Highlights of EU Physics R&D Plans

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SYNOPSIS:

- Developments in the EU fusion programme
- Recent developments in EU Tokamaks
- Planned contributions to High Priority Physics R&D Issues

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EU Fusion Programme

- **The research budget for the 6th Framework Programme (FP6: 2003-2006) has been approved:**
  - fusion budget of 750MEuro (cf: 788MEuro in FP5)
  - this includes contribution to expected start of ITER construction
- **EFDA Technology Workprogramme for FP6 includes substantial increases in funding of Design and R&D in ITER H&CD and Diagnostics**
- **Initial EU assessment reports on candidate ITER sites at Cadarache (France) and Vandellos (Spain) (preliminary) have been completed:**
  - JASS meetings in December
- **New EU Task Force established to address PWI issues for ITER**
  - focus on erosion, redeposition and tritium retention
  - Leader: V Philipps; Deputy Leaders: J Roth, A Loarte
  - incorporates US collaboration involving PISCES-B

Developments in the Major EU Tokamaks

Principal EU Tokamaks

Device	Location	Config	R (m), a (m)	I_p (MA)	B_ϕ (T)	P_{aux} (MW)
ASDEX Upgrade	Germany	Divertor	1.65, 0.5	1.2	2.0	22
COMPASS-D	UK	Divertor	0.56, 0.21	0.28	2.1	
FTU	Italy	Limiter	0.93, 0.30	1.6	8.0	5.3
JET	EU (UK)	Divertor	3.0, 1.0	6	3.8	35
MAST	UK	Spherical	0.75, 0.55	2	0.6	6.5
TCV	Switzerland	Divertor	0.88, 0.24	1	1.54	4.2
TEXTOR	Germany	Limiter/ DED	1.75, 0.48	0.8	3.0	9
Tore Supra	France	Limiter	2.4, 0.79	2.1	4.25	15

