5 THE EDUCATIONAL ROLE OF THE CRPP

In the frame of the Physics Department of the EPFL, the CRPP plays a role in the education of undergraduate and postgraduate students. Advanced education and training in fusion related topics is carried out in the frame of the research activities of the Association. Section 5.1 presents the 6 courses which were given to physics undergraduates and to engineering undergraduates. In their fourth and final year, physics undergraduates spend time with a research group at the EPFL, typically one day per week for the whole year. During this period, they perform experimental or theoretical studies alongside research staff, discovering the differences between formal laboratory experiments and the "real" world of research. After their final examination at the end of the 4th year, physics students are required to complete a "diploma" work with a research group, typically lasting a full semester. This diploma work is written up and defended in front of external experts. The CRPP plays a role in all of these phases of an undergraduate's education, detailed in Sections 5.2 and 5.3.

As an academic institution, the CRPP supervises Ph.D. theses, also in the frame of the Department of Physics of the EPFL. At the end of 1999 we had 22 Ph.D. students at the CRPP, mostly in Lausanne but also one in Villigen. Their work is summarised in Section 5.4.

5.1 Undergraduate courses

K. Appert, ***Chargé de cours – "Plasma physics II"***
Option course presented to 4th year Physics students, introducing the theory of hot plasmas via the foundations of kinetic and magnetohydrodynamic theory and using them to describe simple collective phenomena. Coulomb collisions and elementary transport theory are also treated. As a by-product, the student learns to use various theoretical techniques like perturbation theory, complex analysis, integral transforms and solution to differential equations.

N. Baluc, ***Chargée de cours – "Material Physics"***
Basic course on material physics, presented as an option to 4th year Physics students. The course covers the theory of diffusion, dislocation and plasticity as well as the characterisation of materials. Experimental techniques used in materials studies, as well as analysis methods are presented for super-alloys, quasi-crystals, ceramics, composites and polymers.

J.B. Lister, ***Chargé de cours – "Plasma Physics III"***
An introduction to controlled fusion, presented as an option to 4th year Physics students. The course covers the basics of nuclear fusion energy research. Inertial confinement is summarily treated and the course concentrates on magnetic confinement from the earliest linear experiments through to tokamaks and stellarators, leading to the open questions related to future large scale fusion experiments.

M.Q. Tran, ***Professor – "General Mechanics"***

Winter semester 1999-2000 (2 hours of lecture and 2 hours of exercises) for the "Microtechnics and Materials" section. The course covers kinematics and basic Newtonian mechanics of material points and rigid bodies.

M.Q. Tran, ***Professor – "Plasma Physics I"***
An introduction to basic plasma physics, presented as a one semester optional course to 3rd year Physics students. The course treats the fundamental physics of both magnetised and unmagnetised plasmas.

L. Villard, ***Assistant Professor – "General Physics I-II-III-IV"***
An elementary introduction course in physics for engineering students at the EPFL, spanning 4 semesters.

5.2 Undergraduate work

EPFL Students

Fabien WERNLI: ***"Formalism of Langmuir waves."*** The goal was to train a student without any prior knowledge of plasma physics in the use of a variety of tools which are essential for a plasma physicist, linearisation of differential equations and their analytical and numerical solutions. At the same time he has been introduced into the fluid theory of Langmuir waves in a hot plasma. He has solved the eigenvalue problem describing the oscillations of these waves in both a uniform and a non-uniform plasma contained in a cylinder.

Malko GINDRAT: "***Diagnostics of a DC plasma torch by optical emission spectroscopy: determination of temperature and density of the plasma jet.***" DC plasma torches are widely used for deposition of metallic and ceramic materials by thermal spraying. Determination of the plasma jet parameters is needed to further improve the spraying processes. In this work optical emission spectroscopy was used to determine the temperature and density profiles of the plasma jet of a DC torch operating with argon and argon/hydrogen mixtures. Absolute emission intensities of neutral and ionised argon lines were measured using a monochromator fitted with an optical multichannel detector. The system was calibrated using a spectral radiance standard. Assuming cylindrical symmetry of the plasma jet, Abel inversion was used to obtain the radial profiles of local emission. Temperature profiles were obtained from calculated emission coefficients assuming local thermodynamic equilibrium. The plasma density was estimated from collisional spectral line broadening measured with a high resolution monochromator. *

Gilles ARNOUX: "***Heterodyne interferometry.***" This work was an introduction to interferometry and heterodyne techniques, as used on all high temperature plasma experiments including TCV. It consisted in assembling a table-top Mach-Zehnder interferometer using a low power He-Ne laser, a fast time-response photodiode and an optional photoelastic Bragg-cell 40 MHz modulator with coherent detection. The simplest experiments aimed at determining the refractive indices of objects such as sheets of transparent plastic and glass. Similarly, the refractive index of air was measured by evacuating a short piece of tube in the measurement arm of the interferometer. A more ambitious experiment was then undertaken in which the propagation of sound waves (f~15 kHz) in air was measured interferometricslly. To this effect the output of the 40MHz coherent detctor was further demodulated by a

* The work described under this Section was not performed within the frame of the Association Euratom – Confédération Suisse.

lock-in amplifier to extract the phase and amplitude of the acoustic wave as its source was slowly moved with respect to the interferometer. In a final experiment the student measured the effect of air turbulence produced by a jet of air from a compressed air nozzle on the interferometer. The student will contine practical work on the TCV interferometer in the following term.

