Centro de Fusão
Nuclear

INSTITUTO SUPERIOR TÉCNICO
ASSOCIATED LABORATORY
ON
PLASMA PHYSICS AND ENGINEERING

Centro de Fusão Nuclear

Centro de Física dos Plasmas

Centro de Física
dos Plasmas

WORK PROGRAMME FOR 2004 - 2006

IST, July 2004

1. INTRODUCTION

This document presents the foreseen work-programme (WP) of the Associated Laboratory (AL) on Plasma Physics and Engineering for 2004-2006.

The main objectives of this WP are:

- To pursue efforts to strengthen the position of this AL as one of the Research Units of excellence in Europe, in the fields of Nuclear Fusion, Plasma Physics and Technologies and other related topics;
- To assure significant participation of Portuguese Research Units and Industry in international projects in the AL activity areas;
- To install at IST new experimental facilities and to improve the present apparatus and Laboratories: Tokamak ISTTOK, Multi-TeraWatt Laser System, Laboratory of Microwave Circuits and Systems and Laboratory of Digital Instrumentation;
- To proceed with the transfer of technologies to the industry and the collaboration on post-graduation programmes;
- To assure the Portuguese participation in the management of the Fusion Programme of the European Atomic Energy Community (EURATOM), European Fusion Development Agreement (EFDA) and ITER European Legal Entity (ELE).

Sections 2 and 3 describe the activities to be performed by "Centro de Fusão Nuclear" (CFN) and "Centro de Física dos Plasmas" (CFP). Section 4 summarizes the tasks that will be jointly carried out by CFN and CFP staff.

2. WORK-PROGRAMME OF CENTRO DE FUSÃO NUCLEAR

2.1. Introduction

The CFN work-programme for 2004-06 is carried out in the frame of the Contract of Association signed in 1990 between EURATOM and Instituto Superior Técnico (IST). It has been already assessed by the "Scientific and Technical Advisory Committee"[1] and approved by the "Consultative Committee for the Specific Research and Training Programme on Nuclear Energy Fusion", of the EURATOM Fusion Programme.

The CFN WP has the following main objectives:

- Operation and scientific exploitation of the tokamak ISTTOK;

[1] An advisory committee of the Fusion Programme and EFDA.

- Participation in the programmes of other European fusion devices: JET, ASDEX-Upgrade, TJ-II, MAST and TCV;
- Participation in the ITER Project and in the European Accompanying Programme in the frame of the so-called Broader Approach to Fusion Energy;
- Collaboration on Nuclear Fusion with Brazilian Institutions;
- Collaboration on education and training universitary programmes in Plasma Physics and Engineering as well as on dissemination and technology transfer activities.

The WP includes activities to be carried out in the frame of the following projects:

- Tokamak ISTTOK;
- Participation in the collective use of the JET facilities by the EFDA Associates;
- Participation in the ASDEX Upgrade Programme;
- Participation in the MAST Programme;
- Participation in the TCV Programme;
- Participation in the TJ-II Programme;
- Participation in ITER activities;
- Participation in the TCA-Br and ETE Programmes;
- Other studies on modeling and current drive;
- Other activities on control, data acquisition and remote participation;
- Other fusion-related activities.

which are described in detail in sections 2.2 to 2.12.

2.2. Tokamak ISTTOK

The main research line of this project in 2004-06 is the testing of the liquid metal limiter concept. The liquid metal system is now being commissioned in the ISTTOK Laboratory and will be tested until the end of 2004. The influence of a magnetic field in the liquid jet will be also analysed until the end of January 2005. As soon as the results of the laboratorial tests provide confidence on the safety operation of the liquid metal system, it will be installed on ISTTOK. The analysis of the influence of the liquid metal limiter on the plasma characteristics will be made.

Others research lines are related with the study of the influence of edge-biasing on the plasma equilibrium and stability, the operation on an alternating plasma current regime, the analysis of the influence of spatial ripple of the toroidal magnetic field on the MHD activity and the study of edge turbulence with emissive probes.