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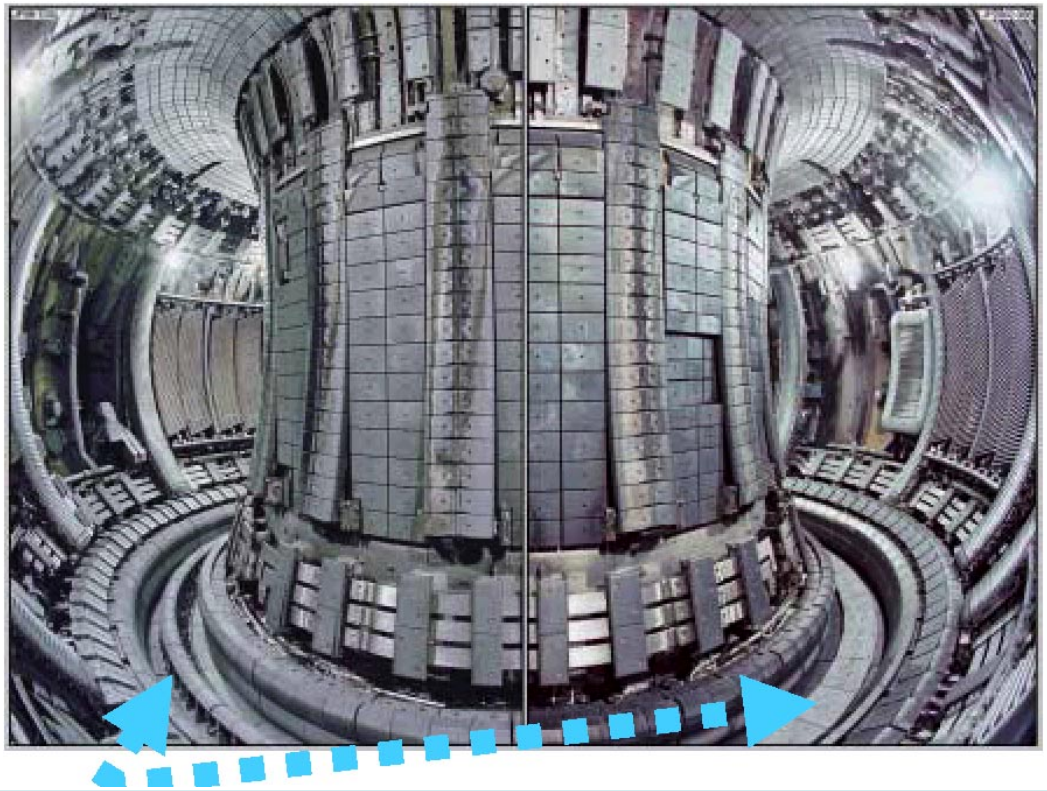
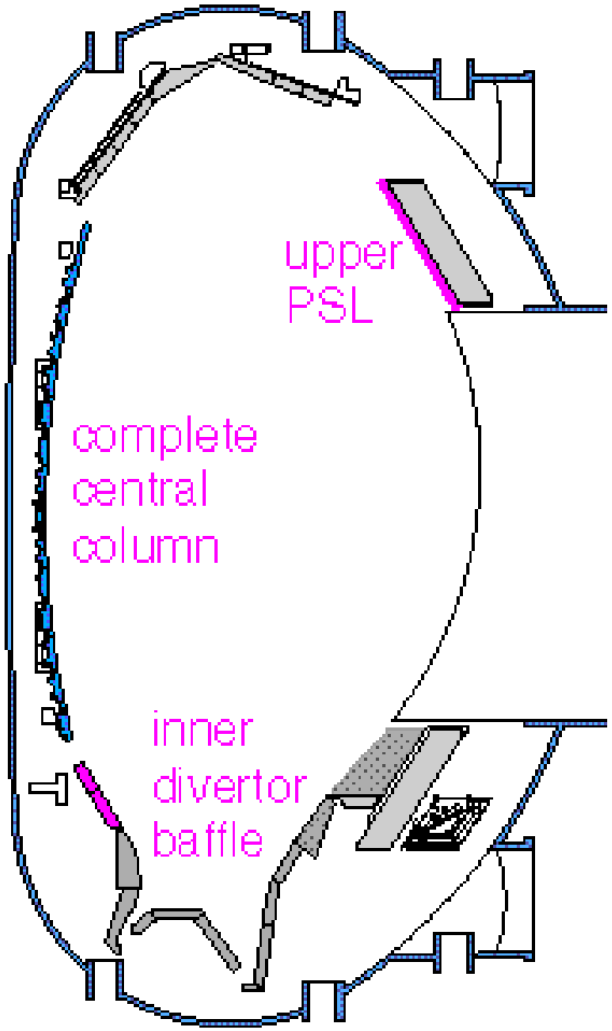
EFDA-JET



