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VOLUME III

**STRATEGY FOR INTERNATIONAL COLLABORATIONS IN THE AREAS OF
PLASMA MATERIALS INTERACTIONS AND HIGH HEAT FLUX MATERIALS
AND COMPONENTS DEVELOPMENT**

Summary of a Panel Meeting held at DOE Germantown

January 9, 1984

UCLA/PPG--816

DE85 001145

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Strategy for International Collaborations in the
Plasma Materials Interactions and High Heat Flux
Materials and Components Development Areas

I. INTRODUCTION

International collaboration in fusion research is receiving increased attention for good reasons. The scope (and cost) of current and planned fusion devices is such that only small numbers of them are available or being planned throughout the world. Yet each still addresses only a subset of the outstanding technical issues. Without unrealistic assumptions about budget growth it makes sense, then, to at least coordinate an international development effort toward the goal of a technically and economically viable fusion reactor.

A similar argument applies to areas of technology such as the development of high heat flux materials and components and research on the interaction of plasma with materials. A substantial research and development effort is required in these areas to provide the information needed to reliably design future machines, and in particular to address impurity control issues. Again, it makes sense to share this task and, where possible, to make use of uniquely suitable machines or other facilities in collaborative programs and projects.

The purpose of this summary is to assess opportunities for such collaborations in the specific areas of Plasma Materials Interaction and High Heat Flux Materials and Components Development, and to aid in developing a strategy to take advantage of them. After some general discussion of international collaborations, we summarize key technical issues and the U.S. programs to address them. Then follows a summary of present collaborations and potential opportunities in foreign laboratories.

II. SOME ASPECTS OF INTERNATIONAL COLLABORATIONS

Before attempting to develop a strategy, it is useful to consider some fundamental points regarding collaborations, particularly international ones.

1. Scope

Collaborations can cover a wide range in terms of scope. Even the free flow of information is already a form of collaboration, and this raises the concern mentioned below under the heading of "parity." The normal range of collaborations extends from personnel exchanges to the much more complex undertakings that involve joint facilities.

Personnel exchanges have been going on for some time and appear to work well. Table 1, which is a list of recent exchanges in the PMI area, shows first that most of these have been with European laboratories, and second that they have been going in both directions. Participating laboratories appear to find them beneficial and they cause no budgetary, programmatic or organizational concerns.

However, collaborations on a larger scale, particularly once hardware is involved, require careful planning and raise additional issues.

2. National Program Plans

When the allocation of substantial funds is required for an international collaboration, each participant must show how the project under consideration fits into the national program plan and must justify the costs in relation to other demands on the total budget. This also implies that each project must be considered in the appropriate national review processes.

3. Joint Planning

It follows from the above that each participant must be involved in planning from the earliest stages to assure that he can make the necessary commitment. It is less likely that a participant will receive funding if

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Printed in the United States of America

Available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed Copy A02
Microfiche A01

Table 1.

Some Recent International Exchanges in PMI

ORNL

R. Clausing	ORNL → KFA/JET	TEXTOR cleanup, JET diagnostics
E. Dulini	KFA → ORNL	Laser fluorescence
J. B. Roberto	ORNL → Garching	TEXTOR probes
M. Robinson	ORNL → Garching	Theory
J. Roth	Garching → ORNL	Sputtering
R. Zuhr	ORNL → KFA	TEXTOR probes

PPPL

F. Dylla	PPPL → Garching	ASDEX
G. McCracken	Culham → PPPL	Diagnostics
S. Rossmagel	PPPL/CSU → Garching	ASDEX
T. Satake	Hokkaido → PPPL	Probe studies
Ph. Staib	Garching → PPPL	Probe studies
C. Singer	PPPL → Garching	ASDEX
D. Heifetz	PPPL → Garching	ASDEX
D. Heifetz	PPPL → Culham	DITE
K. Rauh	Garching → PPPL	Modeling

SNL

J. Biersack	Berlin → SNLL	Theory
J. Bohdansky	Garching → SNLL	Sputtering
W. Gauster	SNLA → KFA	TEXTOR pumped limiter
A. Pontau	SNLL → KFA	TEXTOR pumped limiter
J. Roth	Garching → SNLL	Sputtering
W. Wampler	SNLA → Garching	Probe studies

LLNL

G. Leppelmeier (Several)	LLNL → KFA	Magnetics
	JAERI → LLNL	RTNS - II

ANL

M. Kaminsky	ANL → Nagoya	Sputtering
M. Mohri	Hokkaido → ANL	Surface roughness

his role in a given project is perceived to be secondary, or if he cannot show that his participation will expand the physics or technology base for his own program. In other words, equitable sharing of costs may not be sufficient; technological and scientific development for each participant and control of project and program objectives are additional concerns.