2.3. Participation in the collective use of the JET[2] facilities by the EFDA Associates

This project has the following main objectives:

- To finalize four tasks for the JET Enhanced Performance Project:
  - Microwave access – Project management[3] and implementation, aiming at improving the JET microwave transmission lines;
  - MPR – Project design and procurement activities, aiming at developing a PCI transient recorder module for the 2.5 MeV neutron diagnostic;
  - TOFOR – Project design and procurement activities, aiming at developing a PCI time digitizer for the 2.5 MeV neutron diagnostic;
  - TESTBENCH – Project design and procurement activities, aiming at developing a test-bench system for the Real-Time Project Phase 2.
- To participate in the JET experimental campaigns (Table 1), through the involvement of about fifteen scientists, namely in the following areas: (i) Diagnostics: measurement of the radial electric field shearing rate; turbulence studies from reflectometry measurements, (ii) MHD and Transport : maintenance and validation of the database related to fast MHD phenomena; analysis of destabilization of AE by super-Alfvenic beams; comparison of the effects of enhanced radiation on ELM behaviour; study of the onset of neo-classical tearing modes; transport modeling in impurity seeding experiments; assessment of the use of LH heating to mitigate the runaway electrons generation and the thermal quench during disruptions; modeling of the impurity behaviour both in the core and in the SOL , through the coupling between the codes JETTO/SANCO and EDGE2D, (iii) Edge: study of momentum transport in the boundary plasma; investigation of the energy transfer between flows and turbulence through Reynold stress measurements;

Year	2005			2006			
Campaign	C15	C16	C17	C18	C19	C20	C21
From	11/07	05/09	10/10	02/05	31/05	24/07	04/09
To	26/08	07/10	18/11	26/05	21/07	18/08	27/10

Table 1 – The 2005 and 2006 JET campaigns

- To participate in the development and implementation of new hardware for the JET programme beyond 2006, presently under discussion in the EFDA Steering Committee.

[2] JET is a tokamak located in Culham, operated and scientific exploitated by the EFDA Associates.
[3] Dr. Luis Cupido is the Project Leader.

CFN might be involved in the development of a new reflectometer for density profile and correlation measurements as well as on real-time diagnostics and control systems.

- To provide staff for the JET Operation Team[4], Close Support Unit[5] and Task Force Leaders[6].

2.4. Participation in the ASDEX Upgrade[7] Programme

This Project has two research lines: (i) Microwave reflectometry; and (ii) Studies on MHD, turbulence and transport.

The following developments are foreseen on the *microwave reflectometry system*: (i) a prototype of a full heterodyne advance FM reflectometer with ultra fast sweeping (< 10 µs); (ii) a new data acquisition system and optimization of the control; (iii) the extension of the use of X-mode data to obtain the very edge density profile; (iv) combined O and X mode operation using the X modes channels (Q band and recently upgraded V band channels) and estimation of B_t (r) using O/X mode numerical studies to interpret the reflectometry data. The scientific exploitation of the diagnostic will lead to plasma studies on: (i) Impact of the signatures of islands on reflectometry signals and possible contribution to q-profile estimation; (ii) Level of phase fluctuations and amplitude fluctuations and its relation with the injected power and dependency from the plasma current; (iii) ELM's characteristics including HFS/LFS comparison where asymmetries at the precursor and collapse phase of the ELM are observed; (iv) Edge density pedestal characteristics in advanced plasma scenarios; and (v) Effect of pellet injection in ELM's pacemaking.

The following tasks on *MHD, turbulence and transport* are planned for 2004-06: (i) Scientific exploitation of experiments in the area of fast particles and Alfvèn instabilities, namely on density profile optimisation for measurements of TAE using microwave reflectometry, and study of the mode structure of TAE as a function of the shape and plasma beta; (ii) Study of the role of magnetic islands in the energy quench preceding disruptions, with emphasis in the comparison HFS/LFS from reflectometry data. An experiment for the control of the m/n = 2/1 with ECRH before density limit disruptions is planned for 2005; (iii) Analysis of runaway generation in tokamak disruptive events, to analyse the evolution of the primary generated runaway electrons during thermal and current quench stages during

[4] At least three AL members (Sebastien Hacquin, Isabel Nunes and Vladislav Plyusnin) will work in JOC.
[5] At least one AL member (Bruno Gonçalves) will work in this CSU.
[6] Dr. Duarte Borba is the Leader of the Task Force on MHD Studies.
[7] ASDEX-Upgrade is a tokamak of the Association EURATOM/IPP, located in Garching.

disruptions, and comparison with a similar study being performed at JET; and (iv) Code development for the analysis of turbulence and transport in the SOL of ASDEX Upgrade, allowing for the implementation of more realistic models for the boundary conditions, including recombination, electron secondary emission and recycling processes.

