Annex 2 – Forms / Modules I, III, IV
Form B

Programme			**CEEX/ Form B**
Module	1-R&D complex projects	Type of Project	P-CD
Proposal's Acronym	TICF	Proposal's Acronym	

Thematic Fields S/T*) (**3 thematic fields**)	Code 1	11	Title 1	*Basic sciences mathematics, physics, chemistry, biology*
	Code 2	10	Title 2	*Nuclear physics (fusion,fission,other)*
	Code 3		Title 3	
Technological Platform **)	Code		Title	

*) according to Annex 1 – Activities / Thematic Fields S/T
**) according to Annex 1 – Activities / Technological Platforms (for complex projects)

B - PROJECT PROPOSAL DESCRIPTION
(max. 15 pages, Arial 10, 1.5 lines)

1. PROPOSAL'S TITLE IN FULL

Proposal's Title in full, and its acronym : Research on laser-atoms, laser plasma interactions, towards inertial confinement fusion **(TICF)**

1.1 Thematic fields S/T according to Annex 1: 11: *Basic sciences mathematics, physics, chemistry, biology;* 10*: Nuclear physics (fusion,fission,other)*

1.2 Proposal's abstract (max. ¾ pages, Arial 10, 1.5 lines)

TICF aims to advance the research field of laser interaction with matter science by focusing on the laser interactions with atoms and plasma, and to develop a fruitful collaboration between the National atomic, laser and plasma physics communities to bring about a smooth, timely transition from basic research to inertial fusion science and practical applications, making possible the link of the Romanian research to the European research programs.

The Project **TICF** includes the following major objectives: **1**/ experiments and theoretical simulations of technical conditions in order to obtain high density and low temperature laser-produced plasma at the interaction of powerful laser beams of ps and ns duration with solid targets in vacuum; **2**/ National '*critical mass'* of high level scientists to provide fundamental theories, greater understanding of the physics of atoms, lasers and plasmas, predicting and/or interpreting the experimental results;***3/*** experiments and theoretical simulations in order to generate fast relativistic electrons on the rear target surface, as inertial confinement fusion ignitors; ***4/*** modelling of the basic processes involved in the interaction of atoms with short duration and high intensity laser pulses; ***5/*** Implementing Web Services for remote data access and distributed applications;

These advances will require focusing on the following *Policy statement:*

- International cooperative agreements are a substantial factor in inertial fusion progress and will be encouraged. Such agreements, however, are not an effective substitute for focused National efforts and needed National experimental facilities.
- Fusion-related programs in universities and institutes will be selectively strengthened and encouraged to ensure an adequate supply of engineers and physicists with knowledge in this field.

2. PRESENTATION OF NATIONAL AND INTERNATIONAL CONTEXT WITHIN THE MENTIONED THEMATIC FIELDS:

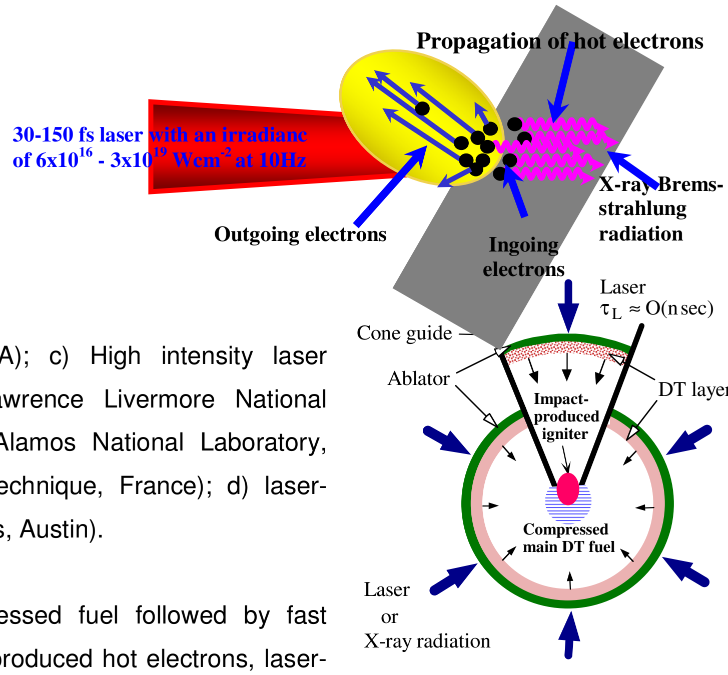
At the present, the physicists are able to do laser experiments with unusual characteristics of the laser beams. For example, Vulcan laser system with the CLF-RAL (UK) can provide laser beam intensities up to 10^{21} Wcm^{-2} in pulse duration of 400 fs. Such unexpected successes lead to a justified effort and optimism of those who hope to yield energy from nuclear reaction in inertial confinement fusion devices on the base of fast ignition method. Moreover, in the last years a new research area, attophysics, the aim of which is the investigation of ultra fast processes at microscopic scale, has advanced as well. The related attophysics activities were been possible due to accelerated progress on the shortness of the pulse duration with increasing its frequency. We refer here to the coherent radiation in the VUV and XUV pulse frequency ranges and from attosecond to femtosecond pulse duration, as those will be provided in the next future at the end of the European XFEL Project with Desy (Hamburg). Alternative way to have such pulse characteristics is the use of high harmonics generation phenomena (HHG) from fundamental frequency of an infrared laser pulse. The X-ray lasers will open new perspectives in the investigation of atomic systems and plasmas.