4. Parity

This complex issue is also best addressed by including it in planning discussions from the start. To begin such discussions, each partner must assess the cost to benefit ratio for himself, and attempts must be made by all parties to develop an equitable allocation of costs.

III. TECHNICAL ASSESSMENTS OF U. S. PROGRAM REQUIREMENTS

Technical Assessment and Program Plans are being prepared by the OFE Reactor Technology Branch Task Groups on Plasma Materials Interactions and on High Heat Flux Materials and Components Development. In addition, a Research and Development Program Plan for TFCX is being prepared. Although these documents are not yet complete, we summarize below the key issues that are emerging in order to provide a background against which to discuss present and potential collaborations.

1. Plasma-Materials Interactions

A technical assessment of the critical issues and problem areas in the field of plasma materials interactions (PMI) in magnetic fusion devices shows these problems to be central for near-term experiments, for intermediate-range reactor devices including D-T burning physics experiments, and for reactor-scale machines.

The main technical issues, questions, and immediate needs for each sub-area are:

2. PMI and Plasma Confinement

a) Poloidal divertors or pump limiters are needed in toroidal confinement devices. Will poloidal divertors be necessary to solve the impurity control and ash removal problems presently encountered and anticipated on longer pulse, strongly auxiliary heated devices, or can a suitable pumped limiter be devised to handle these tasks?

b) Auxiliary plasma heating and alpha particles affect impurity generation and control. What are the detailed effects of radio frequency heating and current drive (ion cyclotron, lower hybrid, and electron cyclotron), neutral beam injection, and fusion-produced alphas on edge impurity generation from limiter and first wall components, and on impurity transport both through the edge and in the main plasma?

c) Alternate conditioning and operational techniques are required to suppress impurities brought in with neutral beams and evolved from RF antenna and wavelength structures. Impurities which accompany neutral beam injection pose a special problem for mirror devices, where these impurities can fill in the thermal barrier in the end plugs.

d) Effects of long pulse, high power discharges on the "conditioning" of the first wall and edge structures need continuing study.

e) Fueling in large, long pulse devices and reactors is also a key issue. It is likely that fueling via pulsed gas through the edge is unacceptable for large, long pulse devices, especially if tritium inventory must be minimized. The only viable alternative appears to be pellet fueling. Therefore, the development of quasi-steady-state tritium injectors must proceed without delay.

f) Plasma edge diagnostics need development. Edge diagnostics needing the most development are those capable of measuring plasma potential, and

those which can give detailed three dimensional spatially resolved information of the edge plasma properties.

g) A further issue is the availability and reliability of primary plasma-supporting technologies and components. As long pulse length, high duty cycle devices are anticipated, the general reliability and availability of auxiliary components must be greatly improved.

3. Plasma Edge Physics Theory and Modelling

The most important immediate needs for modelling the plasma edge (or scrape-off-layer) include:

- a) The development of a combined edge plasma and neutral transport model, including the physical processes required to analyze present experimental results.
- b) The development of an impurity transport model, ideally coupled to the plasma transport model, containing realistic impurity source models.
- c) The development of a time-dependent model of the evolution of the device walls and limiters, including material redeposition and the structure of the reformed wall, and including such topics as the wall tritium inventory.
- d) Modelling of solutions to the particle and power control problems expected in future devices.

The most critical atomic and surface physics data needed for theory and modeling include:

- 1. Reflection coefficients and reflected particle energy and angular distributions at low incident energies (1 to 100 eV), on single and multi-elemental surfaces.
- 2. Hydrogen trapping, diffusion, and re-emission rates from surfaces.
- 3. Sputtering yields, distributions, and physical properties of original and redeposited surfaces, for elemental and compound materials.

4. Radiation rates for electron impact on atoms and H_2 and low (1 - 100 eV) temperatures.
5. Atomic rate coefficients for both hydrogen and impurities at low temperatures.
6. Data from comprehensive edge diagnostics on present and future devices, so that global transport models can be verified.