2.5. Participation in the MAST[8] Programme

This project foresees the implementation of a microwave reflectometer and plasma physics studies based on its experimental results. This diagnostic has initially two channels to yield density gradients and plasma fluctuation characteristics in the edge region. Later on, it should be expanded with additional higher frequency channels to measure complete density profiles.

2.6. Participation in the TCV[9] Programme

This project has two research lines: (i) Development and scientific exploitation of three X-ray diagnostics: an horizontal pulse height analysis (PHA) diagnostic, a vertical real-time PHA diagnostic and a rotating crystal spectrometer; and (ii) Development of a new real-time VME system for plasma control.

Software to improve the analysis of the data provided by the *horizontal PHA diagnostic* will be developed. New models to facilitate the understanding of tokamak physics studies from the experimental results will be tested.

The *vertical PHA diagnostic* should be implemented on TCV until the end of 2004. Hardware and software needed for the transformation of the diagnostics in a real-time tool based on an IST multi-DSP VME board as well as software necessary for the integration of the dedicated data acquisition system into the TCV central control and data acquisition systems will be developed.

A joint evaluation of the scientific merit of the *rotating crystal spectrometer* as well as of the effort needed to bring it to operation has to be urgently carried out. If the work on this spectrometer will proceed, it is necessary to complete the design, to assembly and implement the diagnostic on TCV and to develop the software necessary for the spectrometer operation.

The scientific exploitation of these diagnostics will give important contributions for the TCV plasma physics programme.

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[8] MAST is a tokamak of the Association EURATOM/UKAEA, located in Culham.
[9] TCV is a tokamak of the Association EURATOM/Helvetic Confederation, located in CRPP-Lausanne.

The development of the necessary hardware and software for the *real-time VME control system* will be finalized. The new system will be implemented and tested on TCV.

2.7. Participation in the TJ-II[10] Programme

This project has three research lines in the areas of microwave reflectometry, heavy ion beam diagnostic and edge physics and plasma turbulence.

The operation and scientific exploitation of the frequency hopping correlation *reflectometer* is foreseen. Improvements on the TJ-II reflectometry systems might occur depending on ITER decisions.

The development of the dedicate control and data acquisition system of the *heavy ion beam diagnostic* will be finalized. Different types of the multiple cell array detectors will be tested. Plasma physics studies will be performed based on the results of this diagnostic.

Regarding *edge physics and plasma turbulence*, the effect of electrode biasing on plasma confinement and edge transport will be investigated. An edge diagnostics (rake and Gundestrup probes) will be installed on TJ-II to evaluated in detail the effect of bias on the edge electric field and flows. Further investigations will be made on the mechanisms responsible for parallel momentum redistribution via turbulent fluctuations.

2.8. Participation in ITER[11] activities

This project includes engineering and design activities and participation in the construction of this tokamak.

The *engineering and design activities* will include: (i) the participation of Portuguese engineers in the ITER Central Team working in Garching on diagnostics integration; (ii) and design analysis of the ITER main-plasma and plasma position reflectometers. This last task is implemented through two EFDA contracts, one under CFN responsibility, and it foresees the assessment of existing designs, the evaluation of the waveguide performance and engineering design analysis. This work will imply a significant improvement of the CFN Laboratory on Microwave Circuits and Systems.

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[10] TJ-II is a stellarator of the Association EURATOM/CIEMAT, located in Madrid.
[11] ITER is a tokamak to be built in the frame of an International Agreement between EURATOM. Japan, Russia, Korea, China and United States of America.

During ITER *construction* in Cadarache, CFN might be responsible for: (i) diagnostics integration in one tokamak port; and (ii) the development of the plasma position reflectometer as well as digital instrumentation for control and data acquisition. Participation in the development of other diagnostics is also under discussion. A workshop about ITER industrial demands will be organized after a decision on ITER site. CFN will give technical assistance to the participation of Portuguese industry in the construction of this tokamak. Partnerships with industries will be set-up.

