3.4 Theory and modelling

3.4.1 Stationary MHD modes in magnetically confined plasmas

Background and Objectives: This activity aims at constructing equilibria and relaxed states of laboratory plasmas of fusion concern (e.g., plasmas of tokamaks and reversed-field-pinches) with flow or/and finite electrical conductivity and investigating their linear and nonlinear stability. Understanding these issues can contribute to improving the current magnetic confinement systems and possibly developing new ones.

Work performed in year 2009 (*in co-operation with IPP*):

1. We have extended the counter-rotating-vortices hydrodynamic equilibrium [Mallier and Maslowe, Phys. Fluids A Vol. 5, 1074 (1993)] to cover MHD magnetically confined plasmas with incompressible flow. The solution satisfies a Liouville's type equation and represents a row of identical counter rotating vortices in plane geometry. Velocity, magnetic field and current density of the extended equilibrium share the same surfaces. The equilibrium is generic enough because four surface quantities remain free. Also, the solution is more pertinent to laboratory fusion plasmas than the extended cat-eyes equilibrium [Throumoulopoulos, Tasso, Poulipoulis, J. Phys. A: Math. Theor. Vol. 42, 335501 (2009)] because it can be bounded. Furthermore, the flow caused departure of the pressure surfaces from the magnetic surfaces has been examined. It turns out that unlike to linear equilibria, the flow strongly affects the pressure surface topology by forming pressure islands on the poloidal plane within the counter rotating vortices which are twisted at an angle of $\pi/2$ with respect to the pressure islands of the cat-eyes equilibrium. The results of the present study provide additional evidence that the nonlinearity in conjunction with flow can significantly affect the equilibrium characteristics (see **Annex 23**).

2. A sufficient condition for the linear stability of MHD equilibria with incompressible flow [Throumoulopoulos and Tasso, Phys. Plasmas 14, 122104 (2007)] was applied to the extended counter-rotating-vortices equilibrium. It turned out that a magnetic-field-aligned flow

of experimental fusion relevance, i.e for values of β (defined as the ratio of the thermal pressure over the external axial magnetic-field pressure) of the order of 0.01 and Alfvén Mach numbers of the order of 0.01, and the flow shear in combination with the variation of the magnetic field perpendicular to the magnetic surfaces have significant stabilising effects potentially related to the equilibrium nonlinearity. The stable region is enhanced by an external axial magnetic field. Details are given in **Annex 23** .

3. The results described in items (i) and (ii) above indicate that ITER accessible flows may have stabilising effects. For this reason we found it interesting to be continuing this study by applying the aforementioned stability condition to additional linear and nonlinear equilibria in place of the numerical construction of dissipative MHD equilibria originally planned. In particular, one of the main objectives of this project is to check the conjecture that the equilibrium nonlinearity activates stabilising effects of flow. Accordingly, we applied the condition to the complete Whittaker-function equilibrium with current density vanishing on the boundary [Apostolaki, Master Thesis, University of Ioannina, 2009] and low flow shear. It turned out that unlike to nonlinear equilibria the flow has negligible stabilising effect, in favour with the above conjecture. Details are given in **Annex 24** . Examination of the Whittaker-function solution for flows of arbitrary shear and of the generic linear analytic equilibrium as extension to the respective quasistatic solution [Atanasiu et al., Phys. Plasmas Vol.11, 3510 (2004)] consists part of the work plan of 2010 (to be conducted in cooperation with MEC-EURATOM Association).

4. Understanding the role of sheared equilibrium flows in the formation of improved confinement modes either in the edge region of tokamaks (L-H transition) or in the internal region (internal transport barriers) is incomplete. A possible way to shed light into this problem is by employing a more fundamental model than MHD as kinetic theory. In this respect, a recent paper on one dimensional Vlasov-Maxwell equilibrium for the force-free Harris sheet [Harrison and Neukirch, PRL 102, 135003 (2009)] motivated us to construct analytically two-dimensional Maxwell-Vlasov equilibria with finite electric fields, axial (“toroidal”) plasma flow and isotropic pressure in plane geometry. This was accomplished by using the quasineutrality condition to express the electrostatic potential in terms of the vector potential. Then, for Harris-type distribution functions, Ampere's equation becomes of Liouville type and can be solved analytically. As an example, the periodic “cat-eyes” steady state consisting of a row of magnetic islands is constructed in such a way that the relations between the microscopic and macroscopic parameters are explicitly found. The method can be extended to (toroidal) axisymmetric equilibria. Details on this study are provided in **Annex 25** .