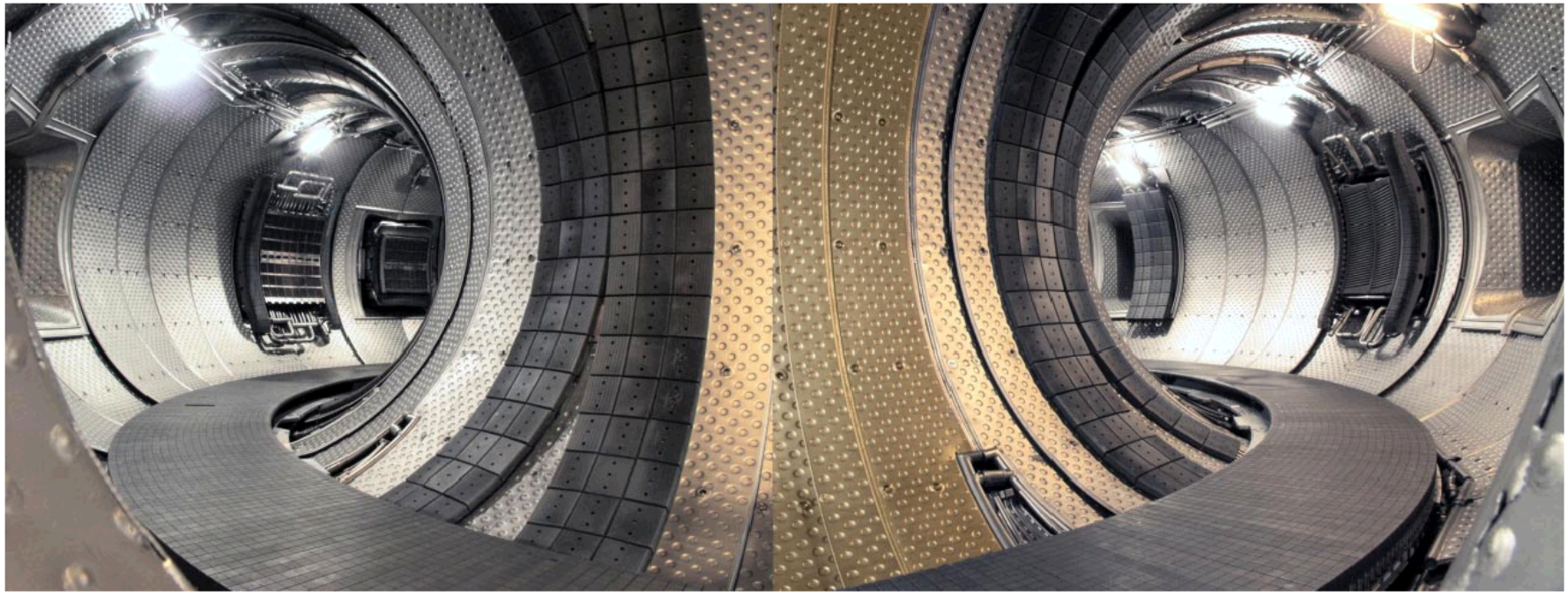
- **JET now operating without divertor septum**
- **Planned programme for 2003 includes:**
  - trace tritium experiments
  - reversed B_t/I_p studies
  - confinement studies to 4-5MA

ASDEX Upgrade



- **extension of tungsten coverage of vessel:**
  - inner divertor baffle and upper PSL
  - higher power capability in limiter discharges
- **C & W erosion/ deposition markers**
- **Extended pulse and heating capability:**
  - δ=0.45, 1MA, 15MW for 6s
  - δ=0.55, 0.8MA, 15MW for 10s
- **2MW ECRH for 2003:**
  - 110/ 140GHz, partly step tunable