'Fast ignition' (FI) is an approach to inertial confinement fusion (ICF) in which fuel compression and ignition are separate processes. The FI concept offers the advantage of separating pellet ignition from its compression phase and additional degrees of freedom in pellet design. Fast ignitors (hot electrons, heavy ions, energetic protons etc.) have potentials for substantial advantages over conventional ICF: flexibility in compression drivers, higher gain and lower driver energy (and cost), lower susceptibility to hydrodynamic instabilities. The price to be paid is the need for coupling an ultra-intense energy source to the compressed fuel. In the most studied concept the hot spot is created by relativistic electrons produced in ultra-intense laser-plasma interaction. A variant of the scheme uses laser-accelerated protons, intense heavy-ion beam and macro particles. Since Fast Ignition (FI) was proposed in 1994 to ignite deuterium/tritium (DT) pellets [M.Tabak et al. Phys. Plasmas **1**,16269(1994)], it attracted vivid interest owing to the new prospects it opens in the field of Inertial Confinement Fusion (ICF) with lasers and heavy ion beams [J. Lindl, Phys. Plasmas **2**, 3933(1995)]. FI consists in heating a portion of pre-compressed DT pellet to temperatures above 8 keV during the time of typically 20ps by a laser beam of at least several 10^{19} W cm^{-2} intensity. Currently we may distinguish three FI approaches: Fast Beam Ignition by intense laser-generated particle beams [M. Roth et al., Phys. Rev. Lett. **86**,431(2001)]; Cone-guided Fast Ignition; Fast Coronal Ignition [S.Hain, P. Mulser, and Phys. Rev. Lett. **86**, 1015(2001)].

Basic Research on Fast Ignition of Fusion Target covers many complex physics domains: 1/ Plasma formation and evolution (laser-solid interaction: basic physics and models); 2/ Laser-plasma interaction, fuel compression; 3/ Optical techniques for plasma characterization; 4/ Plume characterization by charged species analysis; 5/ Target physics and design; 6/ Atomic physics and radiation transport; 7/ Diagnostics. Each of these issues has to be considered in the next future making possible a successful National research and the link to the next European and International Research Programs. Many others research groups including Europe (LULI Palaiseau, MPQ Garching, LOA, Queen's University of Belfast, Strathclyde, Warsaw, Prague, MBI Lisbon, Pisa), USA (Lawrence Livermore National Laboratory, University of Michigan, Los Alamos National Laboratory, General Atomics, UCLA, University of Nevada) and Japan (University of Tokyo/JAERI, ILE/Osaka University) have already reported their national programs in the field. The strong interest in this field is largely due to the fact that both fundamental aspects of laser-solid interaction and consequent plasma generation, and applied techniques in material processing technology and sample elemental analysis are involved.

Progress in ten years of fast-ignition research can be summarized as follows:

1/ **Plasma** can be created a) at the interaction of high-intensity laser pulses with solid target in vacuum or gas (LULI, Ecole Polytechnique, France, Rutherford Appleton Laboratory, Central Laser Facility, U.K., OMEGA/OMEGA EP Laser Systems, Laboratory for Laser Energetic, University of Rochester, U.S.A., Institute for Laser Engineering, Osaka, Japan); b) in pulsed power machines as the Z–pinch (Sandia National Laboratories, Albuquerque, USA); c) High intensity laser produced ions interaction with fuel (Lawrence Livermore National laboratory, University of Michigan, Los Alamos National Laboratory, Imperial College of London, Ecole Polytechnique, France); d) laser-interaction with clusters (University of Texas, Austin).



2/**Target physics and design**.

Fast ignition entails assembly of compressed fuel followed by fast heating. There are different drivers: laser-produced hot electrons, laser-generated protons and macro particles. Focusing the laser on a metal target (European Laboratories: RAL, LULI, LOA) produced a large relativistic electron current. It then propagated in a gas jet placed behind the foil. In these conditions the penetrating fast electron current cannot be easily compensated by a return current from the background electrons, due to the low density of the gas; hence a very strong charge separation is expected giving strong propagation inhibition [Zhang et.al.PRE64,046407(2001); PRE66,027402(2002)]

The simulation of the effects of the relativistic electron beam produced by the laser requires the modelling of the electron source and the transport of relativistic electrons in high-density materials. Usually, cone gold near the imploded core is used. The cone thickness, material, cone angle, cone tip shape, thickness and position are important characteristics of the target.

Cryogenic targets without channelling or cone focusing are used by the American teams. A cryogenic target (capsule) has been designed at the Sandia National Laboratories (USA) to achieve the required core areal densities near 0.5 g cm^{-2} that will stop electrons up to 2 MeV). The hybrid target and the Z double-pinch target use internal shield to control symmetry. The shim is a thin layer of material that is placed on or near the ICF capsule surface to block the capsule from excess radiation. Because radiation is smoothed, it is easiest to remove the asymmetry very close to the capsule surface.

3/ **Atomic physics and radiation transport**. Plasma can be studied and characterized by the analysis of its radiation. Signals obtained by passive spectroscopy contain much information about temperature, density and flux of the main species and impurities. The interpretation of measured line intensities requires the knowledge of atomic physics describing the specific radiation from the plasma. Theoretical calculations are the primary source of information on electron collisions with many atomic and molecular systems.