3.4.2 Use of ab initio molecular dynamics to provide atomic/molecular data for the understanding of the chemical erosion at the plasma-wall interface (in particular Be)

Background and Objectives: Ab-initio (Car-Parinello) molecular dynamics (MD) can play an important role in fusion related research since the results do not depend on empirical force fields as in the case of classical MD. In 2009, the objective was to apply the ab-initio MD to a known system of proton + graphite (see **Annex 26**) in order to validate the model with the goal to use it further for studying the H-Be system and at the same time to investigate empirical potentials to be used in classical MD.

Work performed in year 2009:

- (i) Thepossible pitfall that can occur in the DFT calculation of graphite–hydrogen interactions under tokamaks conditions has been investigated by means of the ab initio MD. Then, the H release from Be and Be-O surfaces has been simulated and the results found were not satisfactory. In the case of release of H from pure Be, our results detected a release temperature lower than the experimental one, while in the case of Be-O surfaces, we did not detect the formation of H_2O molecules. This disagreement with experimental data can be explained by the small size of the system (100-200 atoms) – a restriction placed on ab initio MD due to current computational resources. Because of this we do not plan to pursue ab initio MD in the next period.
- (ii) We investigated the performance of several potentials published before. These potentials were compared for small Be- Be-H, and Be-He clusters and it has been found that the forces inside the clusters are relatively accurate and can be used for classical MD. Initially, we thought that the Be-Be potential was too simplistic because it is based on a pair-potential instead of a theoretical more correct multi-body potential. After, however, evaluating the possibility to describe the Be-Be interaction by means of a MEAM or a Finnis-Sinclair potential, we found that the best compromise between numerical accuracy and reasonable computational time was the Be-Be potential provided by Ueda, Ohsaka and Kuwajima, J. Nucl. Mat., Vol.258-263,p .713, 1998 and Vol. 283-287 p.1100, 2000.

3.4.3 Turbulence and anomalous transport phenomena

Background and Objectives: This activity addresses several tasks:

In a first part of the activity, we study particle and heat transport in turbulent environments, with the use of realistic models of turbulence and in toroidal topologies, and with particular focus on the edge region, impurities, fast particles, and anomalous transport behaviour. Several tools are used in parallel in this study: (1) We perform test-particle simulations in turbulent electromagnetic field environments. (2) A code for the solution of the Fokker-Planck equation is developed, as an alternative tool to the test-particle simulations and the Langevin equation, and moreover for comparison to the ETS code. (3) Random walk models and fractional diffusion equations are developed as tools to describe anomalous transport, with particular aim to describe in parallel the combined diffusion in position and velocity space. (4) The Langevin equation is investigated and solved numerically for realistic, stochastic field environments. (5) Eulerian-Lagrangean CFD models are being developed for the study of near-wall motion of particulate matter and its interaction with stochastic turbulent fluid flow in the presence of deterministic/stochastic magnetic fields.

In a second part of the activity, we explore particular turbulence models that are based on the concept of Self-Organised Criticality (SOC), where the turbulent plasma is considered as a complex system, in which localised instabilities are relaxed in small-scale diffusive events. SOC is usually modelled in the form of Cellular Automata and the sand-pile analogy is made use of, yet it is a particular aim of our approach to use the natural physical variables and that the SOC models have a consistent physical interpretation. In particular, we develop the Extended Cellular Automaton (X-CA) model for the magnetic field, which is fully MHD compatible, as well as a SOC model for turbulence driven by micro instabilities. In parallel, we build the MHD code MYDAS2, as an alternative to the X-CA model and in order to validate results of the latter.

A third part of this activity considers the description of the anomalous transport in tokamak plasmas using the gyrokinetic formalism, which has been of great interest in recent years. Gyrokinetic calculations and their comparison with the experimental database can be used in order to extend the understanding of transport phenomena and to further develop the theoretical framework of the gyrokinetic formalism. The growth rates of the ITGs and the density peaking at JET need to be investigated numerically and compared with the experimental data available.

The last part of this activity utilises Hamiltonian methods for obtaining evolution equations of the particle distribution functions under the presence of turbulent or other perturbing modes. These equations describe anomalous transport phenomena more accurately than standard theories, such as the quasilinear theory, since they incorporate the actual underlying particle dynamics and are not based on commonly used statistical assumptions with questionable validity in realistic cases.