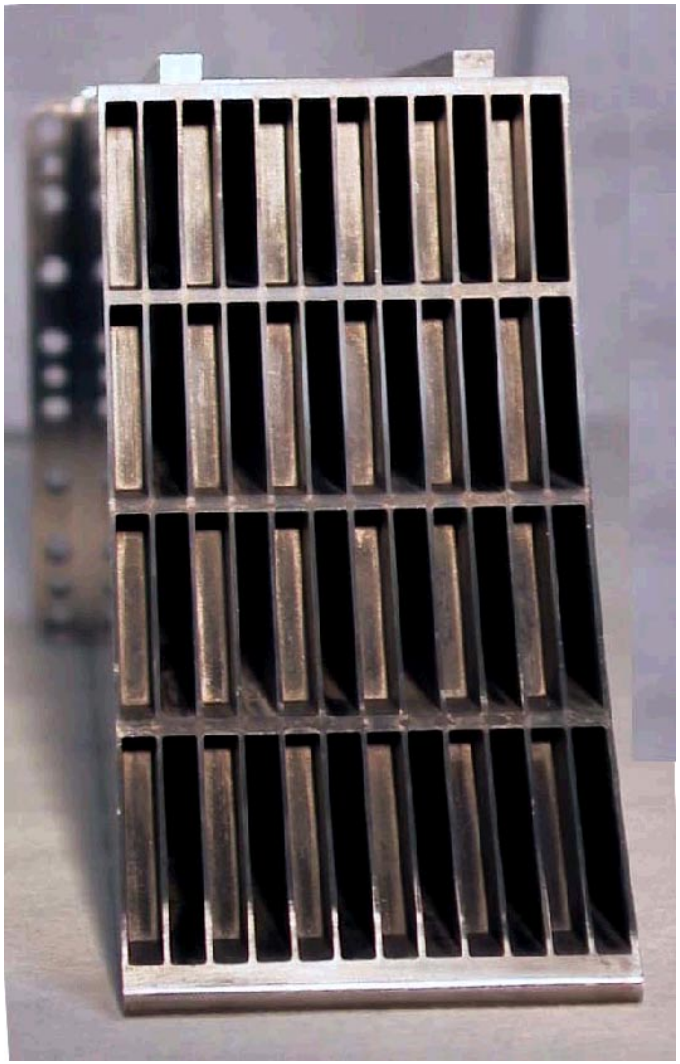
Tore Supra



- **CIEL limiter now in routine operation:**

  >800MJ of energy deposited into plasma

FTU

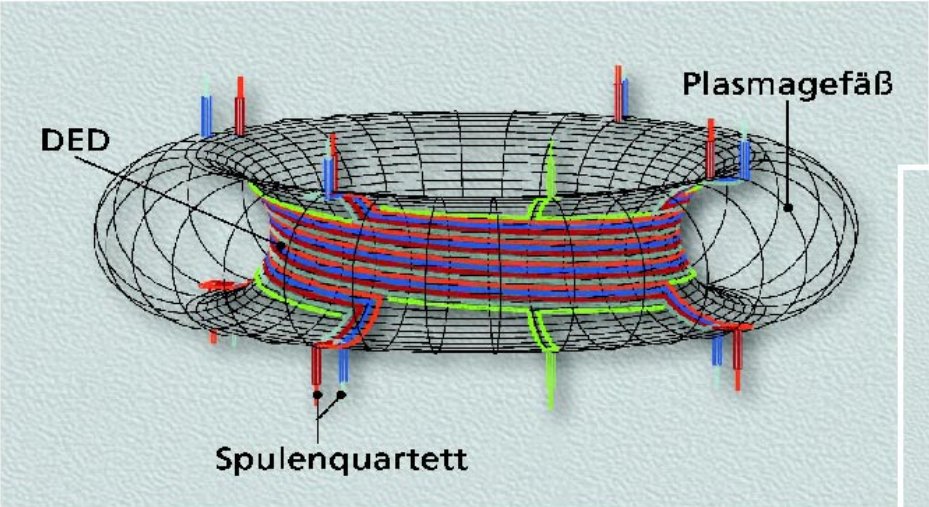


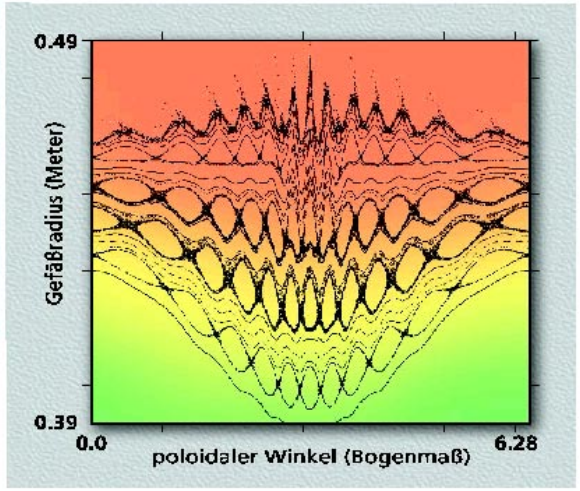
- **laboratory characterization of PAM launcher complete:**
  - installation in FTU scheduled for early 2003

FTU port	420 × 80 mm
PAM modules	4 × 3
Active/passive wgs per row	6/6
Output waveguide	28 × 5 mm
Wall thickness	0.8 mm
Phase pitch (active wgs)	270°
$N_{\parallel}$ peack	2.4
$N_{\parallel}$ (φ = -180° ÷ +180°)	1.6 ÷ 2.9