4. Surface Physics: Experiment and Theory

Surface physics technical issues and problem areas conveniently fall into three topical headings: hydrogen recycling; impurity generation; and vacuum and surface control. For each of these topics, the technical issues of highest priority are:

a) Hydrogen Recycling

1. Reflection coefficients and reflected particle energy and angular distributions at low incident energy (1 - 100 eV) for single and multi-component surfaces.
2. Hydrogen trapping and desorption measurements by ion-impact, photons and electrons. This need also is the same as identified under theory and modelling.
3. Tritium transport in first wall and in-vessel components. This topic is critical for near-term D-T machines. Tritium permeation will be important for high duty cycle devices. A reasonable data-base and theory exists for metals.
4. Experiments and theory of hydrogen/tritium interactions with low Z materials and coatings, e.g., graphite, the carbides, etc., at relevant operating temperatures.

b) Impurity Introduction

1. Sputtering yields as a function of selected parameters such as angle of

incidence. Also, hydrogen and self-sputtering from surfaces with re-deposited material. This work is required to add important data to a general sound data base.

2. Evaporation/sublimation and thermal shock data are needed for composite and neutron-irradiated materials. Generally, the thermal data base is good and numerical codes are available to analyze thermal response.

3. Chemical erosion rates and influence of simultaneous processes such as redeposition.

4. Arcing data for special materials and coating such as graphite and the carbides.

c) Vacuum and Surface Control

1. Physics and chemistry of surface conditioning of in-vessel components, especially those subject to high heat and particle loadings.

2. Getters for use in near-term devices with the characteristic of a low regeneration temperature.

3. Desorption and secondary electron emission data and secondary electron emission suppression for special components such as RF transmission and launching structures.

IV. MATERIALS TECHNOLOGY

For all confinement approaches, the fundamental materials technology problems for in-vessel components are related to the ability of the material to survive the plasma environment while mitigating the deleterious effects on the plasma caused by the introduction of impurities.

We note that this issue is closely tied to the control of plasma edge properties. It is unrealistic to expect that materials can be found to survive arbitrary particle and heat flux environments, and some scenarios lead to impractical requirements in terms of the frequency of replacement

of in-vessel components. Since shaping of the plasma profile is a critical physics issue, and since plasma-wall interaction strongly influences the edge characteristics, a coordinated effort in the fields of plasma physics, plasma-wall interactions, and materials technology is required. The goal of this task will be to achieve acceptable edge cooling scenarios that provide optimal plasma properties while assuring economically acceptable survival of components.

The technical assessment has identified the detailed critical issues and problem areas to be:

1. Develop the technology to apply thicker coatings to in-vessel components or plasma-side materials. Two promising approaches for low Z and refractory materials are plasma spray deposition and bonding of monolithic overlays.
- b. In situ and self-coating materials can be important for the intermediate and long-term and, given the great potential benefit, deserve attention.
- c. For the immediate and intermediate term, candidate protective surface materials include, in non-priority (alphabetical) order, Be, BeO, C, Mo, SiC, Ta, TiC and W. Candidate materials for cooled substrates are copper alloys and vanadium alloys.
- d. Research and development should concentrate on characterizing, developing, and testing both coatings and tile-to-substrate attachment techniques. Specifically, mechanical and thermal testing of joined materials needs emphasis.
- e. Testing and analysis of specific electromagnetic configurations and materials under the expected electromagnetic conditions are required to establish feasible approaches to avoiding the arcing problem.

f. Tritium permeation through the surface of the first wall and IVC's is a major problem area influencing on-site inventory, handling, and safety. A program to evaluate the magnitude of the permeation problem and for developing solutions to the problem, should it be significant, is required. Characterize: a) the production of trapping sites for tritium by neutrons; b) release of tritium through interfaces; and c) designs that act as tritium barriers.

V. STATUS OF THE TFCX R&D PROGRAM PLAN

TFCX R&D is intended to be project specific and technology related. For the present planning, it is assumed that TFCX will be designed for simultaneous ignited ($Q > 10$), long pulse ($t > 1$ min) operation. A pump limiter is the likely impurity control system. Plasma parameters will be comparable to FED/INTOR although the lifetime neutron loading will be $\ll 1$ MW - yr/m². The TFCX schedule currently calls for final design to take place in FY 1987-89. This probably restricts materials choices for high heat flux surfaces to carbon and beryllium, with copper substrates for actively cooled components.