Work performed in year 2009 (*in co-operation with the Institutes indicated*):

1. Having established the validity and accuracy of the implemented alternative approach based on the expansion of the random force in Fourier series, the stochastic motion of a charged particle in a random electric field has been investigated. The numerical solution has been successfully tested with corresponding analytical results in the particular case of a stationary electric field, expressed by a cosine function with a random, uniformly distributed phase. Then, simulation of trajectories for a particle in a helicoidal magnetic field has been obtained for several random electric fields with arbitrary noise. The effect of the electric field noise on the trajectories and on the mean square displacement has been investigated. It is noted that this problem set up may be used as the basis for modelling magnetic confinement in toroidal geometry. Also, the Fourier expansion method can effectively model fluctuating fields of any correlation type. This feature allows the simulation of motion under the influence of other stochastic forces, such as one imposed by a Lorentzian correlated or a time-dependent field. A detailed presentation of all this work is included in **Annex 27** . (*In co-operation with ULB and MedC.*)
2. Direct numerical simulations (DNS) of MHD turbulent channel flows laden with large-ensembles of particles were conducted in order to investigate complex particle/turbulence interactions. The parametric study covered several particle diameters, density ratios between the electrically conducting fluid and the particulate impurities, and combinations of orientation and magnitude of the external uniform magnetic field. A numerical tool for the post-processing of the DNS data was also developed. It extracts the near-wall coherent structures responsible for the dynamic behaviour of the particles. It also calculates the level of particle preferential concentration, the mean, rms particle velocities and higher moments (up to 4th order), terms in the particle kinetic energy budget, and finally the instantaneous and the time-averaged particle concentrations. Various subgrid turbulence models and models that account the effect of small scales on the transport of particles by turbulence (Langevin based models) were developed in order to perform large eddy simulations of MHD turbulent flows at higher Reynolds numbers. The numerical code was further modified to simulate 3D cylindrical geometries with heat/mass transfer. (See also **Annex 28** and **Annex 29**). (*In co-operation with ULB*).

3. (A) In order to further adjust the X-CA model to the reversed field pinch (RFP), the driving process was modified such that the system is driven through both, the toroidal and the poloidal current, respectively. The concrete set-up used is derived from the Bessel Function Model for relaxed Taylor states, formulated in terms of the magnetic vector potential. The system reaches again the state of SOC, with now a safety factor profile and

reversal of the toroidal magnetic field as characteristic for the RFP. The X-CA model so-far was constructed in a rectangular, Cartesian grid in the poloidal plane, which led to unnaturally shaped flux-surfaces, so that we made the transition to polar coordinates. Thereto, the interpolation technique in the poloidal direction, which now is periodic, was changed from cubic splines to Fourier interpolation, as well as the radial interpolation was changed from cubic splines to Chebyshev interpolation. The resulting flux-surfaces are now of the form of distorted circles, and also field reversal is achieved again. The statistics of the magnetic field dissipation was studied, and the distribution of dissipated energy was found to exhibit a small power-law regime with an exponential fall-off. The instability criterion and the redistribution rules were not yet formulated in a way adequate to polar coordinates, since priority was given to the development of the MHD code MYDAS2.

(B) The derivatives in the X-CA are now calculated in the same way as in pseudospectral methods for the solution of partial differential equations, so that, as a natural spin-off, the new project to build the MHD code MYDAS2 was initiated. The code is 2.5 dimensional, the modelled domain is the 2D poloidal plane, and it uses polar coordinates. The construction of the code has been completed, and it is now being tested with simple cases that are analytically treatable. - The diffusive behaviour of test-particles in the X-CA model was not yet investigated, since priority was given to the test-particle simulation in task (v) and to the development of MYDAS2. (For details see **Annex 30** .)

4. In the period in subject, the initial plan to use experimental data of ion temperature profiles from JET for direct comparison with the SOC model was found not to be viable (the designated procedure of accessing JET data would have caused a far too long delay in completing the work, it possibly may though be undertaken in the future). Instead, values for the threshold in the normalised ion temperature-gradient scale-length, as determined from JET data with the use of gyro-kinetic models, were used as input parameters in the SOC model, and the comparison with the data was done qualitatively. Moreover, the model was substantially improved by determining the local heat fluxes, which allowed identifying the normalised diffusivity as one of the free parameters of the model. The distributions of internal heat-fluxes and of heat out-fluxes were calculated, and they are all of single or double power-law shape, depending on the free parameters. The problems of finding a way to reduce the stiffness of the model and the extension to two dimensions could not yet be addressed in the period in subject (for details see **Annex 31**).