2.9. Participation in the TCA-Br[12] and ETE[13] Programmes

Concerning the *TCA-Br programme*, this project will include activities on microwave reflectometry, plasma control and data acquisition as well as studies on transport and MHD activity.

The CFN participation in the *ETE programme* will be mainly focused in the development of a multi-fiber Thomson scattering diagnostic,

2.10. Other studies on modeling and current drive

This project will include the following main activities:

- Further studies on the *effect of forced/free magnetic field line reconnection on plasma poloidal* $\vec{E} \times \vec{B}$ *velocity and global momentum braking* , to assess the importance of mode coupling on the tailoring of plasma rotation profiles
- Studies on the *physics of NTM triggering*, namely on the effect of a plasma geometry that is closer to the toroidal tokamak concept on basic problems of magnetic reconnection (such as NTM triggering and error field penetration)
- Studies on *lower-hybrid wave propagation*: The complete assessment of diffraction effects within the framework of beam tracing is to be pursued; moreover, the simple 3d model that has been proposed to address the effects of magnetic ripple and toroidicity will be extended to high orders in the inverse aspect ratio approximation in the near future.
- *Reconstruction of tokamak MHD equilibria*. The method developed will be generalized and applied to several tokamak scenarios, including hollow current profiles.

[12] TCA-Br is a tokamak of the “Laboratório de Plasmas da Universidade de São Paulo (Brazil)”
[13] ETE is a tokamak of the “Laboratório Associado de Plasmas do Instituto Nacional de Pesquisas Espaciais”, located in São José dos Campos (Brazil).

2.11. Other activities on control, data acquisition and remote participation

This project will have three main objectives in 2004-2006:

- To improve the following specifications of the PCI modules developed for the JET neutron diagnostic:
    - Time Digitizer: increase of the input channels up to 20, resolution to 100 ps and event rates of up to 20 Mevents/second/channel;
    - 200 MSPS Transient Recorder: increment to 1 GHz of the acquisition rate, resolution to 12 bits and inclusion of analog optical isolation for critical signal to noise applications in the harsh environment of a tokamak;
    - Increment of the digital signal processing capabilities of the modules;
    - Integration of the transient recorder and time digitizer functions.
- To develop an event-driven, real-time, integrated, scalable and adaptive data acquisition system targeted to have the following capabilities:
    - Development of autonomous modules, which will not be bus based, interlinked through gigabit serial optical communications;
    - Higher number of channels per module;
    - Integration of the data acquisition task in a real-time and event-driven distributed control system;
    - Support for the correct synchronization of all control and data acquisition modules;
    - Development of graphical modelling programs for the design of the control and interface codes for the modules and systems.
    - Target the specificities of the fusion diagnostics and incorporate features foreseeable to be of use shortly;

  This system is believed to be adequate for the fast changing needs of the actual and future fusion experiments and will permit to reduce significantly the development period of new modules and systems. Also the systems cost will be reduced: (i) due to the higher number of channels per module; (ii) by avoiding the costly, standard based crates and controllers and (iii) by being designed from root to the fusion environment, thereby avoiding costly commercial systems where the entirety of requirements is frequently difficult to met and the addition of new features can be expensive.
- To upgrade the ISTTOK data acquisition system, specifically on the following areas: diagnostics database server, control and data access programs and subsystems interface.

2.12. Other fusion-related activities

This project will include the following activities:

- Collaboration, on behalf of the Portuguese Government, with the International Atomic Energy Agency (IAEA) on the organization of the "2004 IAEA Fusion Energy Conference" (FEC-2004), to be held on November 1-6, in Vilamoura;
- Collaboration on post-graduation programmes of the Portuguese universities (presently CFN has two Master and sixteen Ph. D. students;
- Participation in an European Ph. D. programme, presently under discussion in the Steering Committee of the European Fusion Development Agreement (EFDA);
- Participation in the management of the EURATOM Fusion Programme, EFDA and ITER European Legal Entity;
- Organization of a FUSION EXPO exhibition in Vilamoura during FEC-2004;
- Collaboration with the Portuguese Physics Society on the organization of an exhibition about the Portuguese participation in the European Research and Development Programmes on Physics, in the frame of the "2005 International Year of Physics".
- Translation to portuguese of a CD and booklets about fusion energy edited by EFDA and the Commission of the European Union.