A description of proposed TFCX R&D activities in the PMI/HNFCD areas has been prepared by the TFCX R&D Coordinators for energy/particle removal and first wall/armor subsystems. The proposed activities were developed from R&D needs defined by the TFCX Project and include seven tasks:

1. Development and testing of limiter fabrication techniques. This task involves the qualification of bonding techniques for duplex structures under simulated HNF, mechanical, and irradiation loading.

2. Development and testing of HNF materials and duplex structures. This task includes prototype testing of heat sink materials, HNF surfaces, and duplex structures under simulated TFCX thermomechanical conditions.

3. Hydrogen retention and permeation in HHF materials. This task includes hydrogen transport modelling and experiments in radiation-damaged Be and C.

4. Erosion/deposition studies of HHF materials. This task includes in-situ measurement of graphite erosion, self-sputtering of graphite at high temperature, and the influence of flux and impurity deposition on the chemical erosion of graphite.

5. Melt-layer stability of metallic HHF materials. This task involves HHF and electromagnetic testing required to determine melt-layer erosion yields for candidate materials, especially beryllium.

6. Advanced wall conditioning techniques for TFCX. This task involves the investigation of tritium-compatible alternative wall conditioning procedures for TFCX such as Cr gettering and surface carburization.

7. Neutron activation analysis of HHF materials. This task addresses neutron activation issues for candidate materials (including trace elements).

Task 1 is the most critical R&D item and requires immediate attention. An adequate design for a duplex limiter does not exist and must be developed. Tasks 2-4 are also critical to qualify duplex limiter designs under high heat flux conditions and to address specific issues in tritium inventory and erosion. Tasks 5 and 7 will begin in FY 1986 in order to take advantage of preliminary disruption and wall conditioning results from TFTR and JET. Task 7 will impact remote handling procedures and will be addressed after materials and component options have been narrowed in FY 1987.

Research areas related to pump limiter performance and edge modelling are not included in this listing since they appear in the TFCX Project under physics development and are not part of the R&D program.

VI. SUMMARY OF ONGOING WORK AND POTENTIAL OPPORTUNITIES IN FOREIGN LABORATORIES

There are five experiments in Europe and Japan of potential interest for impurity control collaborations: JT-60 (Japan) and JET, TEXTOR, ASDEX/Upgrade and TORE-SUPRA (Europe). The parameters for these machines are listed in Table 2. The major need of the U. S. program is for experience with poloidal divertors and large scale pumped limiters. This experience is needed to allow the U. S. to choose between pumped limiters and poloidal divertors for TFCX and other future machines. The U. S. program plan is to obtain much of this experience through collaborations with foreign experiments. The best opportunities for collaboration exist with the ASDEX and ASDEX/Upgrade groups at IPP, Garching, and with the Advanced Limiter Test (ALT) programs on TEXTOR. The TORE-SUPRA group has relatively little interest in collaborations. In addition, the impurity control situation for TORE-SUPRA is similar in scope to the impurity problems with TFTR in that both use toroidally localized limiters. Impurity control issues are not a focus of the TORE-SUPRA.

Similarly, the JET experiment will rely primarily on toroidally localized limiters as for TORE-SUPRA. The impurity control picture is not expected to be markedly different from TFTR, except that JET and TORE-SUPRA are longer pulse machines, which means that the heat removal problems are significantly greater for the two European experiments. Impurity control is not a focal point of the JET program, except as it is required for the achievement of plasma physics goals. One interesting program with regard to JET is the use of Be limiters which are being tested on ISX for use in JET. Be is a promising material for limiters, and progress on JET with such limiters, assuming the ISX tests are successful, will be of great interest to the United States.

Table 2.