5. The study of ion drift in stochastic magnetic fields was initiated, where a stochastic magnetic field component is superimposed on a background magnetic field, with a prescribed spatial auto-correlation function, and where the ions are treated in a low order drift approximation. The aim of the project is to determine the ion diffusion coefficients, and to compare them to the ones yielded by the DCT (decorrelation trajectory) method. It turned out that the results are very sensitive to the grid-size and the numerical resolution of the stochastic magnetic structures. In a first attempt to address this problem, the linear, lowest order interpolation of the magnetic field was replaced with interpolation in terms of trigonometric polynomials, it was though found to be too slow numerically. We then implemented a local third order spline interpolation, which was found to be satisfying with respect to precision and numerical cost. Results on ion diffusion coefficients were compared to the respective results yielded by the DCT method and were found to be in good qualitative agreement. The study was then extended beyond the comparison with the DCT method: (a) The diffusivities of impurities with ITER relevant parameters were determined,

together with e.g. their scaling with the degree of anisotropy in the stochastic perturbation. (b) To assess the appropriateness of the linear gyro-centre velocity approximation, the test-particle simulations were repeated by integrating the Lorentz-force. (c) The perturbed, standard magnetic field in toroidal geometry was used in the simulations, in order to determine the importance of neoclassical effects and of the effects of turbulence. In a new project then, electromagnetic fields were generated by the EMEDGE3D code for the MHD ballooning mode, and an interface between the MHD code output and the particle tracking code was written. The study of the diffusive behaviour (in space and in energy) of impurities in these fields and in the edge region will be done in the next year. For details see **Annex 32**. (*in co-operation with MEdC, CEA /U. of Marseille.*)

6. The one dimensional Fokker-Planck solver CHET1 has been developed and implemented numerically. The spatial derivatives are calculated with a pseudo-spectral method based on expansion in terms of Chebyshev polynomials, and time-stepping is done with a fourth order Runge Kutta, adaptive step-size scheme. Implemented so-far are the cases of Dirichlet and Neumann boundary conditions, and both cases have successfully been tested against simple, analytically treatable solutions. Moreover, the transport coefficients as used in the ETS code have been implemented. Both codes, the ETS and CHET1, respectively, are now in the state of being used and validated for their reliability and consistency. Work on numerically solving the Langevin equation will be started after the completion of work on task (v).
7. A combined fractional diffusion equation in position- and momentum-space has been constructed for the technically simplest case of decoupled dynamics in position- and momentum-space. It has been shown that in some particular cases the derived fractional diffusion equation can be solved analytically by Fourier and Laplace transforms, yielding thus a model that can simultaneously account for anomalous diffusive behaviour in both, position- and momentum-space, respectively. A new, physically meaningful coupling between position- and momentum-space was then introduced in the random walk equations, by choosing a new form of the distribution of walk increments. The problem of deriving the corresponding fractional diffusion equation could not yet be addressed. (*In co-operation with MEdC.*)
8. A large amount of linear runs of the gyrokinetic code GKW have been performed to determine the Prandtl number and the pinch number as a function of radius for dedicated JET experiments. It has been found that the experimental Prandtl number agrees to a large extent with the theoretical predictions, whereas the experimental pinch number is about double the theoretical one. It has also been found that the heat flux is not greatly affected by the toroidal rotation. Further work on this task has not been performed in the second part of year 2009, because collaboration with the principal researcher has been terminated.

9. Linear runs with the gyrokinetic code GS2 have been performed to determine the

density peaking as a function of radius and impurity atomic number for dedicated JET experiments. So far the theoretical predictions agree very well with the experimental observations. Further work on this task has not been performed in the second part of year 2009, because collaboration with the principal researcher has been terminated.

10. Linear runs have been performed with the gyrokinetic code GS2 to determine the growth rate and threshold of the ITG for the hybrid scenario at JET. We have confirmed that the experiments with current overshoot have a much smaller growth rate and larger threshold than those without. This is largely due to the change of the shear and *q* profile. Further work on this task has not been performed in the second part of year 2009, because collaboration with the principal researcher has been terminated.