Exchange students

Benjamin CENSIER: ***"Interfaces for TCV advanced analysis codes"***, Ecole Nationale Supérieurede Physique de Strasbourg, France - A graphical user interface (GUI) using the Matlab software has been developed to enable the connection between the TCV data and the codes needed to analyse the wave-particle interaction of ECH waves. The data are retrieved from the MDS server and automatic fits using cubic spline with tension are performed in order to obtain the electron temperature and density profiles. The geometry of the plasma equilibrium and of the launcher are also obtained from the MDS server. Then the equilibrium code CHEASE is used to obtain the format needed for the ray-tracing code TORAY. Finally TORAY is run and the output are organised such as to be able to visualise them easily from matlab also. Thanks to this very user-friendly interface, it is now easy to compute the waves trajectory and power absorption profiles. This has enabled more scientists to obtain ray-tracing results and has therefore significantly improved the data analysis of the TCV experiments.

Tobias GEMPERLI: ***"Enhancements to the TCV statistical analysis package"***, ETH-Zürich - Development of software for TCV databases in Matlab, both reliable and flexible database manager (MDB 2) and advanced graphical presentation of the data (DBPLOT 3).

Jan HORACEK: ***"Improvements to Langmuir probe analysis"***, Charles University, Prague, Czech Republic - The first task was to build a Graphical User Interface using the Matlab software library allowing the many and diverse routines written for analysis of the TCV Langmuir probe data to be grouped into a common package. The result, after around two months work is an extremely comprehensive suite of routines which have rendered analysis and data manipulation considerably more transparent and which will represent a significant saving in time for the end user. Using this GUI, the aim of a second assignment was to investigate the origins of the manifestly erroneous values of electron temperature, T_e, measured by the TCV Langmuir probes in high recycling regimes common during divertor detachment studies. This is a problem that has long been known in strongly magnetised plasma research but little progress has been made in understanding why. He created a suite of simulated Langmuir probe characteristics appropriate to the low temperature conditions known to be a necessary condition for detachment. Systematic variation of fluctuation amplitudes and cross-correlations (representing plasma turbulence) on T_e, V_f and I_{sat}, the three important quantities derived from the Langmuir probe, have clearly demonstrated that turbulence is not at the origin of the high electron temperatures. In contrast, an alternative explanation, based on the energy filtering action of the probe electrostatic sheath, does turn out to be a good candidate, at least in TCV. He used the results of numerical simulations of density and temperature gradients parallel to the total magnetic field in the TCV scrape-off layer as input to a recently derived analytic theory describing the sheath potential (and hence the form of the Langmuir probe characteristic) dependence on these parallel gradients. The conclusion that this effect can, under conditions of

high plasma edge density, lead to considerable overestimation of T_e when using Langmuir probes is significant and will be reported at a workshop.

Amélie PERRET: ***"Gaussian beams propagation in the microwave range",*** Ecole Superieure de Procédés Electroniques et Optiques, Orléans, France - First, there was a theoretical part where the student had to understand the physics of free-space Gaussian beams propagation (both scalar and vector formalisms) and update an existing computer code to use it in the Matlab environment. The experimental part consisted of measuring the astigmatism generated by the reflection of a Gaussian beam on an ellipsoidal reflector. Il was possible to identify a limiting factor regarding the ratio of the beam size on the mirror to the mirror focal length.

Alexei ZABOLOTSKY: ***"Analysis of impurity injection radiation",*** Novosibirsk University (funded by a Swiss Confederation bursary) - The task was to improve the interpretation of absolute radiation level measurements from X-ray tomography and similar systems, for the determination of impurity densities. We upgraded existing software for determining the carbon density in normal discharge conditions, as well as the density of Neon and Argon injected into divertor configurations for the study of plasma detachment. The results which are in good agreement with Zeff measurements using visible bremstrahlung. The software was then modified to follow the rapid evolution of impurity densities associated with the injection of laser-ablated Aluminum. The analysis of non-recycling injected impurities such as Al gives a direct measure of impurity residence times in the plasma. Current work is aimed at obtaining local values of transport coefficients in the plasma core from the density profile evolution of injected impurities.