- **1MW ECRH available for H&CD and NTM stabilization studies**

TEXTOR

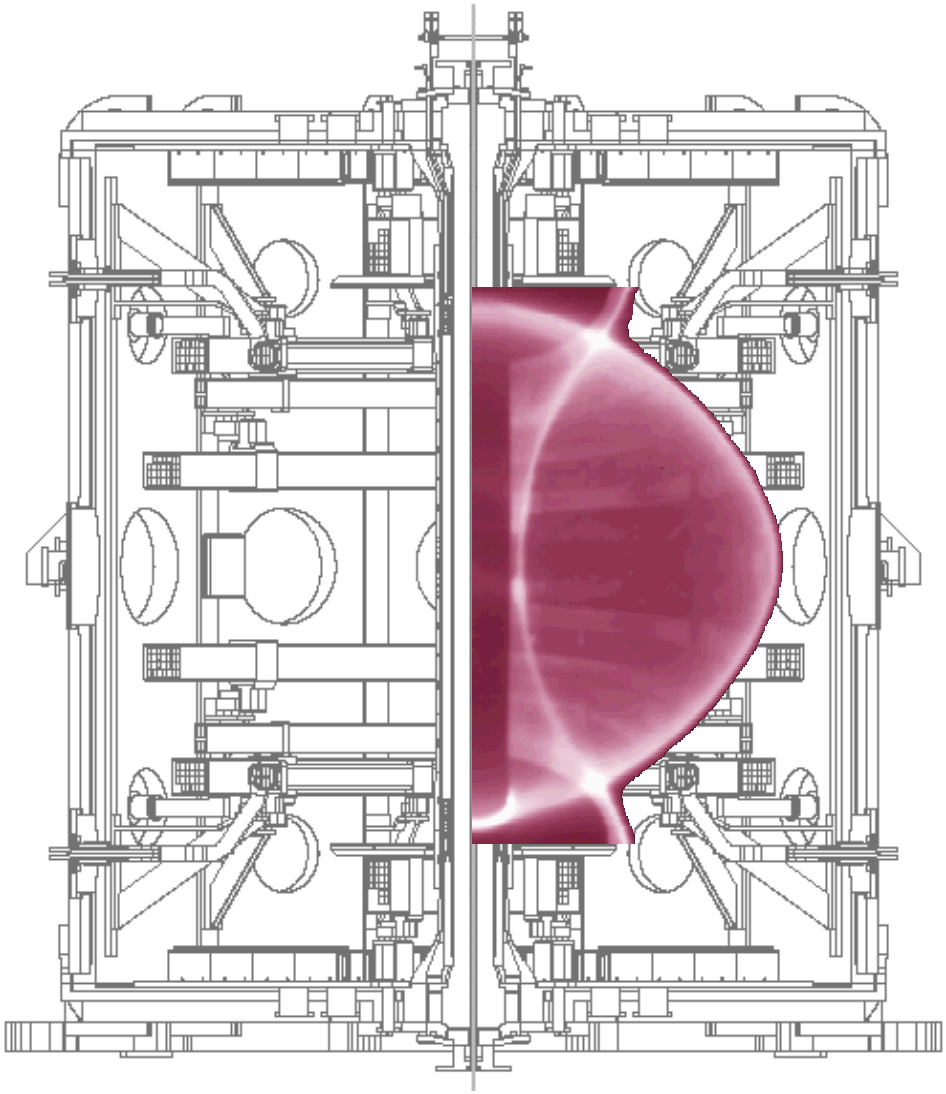




- coils generate distortion field
- 18 coils, phasing generates rotating field
- **DC, 50 Hz, 1 – 10 kHz**