Main Plasma and Machine Parameters

	JT-60	JET	TORE-SUPRA	TEXTOR	ASDEX/UPGRADE
R_0 (m)	3.03	2.96	2.25	1.75	1.65
a (m)	0.95	1.25	0.7	0.5	0.5
b (m)	0.95	2.1	0.7	0.5	0.8
$S=b/a$ (m)	1	1.68	1	1	1.6
$A = R_0/a$	3.2	2.4	3.2	3.5	3.3
I_p (MA)	2.7	3	1.7	0.5	<2
B_T (T)	4.5	2.7	4.5	2.0	3.9
D (sec)	10	20	30	3	<10
(pulse length)					
P_{NBI} (MW)	20	10	8	2.6	4
P_{ICRF} (MW)		15	6	3.0	12
P_{LH} (MW)	20		6		2
(wb)	25.4	25	21	4.7	9.5
Impurity	low-Z	incone1	limiters	incone1	poloidal divertor
Control	limiter	limiter		limiter	+
	+				limiter
	poloidal				
	divertor				
Operational	1985	1984	1987	1983	ASDEX 1979-1986
Date					ASDEX/U 1987-

JT-60 is a large, high power, long pulse experiment. It has a short poloidal divertor on the midplane at the outside. There has not been a lot of interest from the Japanese in an aggressive collaboration on impurity control in JT-60. We can probably learn as much as we need from monitoring the reports of their work and visiting their experiment.

There are two experiments in Europe dedicated to impurity control issues, TEXTOR and ASDEX-ASDEX/Upgrade. The U. S. is already involved in collaborations with TEXTOR group with the ALT-I (Advanced Limiter Test) and ALT-II limiter programs. The ALT-I program consists of constructing a modular pumped limiter, installing and running it on TEXTOR, and analyzing the results. The ALT-I limiter is about the size of the PDX scoop, and is heavily diagnosed. The experiments have begun recently and first results have been obtained. The ALT-I limiter was designed and built by U. S. laboratories (primarily UCLA and Sandia).

The ALT-II limiter program consists of a large, toroidally symmetric pumped limiter to be designed and constructed by the U. S. and Japan, installed in 1986 and run on TEXTOR. This large scale limiter is intended to provide a test of prototypical pump limiter designs for such large experiments as TFCX and INTOR/ETR/NET.

The TEXTOR facility is dedicated to impurity studies, and has a focus that is lacking in the U. S. program. The PDX scoop, for instance, was given only 13 run days, barely enough to condition the limiter. In that sense, TEXTOR offers the chance for U. S. to obtain useful information about limiters and pumped limiters. However, it should be noted that the power fluxes to be expected in TEXTOR are considerably less than those to be expected in a large fusion experiment, unless heating powers in the 10 MW range are used. For reasons due to the localization of recycling, large limiters are also

expected to behave differently than small limiters, and the ALT-II experiment needs to be designed to test a "prototypical" pump limiter system. The cost of the ALT programs are estimated to be 10 - 12 million dollars. The U. S. portion during that time might be between one and two million per year.

The second European experiment dedicated to impurity control is ASDEX (through 1986) and ASDEX/Upgrade (1987-on). ASDEX has a double null poloidal divertor produced by internal coils. The ASDEX experiment has been extremely useful in identifying the key physics involved in divertor operation. The divertor experiments on ASDEX will continue until a second experiment, ASDEX/Upgrade (actually an entirely new machine) comes into operation in 1987. ASDEX/Upgrade will have an external coil null poloidal divertor, similar to the INTOR divertor design. It will also feature pump limiter experiments and 12 MW of ICRF heating. The staff available for these experiments has been reduced due to the need for personnel for JET. An interest in obtaining additional staff for the ASDEX program and in obtaining modeling and data analysis codes from the U. S. has led the ASDEX groups to propose a collaboration on divertor physics with the United States. This collaboration would allow the U. S. to gain experience on divertor experiments after PDX and D-III divertor work ceases. The proposed areas for collaboration are listed in Table 3. The collaboration is planned to involve ~ 5 man years/year, and cost the U. S. \$300 - 500 k/year.

A strong advantage of both the TEXTOR and ASDEX programs is that they are dedicated to impurity control issues. The experimental program and diagnostics are tailored for impurity control studies.

Part of the information which would become available through the TEXTOR and ASDEX collaborations could be obtained in the U. S. if the U. S. funded some more experiments. The proposed Alcator DCT experiment would be a

single null poloidal divertor experiment as well as a pumped limiter experiment. Significant pumped limiter experiments have been done on ISX and PDX. PLT has several planned and one in operation. The PDX and PLT pumped limiter experiments are as large as the ALT-I experiment. A large scale pumped limiter experiment could be fielded for PLT for \$2 - 4 million dollars. The D-III expanded boundary divertor is quite prototypical of the "INTOR" divertor. The Big D program has some pumped limiter and expanded boundary divertor experiments planned.