Pierre BRIANCEAU: ***"Etude d'un dépôt rapide de silicium microcristallin par plasma VHF (60MHz) et haute puissance, à partir d'un mélange de $SIH_4/SiF_4/H_2$",*** Ecole Superieure de Procédés Electroniques et Optiques, Orléans, France - Rapid deposition of microcrystalline silicon for industrial production is most efficiently obtained at VHF frequencies, although high power densities (several kW per square metre) are necessary. Plasma chemistries different from the conventional silane/hydrogen mixture, in conjunction with VHF plasma, could conceivably be used to boost the deposition rate still further. In this work, the admixture of silicon tetrafluoride (SiF_4) to silane/hydrogen was investigated because the introduction of fluorine, an efficient etchant, would be expected to supplement the action of atomic hydrogen in converting the amorphous phase to microcrystalline. A wide range of plasma diagnostics was applied in this study which demonstrated that a large flowrate of SiF_4, relative to SiH_4, was required to achieve any significant effect. The conclusion was that the bonding energy of SiF_4 was too high, compared with silane and hydrogen, for atomic fluorine to be efficiently generated by plasma dissociation of SiF_4. The report recommends the use of fluorine gas, although it is more hazardous than SiF_4.*

Dirk WOLLHERR: ***"Improvements to the TCV DPCS and ELM modelling"***, Technische Universität, München, Germany - The Digital Plasma Control System for TCV functioned adequately to perform specific experiments validating new control methodology during 1998. However, some aspects of its operation were insufficiently reliable for routine use. Work was carried out in 1999 to identify the weaknesses and some of these were remedied in collaboration with the original

* The work described under this Section was not performed within the frame of the Association Euratom – Confédération Suisse.

turnkey supplier. A second part of the work consisted of establishing an input-output transfer function between the signal of visible light emission and the vertical movement of the plasma during an Edge Localised Mode. Such ELM events were successfully modelled individually, but a generalised transfer function which is valid for all TCV conditions was not yet identified. The results were sufficiently encouraging to be continued.

5.3 Diplomas awarded in 1999

Luc CHEVALLEY: "***Optimisation of the deposition of microcrystalline silicon by Very High Frequency (VHF), high power plasma*".** Thin films of microcrystalline silicon are required for large area electronics applications such as flat panel displays and photovoltaic solar cells. However, the deposition rate obtained using the conventional mixture of silane and hydrogen, at the industrial frequency of 13.56MHz, is limited to a few Angstroms per second; this low rate is impractical for industrial production. The diploma work characterised various plasma parameters in a 47cm x 57cm plasma box reactor using infrared absorption spectroscopy for the fractional depletion of the silane gas, microwave cavity interferometry for free electron density, optical emission for relative excitation rates, and cavity ringdown absorption spectroscopy for negative ion density. The microcrystallinity of the films obtained was determined by ellipsometry, infrared absorption, electron microscopy and X-ray diffraction. Plasma deposition of films with a high degree of crystallinity required both a complete depletion of the silane and a high flux of atomic hydrogen. We showed that a VHF plasma dissociates more efficiently than at 13.56MHz, although the deposition rate was still limited by the maximum VHF power of 500W from a custom-built RF generator. This represents the first implementation of high power VHF in a large area reactor, and its success has motivated the purchase of a 2kW, 67.8MHz generator for future experiments.*

Stéphane PEQUIOT: "***Magnetic electron beam spreader for gyrotron collectors*"**. For the next generation gyrotrons, generating 1MW of radiofrequency power at 100–170GHz in CW operation, the spent electron beam power is also of the order of 1MW and has to be dissipated on the inner surface of a water-cooled copper collector. For such a power level, only an AC magnetic sweeping system can satisfy the two major constraints: first, power density on the copper below 500W/cm^2 and second, for avoiding copper recrystallization due to temperature cycling, a constant power distribution in time. Preliminary numerical results based on a rotating magnetic field transverse to the collector axis are promising and the implementation on a gyrotron is presently being investigated.

5.4 Postgraduate studies

Postgraduate course in the 3^e cycle "Physique et diagnostic des plasmas"

This 64-hour course (including exercises) was given during the second term of the 1998/99 academic year to 15 students, most of whom were doctoral students at

* The work described under this Section was not performed within the frame of the Association Euratom – Confédération Suisse.

CRPP. The course consisted of three parts given by different lecturers from the CRPP:

A: Diagnostics of Fusion Plasmas

H. Weisen: Magnetic diagnostics, Plasma electromagnetic emission, Passive and active spectroscopy, Interferometry, Polarimetry, Imaging diagnostics, Electron cyclotron emission, Reflectrometry (28 hours).
R. Behn: Thomson Scattering in Fusion plasmas (8 hours)

B: Industrial Plasmas

Ch. Hollenstein: Diagnostics of industrial plasmas (12 hours)

C: Space Plasmas

M. Siegrist: Space plasma measurements (16 hours). This part included a visit to the Division of Space Research and Planetary Sciences of the Institute of Physics of the University of Bern.