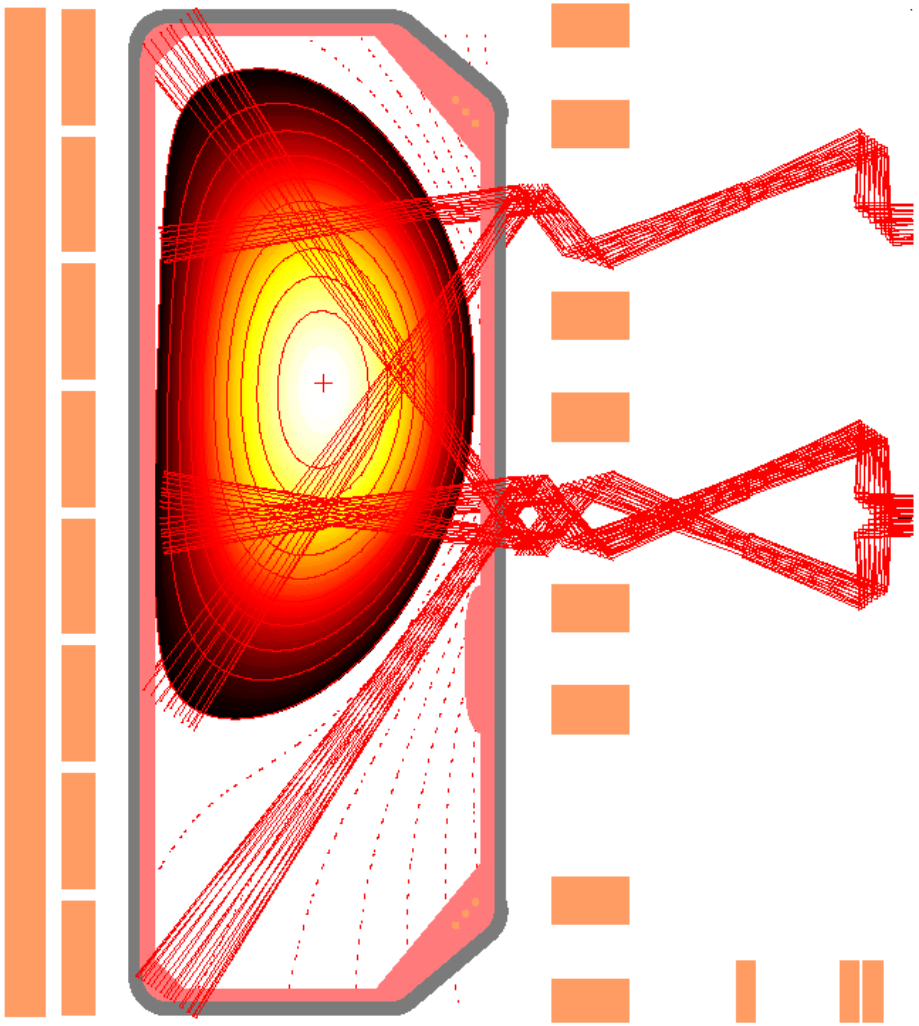
- **Operation with Dynamic Ergodic Divertor expected before end-2002**
- **140GHz, 1MW, 10s ECRH added to 110GHz, 400kW, 200ms**
- **Extensive new diagnostics capability:**
  - 2D reflectometry, 2D ECE imaging, CTS, USXR

MAST



- **Up to 3MW of NBI power available:**
  - extension to 5MW likely during 2003, with pulse length of up to 5s
- **EBW CD planned for 2003**
- **Continuous divertor targets planned for 2003**
- **Extensive high resolution diagnostic set**

TCV



- **Up to 4.5MW of ECRH power available:**
  - 3MW, 82.7GHz ($2\omega_{ce}$)
  - 1.5MW, 118GHz ($3\omega_{ce}$)
- **Extensive core and edge diagnostic upgrades underway**

Planned Contributions to High Priority Physics R&D

Diagnostics

- **Determination of requirements for measurement of q(r) and assessment of possible methods that can be applied to a BPX:**
  - funded within EFDA Technology Workprogramme (CEA, FOM, UKAEA, VR)
  - TEXTOR will perform comparisons of measurements with polarimetry and MSE
  - JET studying use of TAE observations for determining major features of q-profile (eg q_{min})
  - several devices have analysis underway to incorporate polarimeter/MSE measurements in equilibrium reconstruction codes
- **Determination of measurement requirements in divertor region and recommendation of diagnostic techniques:**
  - assessment underway led by CRPP
  - JET have programme on erosion/ redeposition and tritium retention diagnostics