3. WORK-PROGRAMME OF CENTRO DE FÍSICA DOS PLASMAS

3.1. Introduction

During the next two years CFP will pursue efforts to strengthen our position as one of the laboratories of excellence in Europe, in the field of Plasma Physics and related topics. We will keep and eventually extend our broad spectrum of interests in this field, ranging from high intensity lasers and extreme states of matter to the low temperature plasmas and discharge formation, and applying our knowledge to some of the most exciting topics in physics such as fast ignition of fusion targets, plasma accelerators, and astrophysical and space plasmas. In what concerns space plasmas, and in order to leverage on the Portuguese National Strategy for Space, we will choose this field as a common ground for projects that involve the three distinct Groups of CFP, thus improving the efforts of integration already clear in the previous two years.

3.2. Multi-Tera Watt Laser system (L2I)

In 2004 the laser system will be developed in several fronts. The current laser chain was recently upgraded with a new 45 mm Nd:glass amplifier. Two other 65 mm Nd:glass amplifiers will be available soon. These up-grades will allow the increase of the laser power up to the 100 TW level in the next two years. The OPCPA experiments will be performed in order to develop a new independent arm of the laser system to be used in experiments with hydrodynamic time scales. The work in the advanced laser diagnostics will be focused not only in laser pulse optimization, but also in the measurement of the laser pulses during and after the interaction with mater. Planed experiments on diode pumped amplifications should also be mentioned.

During this period a large effort will have to be made to move the L2I system to new installations, due to the construction of an Underground line less than 50 meters distant from the present installations. Two different solutions (ITN in Sacavém, and University of Aveiro) have been foreseen. We hope that a quick decision and a rapid consensus by the appropriate authorities in this process (Ministry of Science, President of IST, President of the IST Physics Department) can be achieved, in order to minimize the negative impact of this unavoidable relocation.

3.3. Femto Laser system

The up-grade of the femto laser system, developed in collaboration with the University of Porto, will be concluded during this period. The system will then attain the Tera-Watt level with a10 Hertz repetition rate and compressed pulses with a duration of 5 femtosecond and energy of 5 milli-Joule. This system will have unique characteristics and will be used to explore new areas of nonlinear optics with ultra-short pulses.

3.4. Electron and photon acceleration experiments

The experimental work to be carried out in this period will be mainly focused on the production of electron beams in plasma channels. The main targets will be to produce nearly mono-energetic electron beams (in the sub nano-Coulomb regime), and approach the GeV energy range. Collaboration experiments with UCLA are planed and will start in the next few months.

Two new and ambitious photon acceleration experiments are being planed and will also be implemented. The first one is being prepared in collaboration with LULI, Ecole Polytechnique, and aims at accelerating and continuously tuning X-rays propagating in non-stationary waveguides. The second one, to be performed with the Strathclyde University, Glasgow, proposes to produce sub-cycle optical pulses in the visible, by up-shifting a Tera-Hertz photon beam.

Both experiments will make use of the interaction of primary photon beams with relativistic ionization fronts, following a technique that was originated from our own laboratory.

3.5. New X-ray sources

Our Centre is the leader of a European Consortium for "Tabletop Ultra-Intense XUV Sources for Femto-biology and Related Applications". This project was prepared in collaboration with the leading groups in Europe and submitted to Europe FP6 NEST Programme, and rated with 19.1 / 20 by the EU Commission, in the top 5% of about 300 international proposals.

3.6. Computer Cluster

Our computer cluster, which is presently with a 80 Power PC CPUs (40 G4 processors + 40 G5 processors), will very shortly attain the level of 126 CPU’s, which is about the largest size that we can manage with our local capabilities. This will boost our computational work to even higher levels of quality and performance, and will help us to keep a strong international visibility in the areas of plasma accelerators, nuclear fusion and fast ignition.