Doctorate degrees awarded during 1999

Siobhán BARRY: ***"The extension of the FIR interferometer of TCV to a polarimeter and measurements of the Faraday rotation caused by poloidal magnetic Field"***, thesis presented at the National University of Ireland, Cork, March 1999
Interferometry is a well known technique for measuring the line-integrated electron density of magnetically confined plasmas. It is based on the phase change that an electromagnetic wave experiences on passing through a plasma with respect to that of a vacuum. In addition, the plane of polarisation of the wave is, in general, rotated due to the birefringence of the plasma. The total rotation angle, which can be measured by polarimetric techniques, is known as the Faraday rotation and is proportional to the line-integrated value of the product of electron density and the magnetic field component parallel to the probing beam. In order to maximise its information gathering capability the TCV tokamak's multi-channel interferometer system was modified to include a polarimeter.
The reconstruction of the density profile is difficult for highly shaped plasmas and requires the line-integrated measurements for a large number or chords. Consequently, a 14 channel instrument with two possible polarimetry methods was installed. Both methods are based on an optically pumped far-infrared (FIR) laser with a rotating polarisation where both the interferometer and polarimeter information are determined from phase measurements with only one detector required per probing chord. The feasibility of the methods was verified during bench tests prior to the installation of the instrument on TCV.
The instrument was used to measure the Faraday rotation of various TCV plasmas, but this thesis concentrated on highly elongated plasmas where the measured rotation angles are relatively large and where the inclusion of the Faraday rotation information was predicted to improve the accuracy of the equilibrium reconstruction. The polarimetric precision of 2% required for the reconstruction has not yet been achieved. However, an independent determination of the central safety factor q_0 calculated from the slope of the Faraday rotation profile, the electron density and some geometric parameters resulted in values of q_0 which were in disagreement with the reconstructed values. This led to a re-definition of

the base functions used during the reconstruction calculations and the attainment of values of the reconstructed q_0 which were in closer agreement with measurements from other diagnostics.

Bertrand BLAU: "***Stability and Quench of Dual Cooling Channel Cable-In-Conduit Superconductors***" Thèse EPFL No. 2076 (1999)
The quench, stability and thermohydraulic behaviour of full-size ITER-type NbTi cable-in-conduit conductors (CICC) was experimentally assessed for the first time. The influence of the central channel perforations on the stability margin of large CICCs was investigated on several samples which varied only by different porosities of the central channel. No significant differences in stability between conductor samples with largely different perforations could be found for currents up to 50 kA, whereas at 60 kA a larger stability margin seemed to appear for the conductor with smallest porosity. These results suggest that for the kind of disturbances applied in the experiment and currents exceeding 50 kA the heating induced helium flow starts to become effective in terms of additional thermal stabilization, which is in agreement with the theoretical predictions.
Premature quenching was observed in many quench experiments. Sudden voltage take-offs far below the expected critical current were observed without displaying any current sharing regime. The quench currents seemed to be determined by the limiting current, which describes the boundary above which only the marginal heat capacity of the strands can be utilized. These results were interpreted as an indication that thermal disturbances are continuously created by current redistribution processes among the strands due to a largely inhomogeneous current distribution over the cable cross section caused mainly by large interstrand contact resistances.
The results of the heat slug measurements in combination with two-dimensional model calculations implied that the heat removal capabilities in long dual cooling channel cable-in-conduit conductors are determined only by the overall flow velocity or the overall mass flow rate, respectively, independent on the ratio between the helium flow velocity in the bundle and in the central channel.

David FRANZ: ***"Déposition assistée par un plasma à arc à haut courant continu de couches minces de Nitrure de Bore et de Silicium microcristallin hydrogéné"*** Thèse EPFL 2029 (1999)
A high direct current arc reactor (HCDCA), used for the industrial deposition of diamond, has been adapted to study the deposition of two types of coatings:

- boron nitride, whose cubic phase is similar to diamond, for tribological applications.
- hydrogenated microcrystalline silicon, for applications in the semiconductor fields (flat panel displays, solar cells,...).

Although various boron precursors were used and a wide parameter range was investigated, cubic boron nitride films could not be produced. The films were essentially hexagonal or amorphous boron nitride with a chemical composition close to stoichiometric.
The study of HCDCA for the deposition of diamond showed that this arc efficiently dissociates molecular hydrogen by way of intermediate vibrationally-excited states. This efficient dissociation was the key factor for the rapid deposition of highly micro-crystalline silicon (up to 0.6 microns per minute), in which the atomic hydrogen was generated by the molecular dissociation of the silane (SiH_4) itself.*

* The work described under this Section was not performed within the frame of the Association Euratom – Confédération Suisse.