The electron transport from cone to fuel involves very high currents and magnetic fields. It is subject to filamentation instability, the nonlinear turbulent stage of which is still poorly understood (J. Meyer-ter-Vehn et al., PPCF **47**, B807 (2005)). Open questions concern beam divergence and anomalous stopping, which may prevent transport to a sufficiently small fuel spot, but may also help energy deposition over a sufficiently short stopping range. Complex laser-plasma interaction (hydrodynamics, transport, absorption,…) determine the implosion characteristics. The laser-plasma is considered as a nonlinear medium for coherent extreme ultraviolet generation. High harmonic generation from low density plasma was detected. In the case of bremsstrahlung emission (degenerate plasma), some of the electron energy transitions are forbidden since the final electron energy state is totally occupied (Fermi Function). FI targets have a low-collisionality corona and kinetic description is very important. Hot electron distribution is affected by simulation size and boundary conditions. A non-LTE atomic physics model is required to account for thermal shifts in laser-solid-plasma system

4/ **Diagnostics**. The key parameters of laser-ablated plumes are density and temperature. As the degree of ionization under ordinary ablation conditions is not negligible, one is led to consider the density and the temperature of the several species constituting plasma, i.e. ions, electrons and neutral atoms. Thus optical techniques already developed for the diagnostics of plasmas of astrophysics interest, gas discharge or nuclear fusion can be usefully applied to the plume produced by laser ablation. Among the main optical techniques devised for plasma characterization are interferometric methods, Thomson scattering by microwave or laser irradiation, and plasma spectroscopy. The determination of the densities of plasma components would require the measurement of absolute intensities which is quite hard to realize in practice. Notable exceptions are the methods for the determination of density from Stark profiles, or optical refractivities. The direct technique for the determination of atom and ion temperature is the measurement of the thermal Doppler broadening of suitable lines. The above-mentioned techniques allow space-time-resolved measurements, which are fundamental for the analysis of the plume evolution in laser ablation. Laser-induced fluorescence presents the same characteristics though it is particularly used for monitoring of the neutrals.

National experience in the field:

During the last 20 years in the National Institute for Laser, Plasma and Radiation Physics, a large part of activity was concentrated on the development of laser systems, studies on laser interaction with matter, laser-plasma formation, its evolution and diagnostics and laser–ablation studies for material processing purpose. *This activity was reported in Annual Reports since 1982*. Briefly, the scientific community with the Department of Lasers was deeply involved in a) laser-solid target interaction investigating the initial stages of plasma formation (*On the evaluation of a breakdown plasma induced in air in front of a metallic target by microsecond pulsed TEA-CO_2 laser radiation*", I.Ursu et al., Proc. XV-th ICPIG, 1983, Dusseldorf, Germany, Vol.2, p.118, *"Laser heating of metals",* A.M.Prokhorov, V.I.Konov, I.Ursu, I.N.Mihailescu, Adam Hilger Ed.,(1990); *IR Laser Light coupling to metal surface",* S.Jovicevic et al., Infrared Phys.**32**,177(1991), '*Multistage plasma initiation process by TEA-CO_2 laser irradiation of a Ti sample in ambient gas (He,Ar,N_2)*', J. Hermann et al., J.Appl.Phys. **73**,1091(1993); *'Influence of irradiation conditions on plasma evolution in laser-surface interaction',* J. Hermann et al., J.Appl. Phys. **74**, 3071(1993);"*Influence of DR on gain of X-ray lasers with Li-like ions",* V. **Stancalie** et al., IOP Conf. Ser.140 (1994); *Spectral analysis of laser-induced cadmium plasma in vacuum",* I.Apostol et al., Rom.J.Phys. **40**,723(1995); "*Modelling of the Recombining Laser-Produced Plasmas',* **V.Stancalie**, Rom.Rep.Phys. **49**,643(1997), and many other works), b) laser systems and optics technology (*Nd:YAG microchip laser frequency doubling with periodically poled and conventional type II KTP crystals',* R. Dabu et al. SPIE **5581**,151(2004), '*Morfology of 1.06µm laser induced damages in GaAs',* M.L.Pascu et al, Rev.Roum.Phys. **34**,925(1989), "*Ablation plume movement in a pulsed laser deposition system",* A. Marcu et al., SPIE **5581**,371(2004); "*Theory,design and fabrication of a diffractive optical element',* V.Nascov et al., Rom.J.Phys. **49**,197(2004), and many other works); c) laser-plasma diagnostics ("*An interferometric electron density. Density estimate of a TE-CO_2 laser sustained plasma in front of metallic target",* D.Apostol et al., Opt.Comm. **44**,333(1983)*; 'An interferometric electron density estimate of a TE-CO_2 laser sustained plasma in front of a metallic target',* D.Apostol et al., Rev. Roum. Phys. **28**,355(1983), '*Electron density determination of the early stage of low threshold plasma',* M.Stoica et al.,TQE ECA, Vol.9G, p. 257); d) atomic physics and plasma modelling (*Forbidden transitions in excitation by electron-impact in Al Li-like ion*", V.**Stancalie**, V.M.Burke, A.Sureau, Physica Scripta **59**,52(1999), '*$1s^2 2pns$ ($^1P^0$) autoionizing levels in Be-like Al and C ions*", V.**Stancalie**, Physics of Plasmas, **12,**043301(2005), "*R-Matrix Method in Atomic Processes of Laser Interest*", V.**Stancalie** Rom.Rep.Phys. **50**, no.10(1998)717-727, "*Complements to non-perturbative treatment of dielectronic recombination : $\Delta n = 2$ transition in CIV",* V. **Stancalie**, Physics of Plasmas **12**, 110255(2005), *"New method to calculate the Gaunt factor for the refinement of Zeff evaluation in fusion plasmas*", V.**Stancalie** and JET-EFDA contributors, Preprint IOPP, EFDA-JET-CP(05)02-49, "*Complex atoms modelling for plasma diagnostics*", A.Mihailescu, **V.Stancalie**, JOAM7(2005)2413.