Such a strong effort in hardware is accompanied by the strongest European effort in plasma simulation codes, with a suite of codes and visualization tools capable of addressing a wide range of plasma physics problems. Among the software and the visualization infrastructure we will continue to develop the massively parallel particle-in-cell code OSIRIS (in collaboration with UCLA and USC) and the massively parallel hybrid-MHD code dHybrid (in collaboration with RAL/UK). This infrastructure is of paramount importance for the support of theoretical developments in our research program, as well as a fundamental tool for the design, development and interpretation of the several experiments to be carried out with intense lasers, either at IST or abroad.

3.7. Space and Astrophysical Plasmas

We plan to proceed with the study of the influence of large-amplitude waves on unstable environments and pursue the analysis of the "magnetic bubble" concept. We will also explore laser propulsion and solar wind interaction with magnetized and un-magnetized planets, and the associated planetary climate change, using pic and hybrid numerical codes. This theoretical work will be performed in close collaboration with ESA, and will involve the three groups of CFP.

More abstract physical problems related to astrophysical plasmas will be considered, in particular, nonlinear gravitational wave phenomena, and neutrino-plasma interaction problems.

3.8 Ecological Plasma Engineering Laboratory

The emission to the atmosphere of hazardous toxic residue products like nitrogen oxides, carbon monoxide, chlorofluorocarbons (CFCs), fly ash, etc. causes stratospheric ozone decomposition, acid rain, photochemical smog, and gives rise to the green house effect. The Recent Report on Destruction Technologies of the United Nations Environmental Programme recommended eleven technologies for the destruction of ozone depleting substances and four of these technologies are plasma based. In fact, during the past decade, the plasma technology has evolved as one of the most promising innovative technologies for hazardous wastes disposal. The waste treatment with plasmas is ecologically safe and economically affordable**.**

We intend to establish an Ecological Plasma Engineering Laboratory (EPEL) with advanced facilities in order to develop and provide “know how” concerning the application of modern plasma based technologies to environmental protection, through research, education and linkage to industry. The aim is to make significant scientific and technological contributions to environmental sustainability through scientific programs leading to cleaner, efficient and equitable processes for environmental remediation. In the last years, different types of microwave plasma sources have been developed and investigated in our Gaseous Electronics Laboratory (Project POCTI 36294/99). These types of plasma make use of high frequency microwave power to create an efficient, electrodeless plasma torches by sustaining a large volume plasma at atmospheric or near atmospheric pressure. These systems can advantageously replace costly traditional technologies as incineration and conventional plasma arc furnaces, and provide a superior environmental treatment. The key scientific activities of the EPEL will be focused on:

- *Destruction of Ozone Depleting Substances (NOx, CFCs) using Microwave Plasma Torches generated by wave heated discharges*.

  Different type of microwave plasma torches will be tested for pollutants destruction. Optical emission and FT-IR spectroscopy will be applied to control the temporal behaviour of the main plasma precursors and to control the by-products of the destruction process. Optimization of the process in respect to the operational conditions (pressure, nature of the gas, pulse parameters etc.) and hazardous by-products will be performed. The development of sophisticated kinetics model, instrumental in respect to the optimization of the treatment processes, will be an integral part of the investigation.
- *Application of Surface Wave Plasmas for VOCs removal.*

  Large-scale wave driven discharges will be investigated as a source for VOCs removal. Investigations on the destruction and removal efficiency of acetone and benzene in low-pressure N_2-O_2 plasmas are planned. The role played by metastable molecules N_2 (A), O_2 (a´Δ) and atoms ($O(^3P)$, $N(^4P)$) in the conversion of organic species into environmentally innocuous molecules will be investigated. TALIF measurements of the N atom density are also planned.
- *Microwave Plasma Torches for Fly Ash Removal.*

  The development of plasma methods for the treatment of fly ashes generated by municipal waste incineration will be the purpose of the investigation. Processing of post-incineration fly ashes in surface wave generated plasma torches will be performed. The role played by the H_2 percentage on the treatment process and the conversion of hazardous species will be investigated. “Dust particle plasma” models for the description of fly ash treatment in a microwave plasma torch will be developed.
- *Application of Surface Waves Driven Plasmas for Biological Sterilization.*

  Plasma sterilization will be investigated both in the glow and the afterglow plasma in a wide range of pressures, under pulsed and steady state conditions of operation in different gas mixtures (N_2-O_2, Ar-O_2, N_2-H_2 plasmas etc.). An essential aspect of the investigations will be the establishment of the principal sterilizing factors relative contributions such as: radicals, atoms, excited molecules, ions, UV radiation. To assess the sterilizing effect of plasmas, one should test the most resistant microorganisms. Investigations on the role of UV plasma radiation in the inactivation process will be performed.