11. The evolution (diffusion) equations with non-singular and time-dependent diffusion tensors derived in the first part of year 2009 have been applied for describing transport phenomena. A simple one-dimensional case, including most of the essential qualitative features which can be met in more complex cases, has been used as an example for demonstrating differences between our approach and standard quasilinear theories. Significant differences between the results of the two theories, with respect to transient as well as asymptotic evolution of the distribution function, have been shown. For more details see **Annex 6** . (*In co-operation with PSFC-MIT, USA.*)

12. Hamiltonian averaging techniques and canonical perturbation methods have been applied for the study of the evolution of particle distribution functions under the presence of wave fields and fluctuations. Evolution equations for partially averaged distribution functions have been derived. The results are very general and apply to a variety of cases where anomalous transport occurs in fusion plasmas. The time-dependence form of the respective operators is proposed as capable of describing anomalous diffusion, in contrast to standard theories where constant (in time) operators are used. (*In co-operation with PSFC-MIT, USA.*)

3.4.4. Discrete kinetic models for transport

Background and Objectives: Discrete kinetic simulations may provide an alternative mesoscale type of description of the transport properties of complex physical systems. The main unknown is a particle distribution function, which obeys a suitably chosen kinetic equation, while the bulk quantities of practical interest are obtained by taking moments of the distribution function. The benefit of this description, compared to the more traditional micro- and macro-scopic approaches, is due to the fact that physics, at particle level, may be investigated with moderate computational effort. This activity aims to develop kinetic computer codes capable to simulate in a computationally efficient manner non-linear resistive MHD flows and vacuum systems in fusion devices.

Work performed in year 2009 (*in co-operation with the Institutes indicated*):

All the objectives set for 2009 have been successfully fulfilled and some additional work not initially scheduled has been performed. It is pointed out that all simulation work presented here is based on kinetic theory and it is valid in the whole range of the Knudsen under any vacuum conditions which is the case in the vacuum systems of DT fusion machines such as ITER and DEMO.

1. Extending our previous work with monoatomic rarefied gases, the flow of gaseous mixtures through ducts of various cross sections has been investigated. The composition of the mixture is consisting of hydrogen and helium, which are the two species with the largest concentrations in the exhaust vacuum systems of DT fusion reactors. The formulation of the problem is based on the McCormack kinetic model and it is valid under low, medium and high vacuum conditions. Based on the solution of the problem it is concluded that the gaseous mixtures in the exhaust systems of DT fusion reactors consisting mainly of hydrogen isotopes and helium can be simulated by considering the gas mixture as a single gas with molecules having molecular mass and diameter equal to the average molecular mass and diameter of the species of the mixture. Useful concluding remarks have been also obtained with regard to the effect of the intermolecular potential model and of the gas-surface interaction law. A detailed presentation of all this work may be found in **Annex 33** .
2. Also an “in house” algorithm has been developed to solve vacuum gas dynamics flows through channels with cross sections which vary in the flow direction. Such flow configurations are common in fusion related vacuum applications, including the divertor vacuum system, where the pumping network is consisting of pipe elements having various cross sections. The developed methodology and code is applicable to any type of varying cross sections. The whole approach is described in **Annex 34** where results are presented for demonstration purposes in the case of a conical pipe element.

In addition, the applicability of the concept of the hydraulic diameter in the case of rarefied gas flows has been investigated. This is achieved by computing the exact hydraulic diameter of non-circular channels and then the introduced error in this approximation is estimated. It has been shown that in most cases the hydraulic diameter concept may and should be applied in vacuum gas dynamics providing accurate results for engineering purposes. It is argued that the hydraulic diameter concept is more valuable in the case of rarefied flows compared to the case of viscous flows, since in the former one the required computational effort and complexity to obtain reliable results is significantly increased and therefore it is more tractable to use the hydraulic diameter concept in vacuum technological applications. A detailed presentation of all this work may be found in **Annex 35**
.

3. Finally, the detailed comparative study between the computational results obtained at UoThly and the corresponding experimental data obtained at the TRANSFLOW facility of KIT in the case of channels with finite length has been continued. Researchers from the

UoThly team have participated to the experimental work. The simulation work is based on the UoThly "in house" Direct Simulation Monte Carlo (DSMC) probabilistic algorithm for simulating gas flows through orifices and channels. Certain pitfalls both in modelling and experiments which have been observed in the past have been recently circumvented and soon this comparative investigation will be concluded and published. (*In co-operation with KIT.*).

