maintenance cask which was reduced to 12 m from the 24 m required for linear storage.

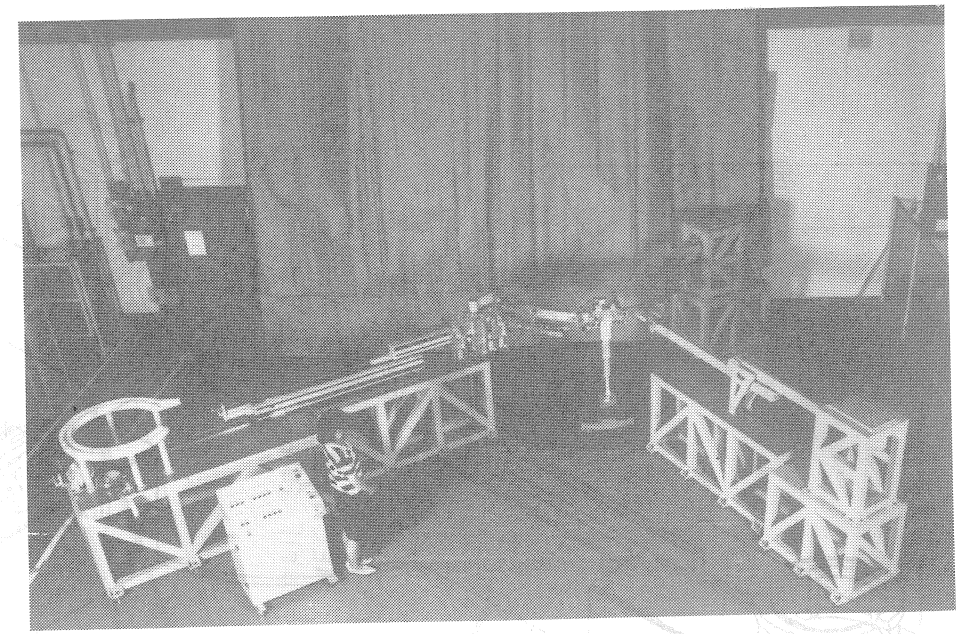


Fig. 3. Divertor handling demonstration by vehicle

Also, by using the deflection data from this model, minimum clearance during maintenance between the divertor plate and surrounding components was estimated and used to determine an inboard profile (protrusion) of the blanket.

R&D results and design feedback

This is one of the results of the short-term R&D conducted during the last three years that has had considerable impact on the design. This shows that a close linkage of the design and R&D is important. If they are closely linked, then fruitful results can be obtained. It should be emphasized that much more extensive R&D is required for both design feedback and verification of the concept feasibility.