  The theoretical modeling of the interaction cell ↔ plasma regarding bacterial spores as macromolecules made up of carbon, hydrogen, oxygen and nitrogen is planned.

With the purpose to get insight into the kinetics of a low-pressure microwave flowing post-discharge in N_2-O_2 for potential applications in plasma sterilization in hospitals, a fully self-consistent modelling of electrons and neutral and charged species will be developed. The model considers the plasma sources and the afterglow chamber, where the objects to be sterilized are placed. The plasma sources includes the discharge tube and its connection to the sterilization chamber. In the latter, a short-lived afterglow occurs. The sterilizer chamber will be modelled using a 2D hydrodynamic model. An analysis of the populating and depopulating mechanisms will be carried out for the species of interest for the inactivation of microorganisms such as O atoms and UV photons from NO(A) and NO(B) molecules.This part of the work will be carried out in collaboration with the Faculty of Engineering of the Oporto University (Portugal), the Physics Department of the University of Montreal, and the Laboratoire de Science et Génie des Surfaces, École des Mines de Nancy (France).

3.9. Optimization of plasma reactors for material treatment

Plasma Reactors for Material Treatment (PRMT) are nowadays an essential tool used in different types of industrial chains with electronics, photovoltaic, optics, food industry, or surface modification. In recent years, new reactor configurations have been proposed in order to give adequate effective answers, according to the objectives of each application. We are interested in developing simulation tools to optimize, in an effective realistic way, the operation conditions of the following PRMT.

- *Plasma Enhanced Chemical Vapor Deposition Reactors (PECVD-R)*, widely used in the electronic industry, for the deposition of silicon thin films. Presently, this sector shows a special interest in optimizing the operation conditions of such devices, aiming the production of microcrystalline hydrogenated silicon thin films (μc-Si:H). We intent to develop a self-consistent, two-dimensional simulation code that describes the dynamics of charged and neutral particles, within a capacitively coupled PECVD reactor for μc-Si:H thin films deposition, operating between 13.56MHz – 80 MHz frequencies.
- *Surface-Wave Plasma Reactors (SWP-R)*, operating in a microwave regime, which are rapidly becoming an alternative competitive answer with respect to the typical plasma reactors for deposition, in view of improving the quality of deposited films in terms of both compactness and homogeneity. We intent to develop a simulation code, describing

energy deposition along radial and axial direction within SWP-R's (in either cylindrical or coaxial configurations), operating at a 2.45GHz frequency.

- *Axial Injection Torch (AIT)*, which constitutes a microwave-driven high intensity plasma source, capable of producing very hot flows, of plasma species that can be used in applications such as etching, stripping, spraying, cleaning, chemical processing, or de-pollution. We intent to develop a two-dimensional simulation code, describing the hydrodynamic behavior of the plasma produced by an AIT, which operates in flow regime at a 2.45GHz frequency.

This work will pursuit the collaboration with the Laboratoire de Physique et Technologie des Plasmas (Palaiseau, France), the Laboratoire de Physique des Gaz et des Plasmas (Orsay, France), and the Instituto de Ciencias de Materiales de Sevilla (Sevilla, Spain). This work will allow engaging a new collaboration with the Research Group FQM-136, Física del Plasma: Diagnosis, Modelos y Aplicaciones, of the Universidad de Córdoba (Córdoba, Spain).

3.10. Multi-scale modelling of an inductively-coupled plasma reactor for the etching of metal oxides by fluorocarbon plasmas

Standard fabrication techniques of CMOS-base electronic devices generally apply deep etching processes to silicon oxide (with low-dielectric constant). Usually, this plasma processing technique is carried out within Inductively Coupled Plasma Reactors (ICP-R), which present the advantage of operating at very low pressures (~mTorr) and high plasma densities (~10^{13} cm^{-3}), thus ensuring both the effectiveness of the etching mechanism and a reduced contamination.