The research group with the Faculty of Physics, University of Bucharest, has developed during time two research areas, both of them belonging to the quantum theory applied on the interaction of atoms with electromagnetic fields. The first one is devoted to the atomic radiative processes. Results published in the best journals of physics refer to fundamental processes as Rayleigh and Compton scattering, excitation of bound-bound transitions with two photons, three photon ionization and bremsstrahlung [M. **Dondera**, V. **Florescu**, R.H. Pratt, "*Retardation effects in nonrelativistic two-photon electron bremsstrahlung*", Phys. Rev. A 53, 1492 (1996)]. In the last period the emphases has been paid on the influence of laser radiation on atomic processes as electron-atom scattering, photon-ionisation and bremsstrahlung. An amount of laborious analytical calculation has been performed to complete these results. The second issue is the development of numerical methods to support analytical models. The group has experience in using time- dependent Schrödinger equation within Floquet method and its direct integration. Results have been published in PRA [**M. Dondera**, H. G. Muller, and M. Gavrila, *Observability of dynamic stabilization of ground-state hydrogen with superintense femtosecond laser pulses,* Phys. Rev. A, 65, 031405(R) (2002)], JPB [**M. Boca**, H. G. Muller and M. Gavrila, *Dynamic stabilization of ground-state hydrogen in superintense circularly-polarized laser pulses*, J. Phys. B 37, 147 (2004)] as well as in Laser Physics or presented at the international conferences.

The research group with the University of Bucharest in collaboration with the National Institute for Laser, Plasma and Radiation Physics has been involved in National and European projects PNCDI, **PC IV,** and together are National representative in the PC VI Programme COST Action P14 the aim of which is to joint the

European effort in inertial confinement fusion research.

The research group with the "Politehnica' University of Bucharest has experience in laser-plasma interaction, experiment and diagnostics and related passive spectroscopy. Has a good expertise in laser-plasma coupling studies and optical component technology and science [(*Iron influence on optical and magnetic properties of lead-bismuthate glasses*, V. Simon, R. Pop, **N. N. Puscas**, Modern Physics Letters B, vol. 17, no. 5, p. 1-10, 2003., *Phase-mismatching effects in the internal second-harmonic generation in InGaAs quantum-well laser diodes*, R. G. Ispasoiu et.al, Journ. of Mod. Optics, vol. 47, no. 7, p.c1149-1154, 2000, *Determination of propagation constants in a bent Ti:LiNbO3 optical waveguide by using finite element method*, V. A. Popescu, **N. N. Puscas**, Optics Communications, Vol. 254, No. 4-6 p. 197-202, 2005). Using spectrally resolved optical emission and absorption spectroscopy to analyze spectral energy flux, ionization stages and population of different components into the plasma, the main parameters of electron density and temperature have been provided (C. Fleurier, S.-S. **Ciobanu**, 47th Annual Gaseous Electronics Conference, 18-21 October 1994, Gaithersburg, Maryland, USA, LB10, S.-S. **Ciobanu**, D. Hong, C. Fleurier : "Etude par spectroscopie d'émission et d'absorption et par imagerie d'un plasma d'arc tournant produit dans un disjoncteur", Proceedings of Deuxième Conférence des Jeunes Chercheurs en Génie Electrique FIRELEC, 6-8 avril 1994, Grenoble, France, III, 61-64,*C. Fleurier, S.-S.* ***Ciobanu*****,** *47th Annual Gaseous Electronics Conference, 18-21 October 1994, Gaithersburg, Maryland, USA, LB10*).

3. OBJECTIVES

Near term goal is to create the necessary multi-disciplinarity and critical mass of national scale and scop through collaborative research, to overcome fragmentation and unnecessary duplication, lack of connection between participants though old and present collaboration, and stimulating basic research on the following topics:

1/ experiments and theoretical simulations of technical conditions in order to obtain high density and low temperature laser-produced plasma at the interaction of powerful laser beams of ps and ns duration with solid targets in vacuum;

2/ experiments and theoretical simulations in order to generate fast relativistic electrons on the rear target surface, as inertial confinement fusion ignitors;

3/ experiments and theoretical simulation of the key plasma parameters (electron density and temperature, density number of ionised species) in laser ablation plasma from spectral analysis of the emission spectrum (discrete component). Calculation of the continuum emission from spectroscopic analysis data.

4/ modelling of the basic processes involved in the interaction of atoms with short duration and high intensity laser pulses;

5/ Implementing Web Services for remote data access and distributed applications

4. SCIENTIFIC AND TECHNICAL PRESENTATION OF THE PROJECT:

The proposed activities are related to the present international research programs on the field. The project participants are involved in the framework European Program COST which allows scientific mobility for experiments at the European facilities sites, exchanging data and information with their colleagues in the field of work, publishing scientific common achievements in partnership.

In cone–guided fast ignition, the ignitor beam consists of a relativistic electron pulse generated in a metal cone. The energy to be deposited into the spherical fuel volume has been studied by Atzeni (1999). The deposition depth is a matter of concern. It depends on the relativistic γ-factor of the beam electrons as well as on the stopping mechanism. In the next, the objectives will be described including their scientific complexity as well as our contribution to solve them.

Objective 1. " Experiments and theoretical simulations of technical conditions in order to obtain high density and low temperature laser-produced plasma at the interaction of powerful laser beams of ps and ns duration with solid targets in vacuum" proposes the following milestone:

Estimate minimum beam requirements for simple analytic model resulting from kinetics.