Pierre-André MANDRIN: "***Production de plasma et démarrage du courant du tokamak TCV avec l'assistance d'onde cyclotron électronique***" Thèse EPFL 1951 (1999)
To limit the value of the inductive toroidal electric field to about 0.3V/m, breakdown of the neutral gas and current ramp-up require the assistance of electron cyclotron heating (EC). This method has been applied on the tokamak TCV. First harmonic ordinary mode launched from low field side allows a reduction of the inductive electric field by a factor of two (~1V/m) with only 15kW of EC power, and enhances the neutral gas prefill pressure range allowable for successful breakdown (lower limit reduced by a factor of two with ~80kW injected). Start-up can also be assisted with second harmonic extraordinary mode launched from the low field side. Strong wave absorption is observed on the upper hybrid absorption layer.

Ph.D. Theses underway at the end of 1999

Clemente ANGIONI: "***1D transport modelling***"
MMM95 (Multi Mode Model 1995) and IFS/PPPL (Institute for Fusion Studies/Princeton Plasma Physics Laboratory) are two almost completely theoretical transport models. They have been implemented in the PRETOR transport code, which is now regularly used in the simulation of TCV discharges. First applications of these two transport models in the simulation of the electron temperature profile of Ohmic TCV discharges have given some satisfactory results. Model validation analysis over a large range of plasma parameters needs a reliable ion temperature diagnostic, which will be available on TCV in the near future. The simulations of ECH and ECCD discharges using the RLW (Rebut-Lallia-Watkins) empirical transport model are in very good agreement with the experimental data. In PRETOR simulations, sawtooth stabilisation has been identified as responsible for the central electron temperature enhancement during counter ECCD experiments.

Juliette BALLUTAUD: "***A large-area and high output coating system (PECVD) for silicon thin-film solar cells***"
The goal of this project is the design and development of a large area and high throughput coating system for silicon thin-film solar cells, based on Plasma Enhanced Chemical Vapor Deposition (PECVD). Balzers Process Systems has experience with the development of in-line coating machines for architectural glass and with PECVD technology. We will work on the modelling and scale-up of the plasma reactor and contribute to the process development by applying various plasma diagnostics and we will optimise the plasma process on the 30 × 40 cm^2 intermediate-size KAI reactor. This includes investigations of the effect of the electrode gap distance on the deposition and of the influence of excitation frequency. The aim of these investigations is to optimise the process and to increase the deposition rate up to a maximum value of 15 Å/s while respecting device quality.*

Patrick BLANCHARD: ***"Electron cyclotron emission measurements from TCV plasmas"***

---

* The work described under this Section was not performed within the frame of the Association Euratom – Confédération Suisse.

This aim of this project is a measurement of local electron temperatures with high spatial and temporal resolution in TCV, for studies of ECH, MHD activity and transient transport. The project is in the hardware procurement waiting for the 24-channel high field side heterodyne radiometer.

Paolo BOSSHARD: ***"Charge exchange spectroscopy measurements of ion temperature and impurity ion density"***
The aim of this project is to measure the ion contribution to stored energy and pressure profiles. Although the contribution is arguably negligible in ECH plasmas at the very low densities currently required for X2 heating, this will no longer be the case for X3 at high density, where electrons and ions can approach equipartition. We have purchased a 50keV, 2A diagnostic injector of neutral hydrogen for CXS spectroscopy and have brought into service a visible spectrometer with 16 fibre-optic input channels from the observation optics on TCV.

Alberto BOTTINO: ***"Modelling of magnetically confined plasmas"***
In the context of a time evolution Particle-In-Cell (PIC) approach for solving gyrokinetic equations, a modified quasineutrality equation has been developed. In the previous version of this code, the finite Larmor radius (FLR) effects appeared through a second order correction term in FLR in the quasineutrality equation. In order to study microinstabilities in realistic fusion device geometry, this limit has been relaxed using a more sophisticated correction term. The algorithm has already been implemented in the case of adiabatic electrons with electrostatic perturbations. The next step of this work will be the development of a similar algorithm for codes solving the same problem in the case of kinetic electrons and electromagnetic perturbations.