Diagnostics

- **Assess impact of RIEMF on magnetic measurements and perform improved measurements on prototype coils:**
  - funded within EFDA Technology Workprogramme (SCK/CEN)
- **Determination of life-time of plasma facing mirrors used in optical systems:**
  - JET and Tore Supra are implementing programmes
  - plasma simulator studies are also under consideration
- **Development of methods of measuring the energy and density distribution of confined and escaping alpha-particles:**
  - Riso, TEXTOR and FTU pursuing studies of Collective Thomson Scattering
  - JET has collaboration with PPPL and Colorado School of Mines on Faraday Cup and Scintillator Box diagnostics for lost alphas

MHD, Disruptions & Control

- **MHD stability analysis of H-mode edge transport barrier under Type I and tolerable ELM conditions:**
  - JET, ASDEX-U, TCV and MAST are undertaking extensive campaigns on ELM studies, including pedestal characterization and mhd stability analysis, with particular modelling contributions from CEA, TEKES and UKAEA
- **NTM island onset threshold scaling and theory:**
  - JET, ASDEX-U, FTU, TCV and MAST contributing to experimental studies and theory validation
  - nonlinear stability analysis at VR (Chalmers) and Ecole Polytéchnique
- **Stabilisation of NTM islands at high ß and ß recovery:**
- **Requirements on RF stabilisation of 3/2 and 2/1 NTMs in reactor plasmas and control system requirements for diagnostics:**
  - ASDEX-U and FTU studying stabilization by ECCD, JET by ICCD
  - JET and TCV studying NTM suppression by sawtooth control
  - studies of ‘FIR’ regimes on ASDEX-U and JET
  - NTM stabilization modelling at CEA and CNR-Milan

MHD, Disruptions & Control

- **RWM analysis and experimental verification of control:**
  - modelling of RWM control at VR (Chalmers)
  - studies foreseen in JET and ASDEX-U
- **Disruption DB extension**
  - wide-ranging experimental and modelling analysis underway
  - JET, ASDEX-U, TEXTOR and MAST contributing to disruption characterization in terms of timescales, halo currents and forces and runaway electron studies
  - programme on 3D modelling of disruptions underway at CNR-Padua involving US collaboration
  - runaway production (via avalanche) and loss modelled in collaborative studies by CEA, UKAEA and VR (Chalmers)
  - disruption mitigation and avoidance studies on JET, ASDEX-U and TEXTOR

Steady-State Operation & Energetic Particles

- **Steady state plasma operation in existing devices: Define proper figures of merit for high fusion gain, high bootstrap fraction plasmas. Investigate full current drive plasmas with significant bootstrap current including real time current profile control:**
  - JET, ASDEX-U (10s), Tore Supra (CIEL - 1000s), FTU and TCV focus a significant part of their experimental programmes on such studies
  - ongoing programmes on several of these devices to address real-time control of plasma parameters
- **Compare model predictions with experimental data for heating and current drive. Study ECCD off-axis beyond r/a~0.4. Assess off-axis NBCD localisation. Optimise ICRH coupling through experiments and models:**
  - detailed modelling studies underway at several laboratories, in particular through JET collaborations
  - detailed assessment of off-axis ECCD to be performed in TCV
  - ASDEX-U continuing off-axis NBCD studies
  - Continuing studies on improved coupling at JET (JET-EP), ASDEX-U

Steady-State Operation & Energetic Particles

- **Studies of fast particles collective modes in low and reversed magnetic shear configurations: identify key parameters; use/identify the necessary modelling code:**
  - extensive studies of AEs, in particular in RS scenarios in JET, but also in MAST
  - Influence of fast particles/ mhd on ITBs in ASDEX-U
  - theoretical developments and model validation at several laboratories, CRPP, ENEA, UKAEA, VR