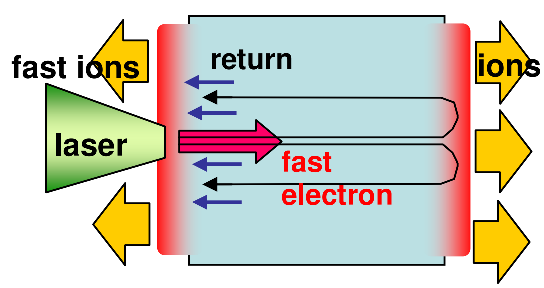
We remind that the conventional fast ignition scheme can be summarised as follows:1/Compression:A dense fuel is assembled by ablation of a thin shell and 2/Igniton with 2.1)A laser accelerates electrons in the corona towards the core; 2.2)The electrons heat the core;2.3)The fuel ignites and burns.

When discuss the fuel ignition and burning (2.3) isochoric ignition model establishes a) minimum size of heat region $n_{DT}R > 1{,}2\ 10^{27}\ m^{-2}$ (0.5 g cm^{-2}), b) minimum temperature kT/e > 10 KeV and c) minimum heating time $t_{ig} < R/c_s$. Numerical models (Atzeni, 1999, Physics of Plasmas **6**,3316) gives $U_{ig}=10(10^{32}/n_{DT})^{1,85}$ kJ; $t_{ig} = 16(10^{32}/n_{DT})^{0,85}$ ps, $I_{ig} = 9{,}3\ 10^{23}(n_{DT}/10^{32})^{0,95}\ Wm^{-2}$.

We refer to laser-produced plasma on cylindrically aluminum fiber target of 7µm diameter. Referring to 2.1., results obtained from laser-solid interaction experiments demonstrated that picosecond pulses with $I\lambda^2 > 10^{11}$ W can transfer up to 50% of their energy into electrons entering the target, absorption efficiency being evaluated at 0.5. In our model, the laser parameters are as follows: I = 10^{13} Wcm^{-2}, λ = 0.53µm and Gaussian temporal shape of 120 ps duration (full width at half maximum) with maximum at 70ps. These parameters will be changed as follows: fiber diameter 100 µm, intensity 10^{12} Wcm^{-2}, λ = 1.06µm, duration 600ps. Relevant quantities will be given versus the distance from the center of fiber, for a number of instant times lying after the begining of the irradiation taken as time of origine. The modelling of the laser-produced plasma requires the knowledge of atomic data such as ionic energy, wavelengths, ionisation and recombination rates, oscillator strength and transition probabilities, number of bound levels involved in the ionisation and recombination processes according to the plasma density and temperature conditions. A special attention will be placed on ion-ion collisions and the comparisons of their excitation rate with those of electron impact processes.

Objective 2. „Experiments and theoretical simulations in order to generate fast relativistic electrons on the rear target surface, as inertial confinement fusion ignitors" covers the following issues:

a. *Electrons and ions production on the rear surface, experiments and modeling*



Focusing the laser on a metal target produced a large relativistic electron current. It then propagated in a gas jet placed behind the foil. In these conditions the penetrating fast electron current cannot be easily compensated by a return current from the background electrons, due to the low density of the gas; hence a very strong charge separation is expected giving strong propagation inhibition. We propose here to analyse these phenomena starting from the modelling of the electron source.

b. *Electrons heat the core*

Our main concern is related to the main task of electron stopping into the plasma. The original proposal on how to stop electrons in plasmas was to stimulate collision processes. Next new proposals were been added: a) electric field (ohmic heating) which imply collisions of return current electrons; b) magnetic field effect (increasing the curvature of the electrons trajectories and as consequent collisional energy deposition per unit length) and c) instabilities effects (small scale collective electric and magnetic fields and ,anomalous' stopping). Basically, the electron energy required to give a stopping distance $n_e s$ = 1,4 10^{27} m^{-2} (0,6 gcm^{-2}) is ~ 1MeV practically independent of density and temperature. For high electron energies $n_e s$ depends only on the logarithm of the electron density. Moreover, the stopping time is ~ $60(10^{32}/n_e)$ fs always much less than the ignition time. We propose here to do numerical simulation on the radially and axially integrated energy deep for an 1MeV electron in the core, under following assumption: a)Slide scattering is negligible (valid for a beam that is not very much longer than it is wide);b)The energy deposition of an electron is uniform along the beam direction up to its stopping distance;c)The distance times the electron density between the source of the electrons and the core is negligible (justified as the corona has been expanded while the core has been compressed);d)Calculate the stopping distance s;e)Assume that the temperature must exceed the minimum temperature everywhere.

c. *Estimate the corresponding laser requirements based on the results of laser-solid experiments*;

Once obtained the beam integrated energy the corresponding laser system requirements can be deduced.

Assuming the collision processes as responsible for electron stopping into the core, the laser intensity required is given by:

$$I_g = 4.7\times 10^{24}\left(\frac{0.5}{\xi_{abs}}\right)\left(\frac{0.4}{\xi_f}\right)\left(\frac{1}{\xi_\theta}\right)\left(\frac{n_{DT}}{10^{32}}\right)^{0.95} \quad \mathrm{Wm^{-2}}$$

Where ξ_{abs} is the absorption efficiency, ξ_f is the distribution efficiency and ξ_θ is the incidence efficiency, which for normal incidence is 1. The laser wavelength required to give a mean energy of 1MeV is related to the laser intensity :

$$\lambda_{ig} \approx 0.1\left(\frac{4.7\times 10^{24}}{I_{ig}}\right) \quad \mu\mathrm{m}.$$

Objective 3. „Eexperiments and theoretical simulation of the key plasma parameters (electron density and temperature, density number of ionised species) in a laser ablation plasma from spectral analysis of the emission spectrum (discrete component). Calculation of the continuum emission from spectroscopic analysis data" aims to solve the following experimental and theoretical problems:

a. *Spectral analysis of the plasma parameters*

To fulfill this objective we propose to characterize ultrashort laser ablation of solid matter in vaccum. We will analyse, spectroscopically, the generation of high-density and high-temperature plasmas by focusing peak power laser radiation onto a solid target emphasing the process of laser ablation and its basic mechanisms.