3.4.5 3D Spectral full MHD Code: Scalar and particle transport in MHD turbulence

Background and Objectives: System rotation and curvature can modify the coherent structures in turbulent MHD flow. On the other hand, coherent structures play a key role in the transport of (passive) scalars and contribute to the preferential concentration of transported particles. This activity examines the effects of rotation and mean shear on the transport of dispersed phases in a simplified setting and aims at the development of a modelling phenomenology that can be incorporated in complex simulation codes.

Work performed in year 2009:

(i) The incorporation of Lagrangian particle tracking in a new 3D spectral full MHD code has been completed. A new scheme has been implemented that can track mean shear without the need for remeshing, leading to improved statistics and simplified particle tracking. As part of this activity, the code performance was improved by using a better parallelisation in a mixed multi-node multi-core environment. A series of simulations of particle dispersion in sheared MHD turbulence was carried out for particles whose Stokes number was matched to the Kolmogorov time scale in order to maximise the expected preferential concentration of particles (see **Annex 36**).
Under the conditions investigated, it was found that in cases of strong anisotropy in the particle distribution, a strong correlation between particle clustering and turbulence structures could be shown. The new statistical tool for predicting preferential particle clustering (the Dispersed Phase Structure Dimensionality) has been introduced and will be further evaluated in 2010.

3.4.8 2-D MHD code for plasma trapping in fusion devices including specific modules on magnetic field topology, neutronics and neutron-pellet interaction

Background and Objectives: Investigations on high density and temperature plasma in compact fusion devices with external magnetic field present an increasing interest due to important industrial applications. Such devices can be used as high flux neutron sources or generators of high energy particles for material tests. The development of the 2-D resistive MHD code in axisymmetric cylindrical geometry, enables us to calculate the spatio-temporal evolution of the state parameters of high density and temperature plasmas. The initial magnetic topology in this open system is given analytically; this allows modification of the initial geometrical configuration and the values of the magnetic field of the device in order to optimise the trapping time of the plasma. Recent laser-cluster and/or laser-micro-droplets interaction experiments produces plasma with density up to 10^{18} cm^{-3} and D ions with high kinetic energy from10 keV to 50 keV. These values are used as initial plasma parameters in the two-dimensional resistive MHD code. The objectives are: (i) Investigate numerical studies on the spatio-temporal evolution of high density, high temperature plasma, in a compact fusion device with externally applied magnetic field topologies corresponding to a mirror-like magnetic configuration and to a uniform (parallel to the axis) symmetric magnetic field configuration. Evaluate the plasma density expansion in the radial direction as a function of the mirror-ratio, B_{max}/B_{min}, (ii) Use the rate equations for eight (8) nuclear fusion reactions in order to calculate the temporal evolution of the reaction products, the neutron production of different energies and estimate the time consumption of the fuel in the compact fusion device as a function of the initial plasma density, (iii) Investigate studies concerning the interaction of pellets with neutrons produced in the high density and temperature plasma.

Work performed in year 2009 (*in co-operation with Ecole-Polytechnique-Paris and CEA*):

1. The development of the 2-D MHD code was continued. The two-dimensional resistive MHD code in axisymmetric cylindrical geometry is used to calculate the spatio-temporal evolution of the state parameters of the plasma produced in a compact magnetic fusion device (see **Annex 22**). The code can handle very large external applied magnetic fields and very steep gradients of the plasma parameters. One of the modules describes the topology of the external magnetic field in the mirror-like configuration. The output from the different modules describes the temporal and spatial evolution of the physical parameters of the plasma such as density, pressure, temperature, expansion velocity, trapping time and magnetic field. Typical initial plasma conditions have been selected in order to be conforming with experimental results: plasma density up to 10^{18} cm^{-3} and temperature up to 20keV. The initial plasma density covers uniformly the high density layer corresponding to a radius of 0.5mm and a length (