Thierry DELACHAUX: ***"Study of carbiding and nitriding plasmas in a high current arc reactor, with application to zirconium coating"***
The aim of this project is to study nitriding plasmas for the surface treatment of zirconia, the goal being to obtain a yellow-gold colour surface (ZrN) with functional wear resistance properties. After designing an adequate experimental set-up, we are studying the possibility of nitriding by ammonia and nitrogen-hydrogen plasmas. We have found that both options lead to the desired treatment and chose to perform a first set of experiments in nitrogen-hydrogen plasmas in order to avoid the safety problems associated with the use of ammonia. An investigation of the reactor parameters showed that the optimum range exists for zirconia nitriding with respect to its colour, is a function of the surface temperature. If it is too high we obtained a grey-yellow colour; if it is too low we were not able to efficiently nitride due to a barrier in the activation energy. A characterisation of the plasma by optical emission spectroscopy and by mass spectroscopy is underway. However, the plasma parameters do not seem to have a strong influence on the surface treatment, except for the temperature setting. In contrast, we showed that pre-treatment of the zirconia can improve the nitriding. *

Christian DESCHENAUX: ***"Dust Growth mechanisms in hydrocarbon plasmas"***
Mass-spectrometry, Cavity-Ring-Down Spectroscopy (CRDS) and infrared absorption have been applied to RF-plasmas of methane and acetylene, used for deposition of thin layers. Large ions with masses up to 300 amu were detected and

* The work described under this Section was not performed within the frame of the Association Euratom – Confédération Suisse.

analysis of the composition of the most abundant masses shows that the number of cyclic structures increases with mass, corresponding to some theories of fullerenee formation. For a given power, pressure and flux, formation of particulates is observed. The appearance of these powders depends strongly on the surface state of the reactor. This was observed with other gases such as silane or mixtures of Hexamethyldisiloxane (HMDSO) and Oxygen, which are studied for the formation of powders. The current model of homogenous growth of powders by trapping of negative ions in the plasma does not explain our observations. New experiments are under way to distinguish between powders enhanced by surface contamination and powders grown by homogeneous process. *

Gloria FALCHETTO: ***"Electromagnetic effects on microinstabilities in tokamak plasmas"***
Results from a ballooning instability eigenvalue code, which solves the gyrokinetic electrostatic equation for the case of full ion dynamics, have been compared with global gyrokinetic code results. The GLOGYSTO code has been run for two scenarios having different toroidal wave numbers and Larmor radii, but being iso-dynamical in the frame of the lowest order ballooning approximation. A discrepancy between mode growth rates has been found: with the ballooning representation they are overestimated by a factor 1.7 with respect to the higher toroidal wave numbers case and by a factor 3-4 to the lower one. In order to study the effects of finite beta on electrostatic drift modes, a new code which solves the general electromagnetic kinetic dispersion relation for microinstabilities has been developed. This local code can solve the full electron dynamics or make use of the quasi-adiabatic electrons approximation and allows us to model the effect of trapped electrons, trapped ions and the Shafranov shift. For the electrostatic case with trapped ions, good agreement is found with ballooning code results. Finally, the GLOGYSTO code has been modified to include finite beta effects. The approximation of quasi-adiabatic electrons is used and, as a first step, only circulating particles have been taken into account. First results of electromagnetic effects on ITG instabilities are in good agreement with the local ones, obtained from the dispersion relation.

Jean-Yves FAVEZ: ***"Non-linear control of a tokamak plasma"***
This work is aimed towards developing methods for the control of tokamak plasmas treating non-linearities as important rather than incidental. The dominant non-linearities are the voltage and current limits of the power supplies, as well as the total required power for control. Control simulations of TCV have been carried out for high growth rates using the fast internal coils and studies have begun on different algorithmic approaches, particularly sliding mode control. This work is targeted at both the TCV and ITER tokamaks. Work has so far concentrated on understanding the modelling of the tokamak.
(In collaboration with the Institut d'Automatique at the EPFL)

Olivier FISCHER*: "The behaviour of magnetic field lines and drifts in 3D configurations"*
The study of the magnetic field lines and the behaviour of the particle drift orbits have been investigated in a reversed shear tokamak configuration that is subject to a weak three-dimensional magnetic perturbation. We have observed that a robust Kolmogorov (KAM) barrier with respect to the perturbation occurs near the maximum of the safety factor of the underlying unperturbed equilibrium state. This

is a consequence of the non-applicability of the KAM theorem. Concerning the particle drift orbits, we have defined the notion of a radius of confinement for which all particles that are launched within it are almost perfectly confined. This radius decreases with increasing particle energy but saturates as the safety factor q approaches its maximum value. For this reason, we have interpreted this phenomenon as a transport barrier for the particles.

Ivo FURNO: ***"Transient transport events in TCV"***
We are studying MHD related transport events such as sawteeth and heat pulses in relation to plasma conditions, especially plasma shape, using fast, multichannel broadband radiation diagnostics. These include the 200-channel X-ray tomography system, a novel fast bolometry system and an X-ray temperature array. The tomography system has revealed a variety of non-standard sawtooth phenomena in ECH plasmas, ranging from large amplitudes for axial deposition to vanishingly small crash amplitudes for a deposition footprint straddling the sawtooth inversion radius. The fast bolometry system was brought into service early in 1999. Beside revealing ELMs and sawtooth heat pulses for the first time with this kind of diagnostic, we overcome the limitations of standard metal foil bolometry, namely speed, dynamic range, sensitivity to neutrals, sensitivity to microwave pickup.