The main experimental techniques, namely optical emission and absorbtion spectroscopy will be used to characterize laser-produced plasmas. In particular these diagnostic techniques are particularly suited for the study of neutrals ans excited species, allowing the investigation of plasma electron temperature and density by Boltzmann plots and Stark-broadening techniques. Moreover, plasma kinetics including electron impact excitation/ionisation and recombination processes, and energy transfer from electrons to ions and neutrals will be taken into account when modelling laser-ablation plasma parameters, such as temperature, density and evaporation rate. A comparison between the nanosecond, picosecond and femtosecond regimes will be done.

b. *Estimate the continuum emission from the experimental spectral data analysis*

Spectrally resolved emission analysis of the laser-produced plume has revealed that the fast and slow part of the laser-induced plume are characterized by very different emission spectra: The luminescence of the fast component is dominated by emission lines of atoms of the target material, while the slow, delayed plume population is characterized by structureless broadband continuum emission spectrum. This slow component is mainly formed by nanoparticles with an average radius of the order of 10nm. The expansion velocity of nanoparticles component reach a specific value that is almost independent of the laser pulse durations in this slow regime. These phenomena will be analysed on the base of experimental data .

Objective 4. „Modelling of the basic processes involved in the interaction of atoms with short duration and high intensity laser pulses" covers the following theoretical issues:

a*)The nonlinear response of atomic systems in intense laser field*

We study two basic processes which appear in the interaction between the intense laser radiation and atomic systems, and which belong to the class of induced laser processes: multiphoton ionization (electron emission following the absorbtion of laser photons by the atoms) and harmonics generation (the emission of radiation with frequency equal with a multiple of laser frequency), both presenting considerable theoretical and practical interest. We will study systematically the features of these processes as function of laser pulse, first of all the dependence of the quantities which characterise these processes on the peak envelope and the duration of the pulse. In strong connection with the themes of this project, a significant part of our efforts will be dedicated to set in evidence the conditions for which the emissions of electrons and photons with high energies, processes known in literature as "Above Threshold Ionization" (ATI) and "High-order Harmonic Generation" (HHG), are inhanced. The production of VUV and XUV coherent radiation, with ultra-short duration, using high order harmonic generation, begins to transform in a current practice. To describe these processes we evaluate, in esence applying some numerical methods, atomic survival probabilities, energy distributions (ATI spectra) of photoelectrons and of photons emitted by the atomic systems. Due to the difficulty of the problem, the atomic systems considered by us are unidimensional and tridimensional, with one active electron. We will explore the possibility to take into account the effect of electronic correlations. Concerning the ionization we shall study the particular case in which the process is due to the interaction of the atom with the laser pulse whose characteristics (average frequency, lenght) are similar to those that will be used in inertial confinment fusion experiments. We shall study the dependence of the atomic response on the laser pulse band width, related to its finite duration, for an intensity range in which the nonrelativistic description is a good approximation. Concerning the radiation emission, we will investigate how the intensities and line profiles change with the laser pulse duration, in particular in the limit of ultra-short laser pulses, consisting of only few cycles. For both processes, our purpose is to discover the cases in which the energy transfer from intense laser field to the photoelectrons or photons emitted by atoms takes place with high efficiency. In this context, the existence of resonances for some values of intensity and frequency of the laser field becomes important. We will display the interesting resonances and will follow their consequences on spectra.

***b**) The study of several radiative processes in laser-atom interaction*

The main processes we shall deal with are the elastic and inelastic scattering of radiation. The study of the scattering of radiation on bound or free electrons, in the presence of a laser field is of particular interest for plasma diagnosis. The analysis of this process requires the calculation of the scattering amplitudes and cross-sections. For intense laser fields, the evaluation of these quantities is based on the knowledge of adequate solutions of the time-dependent Schrodinger equation. A first stage will imply the use of semi-perturbative methods based on approximate wave-functions, the most used being the low-frequency approximation and Coulomb-Volkov approximation. In a second stage we shall use in the scattering amplitude solutions of the time dependent Schrodinger equation (wave-paquets), numerically calculated.

***c**) Electronic dynamics on short and ultra-short temporal scale*

A pulse (or train of pulses) of XUV radiation (like the pulses obtained by HHG) and the duration in attosecond range, which interacts with an atom placed in intense laser field, can generate an electronic wave paquet, and the generation mechanism is controlable by modifying the pulse parameters. We will examine the evolution in time of the wave paquet, for different values of the phase difference between the XUV pulse and the laser pulse (intense and relatively long, with duration in femtosecond range). We will study how are changed and how can be controlled the angular and energetic distributions of photoelectrons and photons, as function of mentioned parameters.

To achieve the activities 4.a-4.c we will use in principal numerical methods for integration of the time dependent Schrodinger equation, and to analyse the wave function obtained by solving this equation. To generate quantitative results we will run codes (some developed in previous projects, others in this project) which implement these numerical methods, for cases which correspond to adequate initial conditions and for different values of implied parameters. In this scope, we will use the computers existing in the laboratories of the partners to the project.