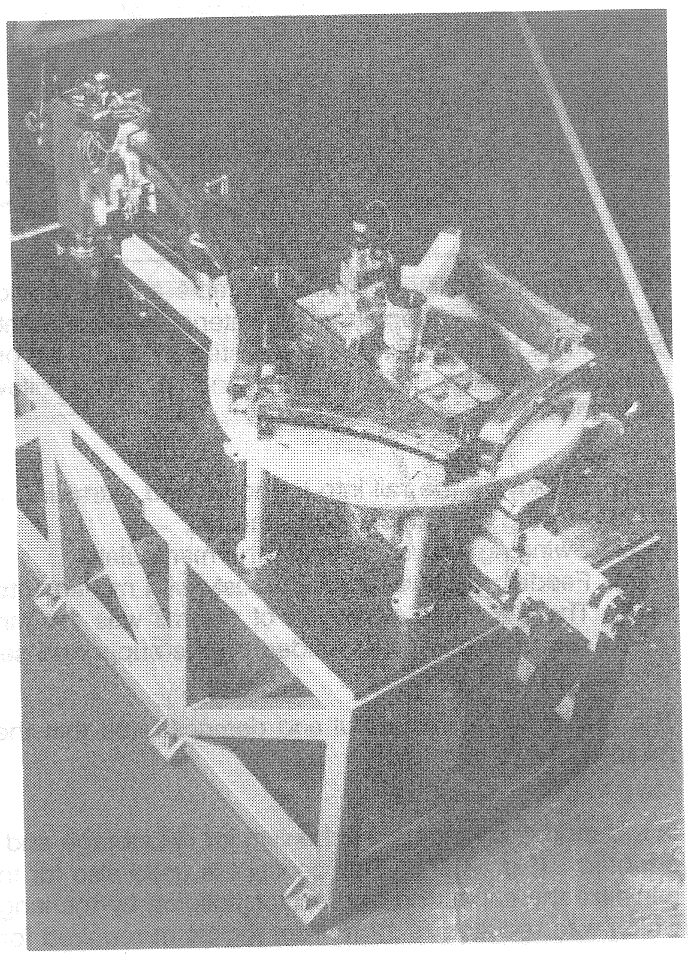


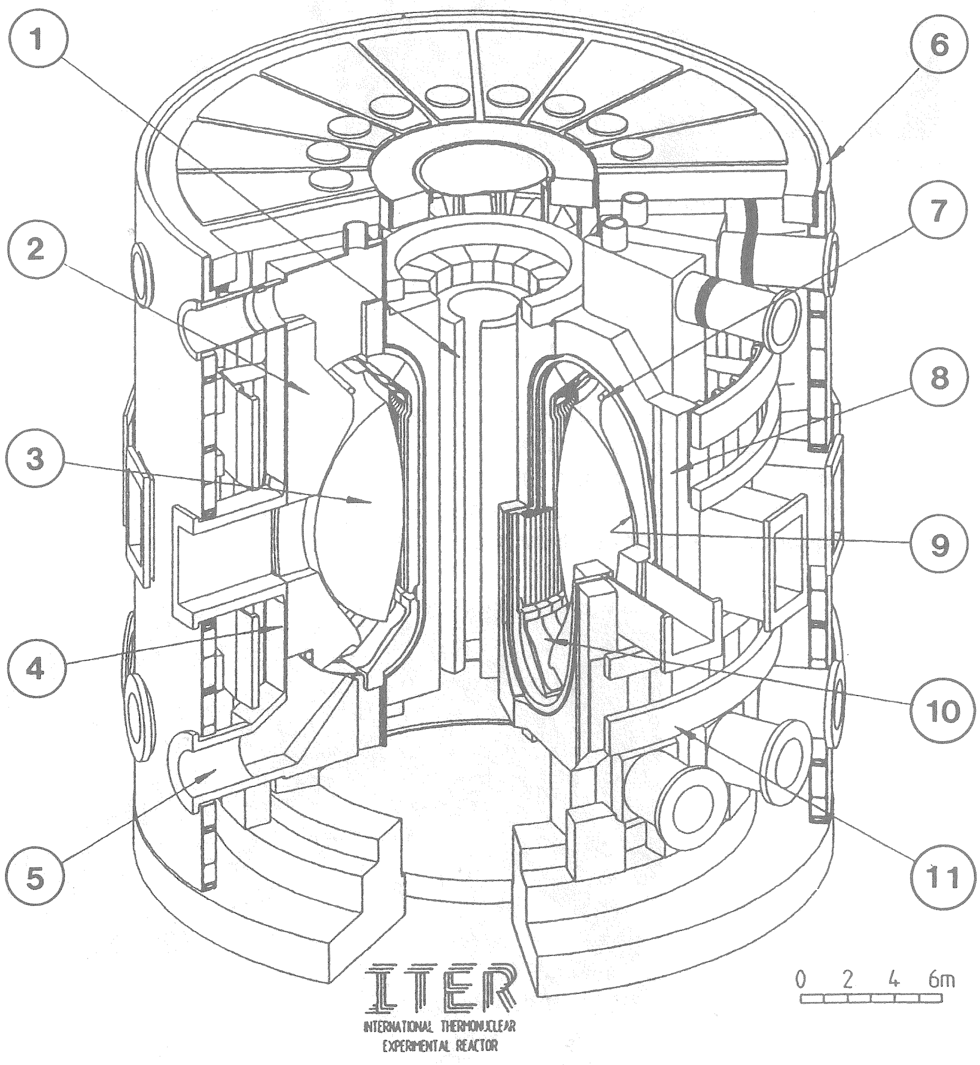
Fig. 4. Storage area of rail (1/5 scale model)

ITER MAJOR EVENTS - 1990

Joint Work Session	Garching	2 July - 16 Nov
13th IAEA Conference on Plasma Physics and Controlled Nuclear Fusion Research (ITER Session)	Washington	4 Oct
ITER Council Meeting	Washington	8 - 9 Oct
ISTAC Meeting	Vienna	28 - 30 Nov
ITER Council Meeting	Vienna	11 - 12 Dec

ITER REFERENCE PARAMETERS

Plasma major radius, R (m)	6.0
Plasma half-width at midplane, a (m)	2.15
Elongation, 95% flux surface	1.98
Toroidal field on axis, B_o (T)	4.85
Nominal maximum plasma current, I_p (MA)	22
Nominal fusion power, P_f (MW)	1000



1- CENTRAL SOLENOID
2- SHIELD/BLANKET
3- PLASMA
4- VACUUM VESSEL-SHIELD
5- PLASMA EXHAUST
6- CRYOSTAT
7- ACTIVE CONTROL COILS
8- TOROIDAL FIELD COILS
9- FIRST WALL
10- DIVERTOR PLATES
11- POLOIDAL FIELD COILS

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