Guillaume JOST: ***"Particle simulations of drift waves in 3D magnetic configurations"***
Drift waves are commonly held responsible for anomalous transport in tokamaks and in particular for the anomalously high heat loss. The next generation of stellarators should be characterised by the much smaller neo-classical transport and by particle confinement close to that of tokamaks. There is nevertheless a strong interest in the stellarator community to study the properties of drift waves in 3D magnetic configurations. We have developed the first global gyrokinetic code aimed at the investigation of linear drift wave stability in general toroidal geometry. As a first application, two configurations have been studied, the Quasi-Axisymmetric Stellarator with three fields periods (QAS3) currently developed at the Princeton Plasma Physics Laboratory and the Helically Symmetric eXperiment (HSX) which started operation at the University of Wisconsin in 1999. The QAS3 is characterised by a tokamak-like field in the outer part of the torus. In this structure the drift waves are mainly affected by the skewness of the field lines, the magnetic shear, and barely by the shape of the plasma. The results are very close to those obtained for a tokamak. On the other hand, results for the HSX configuration, which is characterised by a dominant helically magnetic field, show a clear 3D effect, namely a strong toroidal variation of the drift wave mode structure. This variation is a clear function of the 3D plasma.

Laurent KLINGER: ***"3D numerical simulation of a plasma torch using a finite volume method"***
In the framework of a collaboration with Sulzer-Metco AG, we are studying experimental and modelling aspects of plasma torches. In order to obtain a macroscopic model of a plasma torch working at atmospheric pressure, and in particular of the electric arc column, we based our work on a fluid dynamics code dealing with the complete Navier-Stokes equation. We added a Poisson equation for the electrical potential to this code. The fluid system and the electrical part are coupled through an Ohmic heating source term and the temperature dependence of the electrical conductivity, which assumes that local thermodynamic equilibrium is valid. We obtain a stationary solution by means of an iterative procedure. In order to avoid dealing with the full geometric complexity of a real torch, we are considering, as a starting point, the simple test case of an arc established in a

crossflow in a rectangular duct. The present version of the code uses an implicit scheme and parallelisation and converges with an acceptable rate.*

Matteo MACCIO: ***"Effect of E×B Flows on the Linear Stability of Ion Temperature Gradient Modes, Using a Global and Spectral Gyrokinetic Model"***
Strong electric fields generate an E×B rotation of the equilibrium plasma. Experiments have shown that this effect might reduce the anomalous transport in tokamaks. Study of the effect of these flows on the linear stability of ion temperature gradient (ITG) modes, which are widely held responsible for anomalous transport, has therefore been undertaken. We use the gyrokinetic formalism to solve the full 2D poloidal plane of a tokamak, in a spectral approach. Results show a strong effect of E×B flows: they stabilise the ITG modes and reduce the extent of the convective cells. Studying different profiles of the flow shows that while the shear of E×B flow does stabilise the ITG modes, it is the magnitude of the flow which produces the strongest stabilising effect.

Adriano MANINI: ***"Dynamic response of plasma temperature to additional heating"***
The dynamic response to ECH power excitations of the electron temperature inferred from the soft X-ray emissivity has been studied to determine of the power deposition profile. Several excitations have been analysed, such as square wave modulations and time evolution at the turn on/off of the ECH power. To diminish the pollution of the signals due to the sawtooth instability, a method based on the Generalised Singular Value Decomposition (GSVD) has been developed. It was possible to reduce the sawtooth contribution on average by a factor of 10. Together with the diamagnetic loop which allows us to calculate the power absorbed by the plasma, the GSVD has also been successfully applied to treat the signals at the shut off of the ECH, with the purpose of developing a fast guess power deposition localisation procedure to be applied after each discharge.