However, in each of these cases, either the funds have not been committed (DCT, PLT large limiter), or impurity control issues have been given very low priority. Examples of the low priority given impurity control issues in the U. S. are that PDX gave only 13 run days to pumped limiter experiment, and had less than several months of divertor operation with a closed divertor before shutting down; that by far the best impurity control experiments on the D-III expanded boundary divertor were done by the JAERI group; that the bundle divertor for ISX was built, but never installed; and that the funding for the PLT high heat flux limiter improvements has been eliminated. Possibly, the best recommendation that can be made for a collaborative program with the Europeans is that they will concentrate on the impurity control issues.

VII. PRIORITIZATION OF COLLABORATIONS AND STRATEGY

Figure 1 shows the schedules for some major existing and proposed facilities and programs, both in the U. S. and in foreign countries. Parameters for the foreign devices are shown in Table 2. The schedule for JET, which is already operational, is somewhat parallel to that of TFTR.

The figure shows that significant information flow can be expected from foreign facilities such as TEXTOR, ASDEX-UG, TORE-S and especially JET to

Figure 1. Design, construction, and operations schedule of some major existing and proposed U. S. and foreign facilities.

influence ETR design. A similar statement applies to TFCX, especially if delays in that project's implementation are experienced.

As indicated in Section IV, the highest priority for the U. S. program in international collaborations is to obtain experience with poloidal divertors and large scale pumped limiters. The best opportunities are with the ASDEX Upgrade and TEXTOR programs, as well as with JET.

What is offered by the European program is the availability of long-pulse machines. This means that heat removal problems that will be encountered in next-generation machines and reactors can be addressed in the context of the overall impurity control problem. In addition, the programs of these European machines are on the whole more strongly directed and focussed toward impurity studies than is the case in the U. S.

On the other hand, the European Fusion Technology Program lacks the emphasis on PMI and HNF problems that is a key element of the U. S. program. A recent summary of the European Community's Fusion Technology Program¹ indicates that only with the 1982-1986 Fusion Program has Europe provided separate funding for the technology part, which is now considered essential for meeting the requirements of the NET project. The program elements included are:

- superconducting toroidal and poloidal coils,
- tritium and refueling systems,
- breeding blankets
- remote operations and maintenance
- irradiation studies and the development of fusion materials
- safety and environmental impact studies

1. A. Malein, Nucl. Engin. and Design/Fusion 1, 3 (1984).

The materials work is focussed on the effect of irradiation on bulk material properties and does not specifically include work on materials for in-vessel components. The comment is made that surface damage due to plasma particle bombardment is included in the general surface physics program, which is not part of the Technology Program.

The surface physics or PMI programs at Culham, KFA Juelich, and especially IPP Garching have traditionally been very strong and there has been effective collaboration with U. S. laboratories, as seen in the list of exchanges in Table 1.

Based on the above assessment, a strategy that presents itself is to focus international collaborations on reciprocal participation in each partner's strong program elements. In this way optimum utilization of facilities and parity of investment and returns could be provided.

The means that the U. S. would participate in experimentation, particularly in the area of impurity control, on long-pulse machines available in Europe. To assure an appropriate voice in program direction and control, commitment to joint development of some hardware and diagnostics as well as the assignment of staff for extended periods (several months at one time) is required.

In return, European groups could participate in materials and components development programs in the U. S., especially in the use of test facilities. This would involve assignment of staff for extended periods to U. S. facilities. Research in PMI would continue to benefit from exchanges that make optimum use of the complementary facilities that are available at U. S. and European laboratories.

Table 3.

Areas of Cooperation with ASDEX

- I. Boundary Theory and Modelling
 - A. Theory and Modelling
 - B. Impurity and Atomic Physics
 - C. Predictive Transport Codes

- II. Experimental Operations
 - A. ICRF (ASDEX and ASDEX-Upgrade)
 - B. Fluctuations and MHD
 - C. Continuation of "H-Mode" Studies
 - D. Interpretive Transport Codes
 - E. Plasma Control
 - F. Charge-Exchange Recombination Diagnostics
 - G. Divertor Operation
 - H. Pump limiter Operation
 - I. Pellets

- III. Component Design and Testing
 - A. Limiter and Divertor Surface Physics and Engineering
 - B. Antennas and Systems (ICRF)

- IV. Hardware Contributions
 - A. Plasma Diagnostics
 - B. Limiter Components
 - C. Edge Diagnostics