Objective 5."Implementing Web Services for remote data access and distributed applications"

Research on fusion requires effective collaboration between members who are not co-located in time and space. Remote computing environments are needed to share information between experts in nuclear fusion research from institutes and universities, distributed throughout one or more countries. The amount of available data is increasing continuously, which requires new techniques for compression, archiving and retrieval. Recently, hybrid data acquisition systems with MDSplus have been proposed [Seong-Heon Seo, J.S. Hong and M. Kwon, “CAMAC, VXI, and PXI hybrid data acquisition system with MDSplus”, FED, Volume 71, Issues 1-4, June 2004, Pages 141-144] to acquire data and then archive it onto a hard disk. The data acquisition system of Wendelstein7-X [P. Heimann, S. Heinzel, Ch. Henning, H. Kuhntopf, H. Kroiss, G. Kuhner, J. Maier, J. Reetz and M. Zilker, “Status report on the development of the data acquisition system of Wendelstein 7-X”, FED, Volume 71, Issues 1-4, June 2004, Pages 219-224.] includes three sample DAQ stations typical to experiment, the timing system, the monitoring subsystem and the data archive

A web service will be developed that offers processing routines for standard spectroscopic data. Web services can be created and used in any programming language, including Java, FORTRAN, C/C++ and PHP. Libraries are available that can simplify the programmer's work. For the present application we will use NuSOAP, which is a framework for building and using web services, written in PHP. The reasons for choosing this framework over other ones, like the OASIS Web Services Resource Framework (WSRF) and WSRF.NET, are the system independent implementation of NuSOAP and the easiness of creating and consuming services.

5. PROJECT JUSTIFICATION:

The European research programs advanced research and technology development in major interrelated areas that include physics of laser interactions with atoms, molecules, clusters, solids and plasmas, fusion target theory, target experiments, and laser and optical science and technology. Europe has made a substantial investment in inertial fusion research. An important long-term goal is to explore inertial confinement fusion's feasibility as a clean and inexhaustible source for commercial electric power production by inertial fusion energy. The Project' participants already collaborate with the European teams. (Please find attached copy of the international collaborations in the field).

The researches activities will be done within the present proposal are related to the most important international scientific programs at the moment. Their success is guaranteed by the high level scientific quality of participants the works of whom are already reported in the most prestigious journals of physics as Phys. Rev. A, J.P.B., Phys.Plasmas., Optics Comm., J.Mod. Phys. etc. or presented at the international conferences. The participants are referee for main international journals of physics in the field, authors of recommended books, members of the international or European associations. In our view the project will open new perspectives encouraging of the next national research goals in the field:

- The development of National experimental facilities which includes laser systems, optics technology and research; This objective will be achieved under the next national and international research program the participant or coordinator of which is the National Institute for Laser, Plasma and Radiation Physics.
- Concept improvements emerging at a rapid rate, giving increased confidence that an economically-competitive inertial fusion power plant can be developed. To fulfil this purpose, we consider: the best use of frontier knowledge in multidisciplinary dimensions; maintenance of a 'critical mass' of high level scientists and high rate of exchange of qualified human resources; plasma sciences considered essential elements in a balanced fusion effort. We have to emphases that Laser Department with the National Institute for Laser Plasma and Radiation Physics, and Faculty of Physics with the University of Bucharest are involved in the COST European Program, Action P14 "*Laser-matter interactions with ultrashort pulses, high-frequency pulses and ultra intense pulses. From attophysics to petawatt physics"* (2004-2008) the main objective of which is to unify European research on fast ignition and consequently, laser induced fusion energy research.

6. DIAGRAM OF PROJECT EXECUTION:

The project has five major objectives which will be achieved during three annual stages each of them being executed in partnership , the partners having their specific milestones as follows:

Phase 1. :" *Basic processes at the interaction of powerful laser pulses with atoms and plasmas*" is related to the objective 1 and 4 and finalises with Report of research including description of plasma parameters and characteristics at microscopically scale.

Partners responsibilities:

INFLPR: estimate plasma parameters for laser-produced plasma on cylindrically aluminum fiber target of 7µm diameter. Referring to 2.1., results obtained from laser-solid interaction experiments demonstrated that picosecond pulses with $I\lambda^2 > 10^{11}$ W can transfer up to 50% of their energy into electrons entering the target, absorption efficiency being evaluated at 0.5. In our model, the laser parameters are as follows: $I = 10^{13}$ Wcm^{-2}, λ = 0.53µm and Gaussian temporal shape of 120 ps duration (full width at half maximum) with maximum at 70ps. The atomic structure packadge program ADAS and the group' facilities will be used. Results refer to experiments performed at LULI palaiseau France.

UB Studies to determine the laser pulse characteristics (band width, intensity) which contributes to increasing the ATI and HHG phenomena; uses Personal workstation xw9300 and Athlon2400+ computing systems.

UPB: makes spectral analysis on the laser-produced plasma on the use of Laser Nd: YAG laser system (Surellite II („Continuum USA")); multi-target system, and experimental set-up at INFLPR. Acquisition computer systems or parts of it.

Terms : May, 2006- Dec.,10,.2006

Costs: 12 man-month, research and development equipments, software, computer systems, overheads, consumables.

Phase 2. "*Diagnostics of laser-produced plasmas for inertial confinement fusion purpose"* is addressed to the objective 1, 3 and 4 and finalises by Report on Research involving experimental and theoretical data at the end of the following partner' milestones:

INFLPR: Estimates the main accelerated particle fluxes and their characteristics- Estimate minimum beam requirements for simple analytic model resulting from kinetics; numerical calculation on the cross sections and rates of elementary processes including electron and ion collisions with atoms and ions; collaboration with Task Force Diagnostics EFDA-JET in the framework of FP VI/Euratom. Codes are available at JET and INFLPR

UB: cross sections evaluation for the X-ray scattering on bound and free electrons in presence of laser radiation; dependence on the external field characteristics.

UPB: uses UV-VIS spectroscopic system at the INFLPR site to analyse line radiation and continuum spectrum of the laser ablated plasam.