Transport & ITB

- **Improve experimental characterization and understanding of critical issues for reactor relevant regimes with ITBs, including: ITB formation and sustainment conditions, impurity accumulation (low- and high-Z), compatibility with divertor requirements ($n_{sep}/n_G \geq 0.3$):**
  - detailed studies are underway at all major EU tokamaks to address these issues
  - increasing emphasis on extension of regimes to higher densities - exploitation of pellet injection (steady-state pellet injection on TS in 2003)
  - tritium and helium transport to be addressed in JET in 2003
- **Develop, manage and analyze the new international experimental ITB database in order to test predictive theory-based models:**
  - major collaborations have been established between the EU laboratories to make comparative studies of experiments and modelling

Transport & ITB

- **Study experimental plasma results that challenge whether ion transport is fully understood, such as flat core profiles, etc:**
  - several experiments are using variations of electron/ ion heating and use of pellet injection to manipulate plasma profiles to provide more severe tests of models
- **Test simulation predictions via comparisons to measurements of turbulence characteristics, code-to-code comparisons and comparisons to transport scalings:**
  - extensive model developments and experimental comparisons are underway involving many EU fusion labs (note, in particular, JET Transport Task Force)
  - basic analysis of turbulent transport is underway in several EU laboratories (JET, CEA, CRPP, ENEA, IPP, VR)
  - limited information on experimental behaviour of turbulence, but measurements are underway on several devices (JET, ASDEX-U, FTU)

Confinement Database & Modelling

- **Assemble and manage multi-machine databases, analysis tools, and physics models (global L-mode and H-mode confinement and the H-mode Threshold, and through collaboration with other Topical Groups, the Joint Pedestal/H-mode and Profile Databases):**
  - all major EU devices are contributing to the international confinement databases
  - several labs are providing direct support to assembly and maintenance of DBs (CEA, UKAEA, EFDA)

Confinement Database & Modelling

- **Develop more sophisticated global scaling models (e.g., taking into account profile effects, pedestal parameters, and non-linear dependencies) to identify physical reasons for machine-to-machine differences, and develop and test physics based transport modes against the profile data:**
  - collaborative experiments between the major EU devices are addressing the question of machine-to-machine differences (eg JET/ ASDEX-U)
  - focus on understanding core-pedestal relationship and developing relevant models and scalings
- **Use the models to predict the performance of Burning Plasma Experiments, including an estimate of the uncertainty of the predictions**:
  - major current contribution in modelling from VR
  - studies and IPP and UKAEA on analyzing scaling uncertainties

Pedestal & Edge

- **Improving predictive capability of pedestal structure through profile modelling:**
  - comparative experiments in JET and ASDEX-U are addressing this issue, but theoretical progress is limited
  - theoretical emphasis on mhd stability of pedestal modelling - ‘theory’ of the pedestal not yet in sight
  - TEXTOR may offer new insights through DED
- **Constructing physics-based empirical scaling of pedestal parameters:**
  - JET, ASDEX-U, TCV and MAST are contributing to pedestal database
  - diagnostic capability continuing to improve
- **Improving predictive capability for ELM control and accessibility to small ELM regimes:**
  - JET, ASDEX-U, TCV and MAST are exploring aspects of ELM control
  - JET and ASDEX-U have major programmes on understanding access to small ELM regimes and exploring operating space

Divertor & Scrape-off Layer

- **Understanding the effect of ELMs/disruptions on divertor and edge structures:**
  - JET, ASDEX-U and MAST have programmes underway to obtain improved measurements
- **Tritium retention & the processes that determine it:**
  - substantial efforts underway within the EU programme on JET (tritium retention programme TF-E/TF-FT - improved diagnostics), ASDEX-U (tungsten), Tore Supra (CIEL) and TEXTOR
  - new EU TF on PWI will focus activities on this issue
- **Improve understanding of SOL plasma interaction with the main chamber:**
  - all major EU tokamaks have experimental programmes addressing this issue
- **separatrix density and divertor performance (or edge profile modelling) for high density H-mode:**
  - JET, ASDEX-U and MAST are addressing this issue, particularly through plasma shaping and pellet injection