z-direction) of 2mm. The low density layer corresponds to a plasma density of 10^{17} cm^{-3} and initial temperature of 1 keV and fills the remaining computational domain. We investigate the influence of the external applied magnetic topology on the trapping time of the plasma and the plasma expansion velocity in both direction the radial and the axial. A comparison has been performed for two different configurations concerning the initial magnetic field topology in order to establish the conditions for the plasma trapping and the plasma expansion in both directions the radial and the axial. In the first case a uniform axial magnetic field is applied with a value up to 150 Tesla and zero radial component. In the second case a mirror-like topology was calculated for the external magnetic field with radial and axial field components and different values of the mirror-ratio B_{max}/B_{min}. These tests allow the comparison of the sensitive physical parameters such as the velocity in the axial (z) direction and the temporal evolution of the plasma density (decreasing) that is very important for the neutron production. The value of the mirror-ratio allows reducing the plasma expansion in the radial direction and optimising the plasma confinement. Under these conditions of initial deuterium plasma density of 10^{18} cm^{-3} and plasma trapping in a mirror-like magnetic field topology, a few 10^{7} neutrons was produced with duration of 2nsec which correspond to a flux of 10^{16} n/sec.

2. The work is oriented towards numerically resolving the rate equations of the more important nuclear fusion reactions occurring in the high density compact magnetic fusion device, including nuclear reactions for T (^{3}H) and ^{3}He production from a Li layer. The cross section used for the nuclear reactions with the Li layer corresponds to both the high energy neutrons (2.45 and 14 MeV) and the thermal neutrons. The output of the numerical simulation describes the temporal density (particles/cm^{3}) evolution of the products (and reactants) of the eight (8) nuclear fusion reactions and the neutron production. The results allow studying both the temporal evolution of each species during the operation cycle of the device and the time for the consumption of the fuel. The simulations enable to use different fuel mixtures like D-D and D-T in different compositions or

exotic fuels like D-^{3}He. For a plasma density up to 2.10^{19} cm^{-3}, the consumption time of the fuel is 0.03 sec which is in agreement with the trapping time in the compact device with an external applied magnetic field of 150 Tesla.

3. The work concerns the development of a model for pellet – neutron interaction in the high density and temperature plasmas. For the period in subject data was used from equivalent schemes of interactions concerning the inertial fusion. The work is oriented to describe the physical process of the interaction as a complementary ablation term (CAT) to the basic ablation term. The CAT contributes to an increase of the rate of the ablated matter from the pellet due to the energy transfer from the neutron flux to the pellet.

4. Investigations on the development of a new fast spark gap switch: The study of the new fast switch (spark gap) was described in the previous report and concerns the design of a switch, coupled to a high voltage capacitor bank, capable supporting high current up to few MA. Such high current is used to generate magnetic fields of 120-150 T in a mirror-like magnetic topology for a compact fusion device. The main requirements are: (i) the pulse duration of the switch operation to be relatively longer than the plasma life-time (ii) the losses optimisation of the current due to the total self-inductance of the system (capacitor bank and switch) and (iii) to ensure the stability of the operation for a relatively high number of shots. Our previous studies (last two yeas) show that we can generate magnetic field up to 90-95 T using four capacitors with a charging voltage up to 50 kV. This value is equal to the maximum value supported by the capacitors and limits the operational life-time of the capacitors. A new configuration of the switch and the capacitor bank was designed including a coaxial transmission line. The fast switch (spark gap) is placed between the capacitor bank and the coaxial line and enables an operation to lower voltage 35-40 kV. This configuration can provide 2 MA of current for a capacitor bank composed by eight capacitors. Two configurations of the new fast switch were studied. The first is a flat configuration in which the metallic spheres composed the equipotential lines of the switch have a decreased diameter, with the exterior electrode (big diameter) corresponding to the capacitor high voltage electrode and the interior electrode (smaller diameter) corresponding to the coaxial line. The second configuration of the switch corresponds to a cylindrical geometry placed in the base of the coaxial transmission line, just after the electrical connection of the capacitor bank with the coaxial line. At the end of the coaxial line a specific connection was designed in order to support the single turn coil. The calculations allow optimising the self-inductance of the system (capacitor bank and co-axial line) as a function of the dimensions of the switch. The optimum values correspond to a length of 50-55 cm and a diameter of 60-62 cm. The radial dimension of the switch will be covered by (about) 130 metallic spheres allowing a current density of few kA/cm^2 and a self inductance of few hundreds of nH (*nanoHenri*). This configuration (capacitor bank and switch) can be build and used in near future experiments in order to generate a magnetic field in the single turn coil up to 120-150 T.

1.