David MAGNI: ***"The chemistry in a hexamethyldisiloxane (HMDSO) plasma and consequences for the deposition of silicon oxide"***
Plasma deposition of silicon dioxide is widely used in semiconductor technology as an interlayer insulator and is an emerging technology in the packaging industry to produce new ecological barrier materials. The actual tendency is to work with organosilicated precursors such as HMDSO, TEOS, TMOS, non-toxic and requiring less stringent safety installations. The aim of this study is to characterise the plasma in a mixture of HMDSO vapour, oxygen and helium or argon gases. During 1999 a publication was prepared on the results obtained in 1998 in collaboration with Bari university. Technology transfers were made with an industrial partner. Future work is focused on particle formation in HMDSO+oxygen plasmas.*

Andrei MARTYNOV: ***"MHD activity of tokamak plasmas"***
Several MHD codes have been installed in the CRPP: the non-linear resistive code XTOR (K. Lerbinger, J.F. Luciani, J. Comput. Phys. 97, 444,1991) in collaboration with H. Lütjens (Ecole Polytechnique Palaiseau, France), the linear non-ideal code PEST3 (Pletzer, Bondeson & Dewar, J. Comput. Phys. 115, 530,1994), the new version of ideal KINX code (Computer Physics Communications 103, 10-27,1997) - in collaboration with S. Medvedev (Keldysh Institute, Moscow, Russia).
The codes were tested and are now used for the analysis of MHD stability of TCV discharges and for studies of the dependence of the MHD stability of tokamak

* The work described under this Section was not performed within the frame of the Association Euratom – Confédération Suisse.

plasmas on plasma shape. Several TCV shots with different shapes have been analysed by XTOR and KINX codes and the strong dependence of the ideal kink mode growth rate on shape parameters has been found.
Preliminary calculations of suppression of the internal kink mode by diamagnetic rotation have been performed using XTOR code.

Petri NIKKOLA: ***"Simulations of electron cyclotron wave propagation in TCV"***
The linear electroncyclotron wave ray-tracing and current drive code TORAY has been modified to permit interpolation of the results to the grid used in the equilibrium reconstruction of TCV plasmas. In addition, the dissipated power for each ray, as well as the influence on the non-inductive driven current, are separated. A graphical user interface was developed as a compact tool to exploit the results. This GUI is linked to a functional interface for running the TORAY code. Furthermore, a small modification of TORAY allows calculations for waves at the 3rd harmonic of the electroncyclotron frequency.

Pavel POPOVITCH: ***"Electromagnetic waves propagation in 3D plasma configurations"***
The heating of plasmas by means of electromagnetic waves in three-dimensional configurations is considered. It is being studied using the wave propagation equation in a potential formulation written in Boozer magnetic coordinates. This equation is to be solved numerically with the application of finite elements for the discretisation in the radial variable and Fourier decomposition in the poloidal and toroidal angles.

Holger REIMERDES: ***"β-limiting phenomena in shaped TCV plasmas »***
We are focussing on pressure driven instabilities in TCV, in particular the influence of the plasma shape on MHD stability. Instabilities are observed with fast fluctuation measurements, such as magnetic pick-up coils and soft X-ray diodes. In order to identify the experimental mode structure, a code which simulates the magnetic perturbation at the location of the magnetic probes has been developed. Pressure driven magnetic islands, so-called neoclassical tearing modes (NTM), have been observed in TCV discharges with more than 1MW of additional ECH power. The importance of high local pressure gradients at the resonant flux surface for the destabilization of NTMs has been demonstrated. Furthermore, the shape dependence of sawteeth, which are deemed important for the onset of NTMs, has been analysed in systematic scans of elongation and triangularity. The sawtooth period can increase or decrease with additional heating power depending on the plasma shape. This shape dependence has been related to the role of ideal or resistive MHD in triggering the sawtooth crash.

Pedro Miguel RODRIGUES DE ALMEIDA: ***"TEM measurements of irradiation damage"***
Irradiation induced order-disorder and microstructure evolution have been systematically assessed by transmission electron microscopy (TEM) using both dark field and weak beam imaging modes. These observations have been coupled with a molecular dynamics (MD) codes and a novel image simulation (IS) technique based on the multislice approach (MS). In diffraction contrast imaging mode it has been possible to demonstrate the observability of disordered regions induced by a single ion and to correlate the geometry of these regions of disorder with the loci of the surviving defect clusters. Damage accumulation has been also simulated and observed using IS tools. Phase contrast image simulation has been deployed as means of comparison with published results in related fields. Although extremely

powerful, phase contrast requires stringent experimental conditions to be able to compare TEM and IS due to the low level of image contrast. It appears that irradiation induced amorphization in NiAl is not driven through a direct reaction of type crystalline-to-amorphous. Instead, a defect accumulation mechanism might be in operation.

Edgar SCAVINO: ***"Impurity transport measurements using laser ablation of impurities"***

The major effort during 1999 was devoted to the installation of the hardware and software components of a laser ablation system. This system, now operational, includes the laser, the optical path which focuses the beam on a target plate made of a thin Al film and vacuum pumping. The necessary electronics have been for the computer control of the equipment. The first tests of laser ablation have been successful. The properties of impurity transport in TCV plasmas are obtained by evaluating raw data from existing diagnostics. A code which was used for Ne transport analysis has been upgraded and is ready for the study of the transport of injected impurities of various species.