The full description of etching processes within a ICP-R can significantly contribute to their control and optimization. However, the development of such a global simulation program constitutes a very hard task due to the complex and diverse nature of the phenomena involved: electromagnetic, chemical (either in gas or in surface phases) and transport. The development of such a simulation tool will bring together complementary competences in the domains of Plasma Physics and Engineering, Surface Physics and Material Science. We intend to develop a multi-scale model of an ICP-R for the etching of metal oxides, by fluorocarbon plasmas.

This work will allow engaging a new collaboration with the Laboratoire des Plasmas et des Couches Minces of the Institut des Matériaux de Nantes (Nantes, France).

3.11. Numerical solution to Fokker-Planck diffusion-like equations

In gas discharges, the microscopic description of electron kinetics at intermediate pressures (p~1 Torr) involves the numerical solution to the spatially Inhomogeneous Electron Boltzmann Equation (IEBE). In this pressure region, no simpler alternative approaches are valid: the non-local approach holds in weak collisional situations at very low pressures; the local approach describes strong collisional situations at high pressures.

In hot plasmas, the microscopic description of electron kinetics requires the numerical solution to the spatially Inhomogeneous Electron Fokker-Planck Equation (IEFPE). The results of this study can provide relevant answers for the problem of heating and current-drive fusion plasmas, thus contributing to the breakthrough of major future technological applications.

Both IEBE and IEFPE are diffusion-like equations, exhibiting many similarities in their operator structure. This common denominator will be used to search for a general numerical algorithm, in view of obtaining a robust and efficient description of the electron kinetics in Plasma Physics.

This work will start collaboration with the Grupo de Geração Não-Indutiva de Corrente with the Centro de Fusão Nuclear. The associated tasks will be carried out within the Laboratório Associado de Fusão Nuclear, under the framework of FCT Project CONC-REEQ/65/2001 “Beowulf cluster design: HiP Computing Research Consortium”.

3.12. Discharges in plasma mixtures with methane

The investigation of dc and hf discharges in N_2-CH_4 will be carried out with the purpose of studying the conditions for formation and the possibilities of evolution and detection of organic compounds in planetary environments, especially Titan, comets and Mars. This work will be conducted in collaboration with the Faculty of Engineering of the Oporto University (Portugal), the Service d’ Aéronomie, Université de Versailles Saint Quentin (France), and the Laboratoire Interuniversitaires des Systèmes Atmosphériques, Université de Paris XII-Val de Marne (France).

Studies in N_2-CH_4 post-discharges will also be carried out for the purpose of chemical surface treatments, since it was observed that small quantities of methane of the order of 0.1% added to nitrogen allow to increase the efficiency of nitriding of metallic surfaces. This occurs probably due to the presence of carbon and hydrogen atoms, which may remove the oxide layers and then accelerate the nitriding process by means of the active nitrogen species. These studies are also justified for the detection of carbon impurities. These investigations will be carried out in collaboration with the Faculty of Engineering of the Oporto University (Portugal), and the Laboratoire de Science et Génie des Surfaces, Ecole des Mines de Nancy (France).

3.13. Monte Carlo method for surface atomic recombination

Investigations on the dynamical Monte Carlo method for studying surface recombination of atoms on silica and Pyrex will be pursued by considering more realistic surface parameters, such as activation energies and frequency factors for adsorption and surface diffusion. This work will be conducted in collaboration with the Institute of Physics from the University of Belgrade.

4. JOINT WORK-PROGRAMME FOR 2004-2006

Beside the activities described in sections 2 and 3 of this document, the AL staff will carried out the following joint activities:

- Conceptual design of a new LIDAR diagnostic for leak detection in the ITER hall;
- Numerical solution of plasma kinetic equations

  It is envisaged to put in common the existing know-how on the numerical solution of Fokker-Planck equations on non-uniform grids and of the Boltzmann equation using multi-grid techniques, in order to have highly efficient codes applicable to both equations (which would fit into the more general family of diffusion-like equations) in several regimes of interest (both fusion and discharge plasmas).
- Improvement of the CFN and CFP computer clusters. A larger cluster will eventually be installed at IST, with 512 processors, in the frame of a larger collaboration;
- Participation in the elaboration of a Portuguese programme on plasma waste treatment.