Terms: Dec,10,.2006- March,15, 2007

Costs: 19 man/monts, computing systems or part of it, overheads, consumables, stages of research and participation at the international meetings or conferences

Phase 3." *The laser-plasma-target coupling to generate accelerated particles"* involves an imprevive number of young scientists as the corresponding experiments and results can be detailed in many application purposes. Finalises with Report of research and Paper for publication in draft. This phase is related to the objectives 3, and makes his completion to objectives 1 and 4. Activities are to be executed in partnership as follows:

INFLPR : estimate the coupling laser-plasma-target in order to generate accelerated particles ; experiments with 1.06 µm, and 360mJ, 4.5ns, laser systems at INFLPR and UPB sites;

UB : investigation of resonance effects on multiphoton- ionisation and harmonic generation processes ; uses Personal workstation xw9300 and Athlon2400+ computing systems.

UPB : experiments in order to get information on fast electrons or/ions accelerated by laser pulses after coupling laser beam at 360mJ, 4.5ns with plasma

Terms: March 15,2007- August 15,2007

Costs : 19 man/month, acquisition of research instruments or parts of them, participation at the international workshops and conferences, overheads, consumables

Phase 4. « *Electron dynamics at microscopic and macroscopic scale* » related to objective 4 and contributes to objectives 1 and 3. Results are provided by Report of research and paper in draft. The main part of results refers to the dependence of electron distribution functions (angular and energetic) to the XUV and /or X ray parameters. Partners responsibilities are :

INFLPR: the main task is the 1MeV electron stopping into the plasma considered DT with 0, 6 gcm^{-2}. Numerical models, colllaboration with University of Milano under COST P14.

UB: X-ray scattering of electrons: a) the use of wave package in description of process b) dynamics of one wave-package created with an X-ray pulse.

UPB; optical UV-VIS emission and absorbtion spectroscopy will be used to characterize laser-produced plasmas. In particular these diagnostic techniques are particularly suited for the study of neutrals ans excited species, allowing the investigation of plasma electron temperature and density by Boltzmann plots and Stark-broadening techniques.

Terms : August15, 2007- December 15,2007

Costs ; 19 man/month, overheads, consumable, participation at the international conferences

Phase 5. „*Implementing Web Services for remote data access and distributed applications”* refers to the objective 5 activities and aims to develop, for the present application, web services on the use of NuSOAP, which is a framework for building and using web services, written in php. The Web Services will be implemented on the server “atomic.inflpr.ro “. The partners responsibilities are :

INFLPR: provides data as output from experiments and simulations on laser, target, plasma research

UB: provides data as output from laser-atom interaction research

UPB: provides data as output from plasma diagnostics and fast electrons diagnostics

Terms: December 15,2007-August 15,2008

Costs 22 man/month, services, software, overheads, consumables, publications and reports at the international conferences.

7. RESULTS/ PROFITS AND DIAGRAM/CAPITALIZATION PLAN/ DISSEMINATION

Quantitative results:

- expected results: quantitative results related to laser-atoms, laser-plasma interaction as: the stopping distance s; corresponding laser system requirements, fusion related atomic data: atomic data for ionised atoms, plasma kinetics, abundence of different ionisation stages for different solid targets and possible effects of plasma opacity

- stipulated profits:
- scientific publications (‚bibliometry');
- post-doc positions offered, students and young scientits will be encouraged to develop their research in the field of laser-atoms, laser-plasma interactions toward inertial confinement fusion, contributing through their works to the development of the research issues;
- estimated profit, profitableness;
- results will be published in scientific journals or presented at the international workshops, conferences in the field;
- number of research personnel and exchanged scientists;
- participations in trans-European education schemes
- the modalities of the results dissemination and the potential beneficiaries: the organisation of seminaries, workshops as well as the attendance of international and national conferences

specifications : participants agree concerning the allocation of intellectual rights according to the legislation in force.

8. TECHNICAL, ECONOMICAL AND SOCIAL IMPACT

The project major goal is the building of a complex team including scientists from the research institutes and universities able to develop collaborative works on laser-atoms, laser-plasma interactions towards the very ambitious international programmes on inertial confinement fusion . The collaboration with young people in the framework of the research proposal towards a clean and inexhaustible source for commercial electric power production by inertial fusion energy has impact on their next approach of solving environment and life issues. Moreover, a large number of atomic data, numerical methods and models will be disseminated giving rise to further collaborations in the field. Furthermore, a high visibility of activity would offer higher chances of realizing initiatives toward the general public. Only effective transfer of knowledge can increase levels of science and technology.

9. PROJECT MANAGEMENT

1) The project activities are proposed in partnership, teams being asked to comunicate each other their results as well as to organise common seminaries in the field . The success of the present proposal is based on the past (FP IV) and present (EURATOM, COST) collaboration between scientists. 2)The project activities and duties are included into the agreement between scientists each of them being aware on the milestone and deliverebles. 3)The expertise of the teams is coming from their experience in the field; a lot of published works related to the subject, many national and international contracts under co-ordination, as well as their agreement concerning the allocation of intellectual rights. 4)The laboratories have benefit of the most part of material resources for the project execution 5)The access to the experimental data from laser-solid, laser-plasma interaction and related informations is part of the agreement between NILPRP and Universities. 6)The access to most scientific journals is open on-line.

We consider all these atributes as garant for a succesful activity with the proposed project. Many young scientists are involved into project activities and their presence to related workshops and conferences will be encuraged. The presence of the Universities in the project execution will encurage students to start their theses in the field of laser-atom, laser-plasma, experimental and theoretical investigation.

TICF will continue to make outstanding progress on laser-plasma interaction, laser interaction with atoms and molecules, laser-plasma characterization and diagnostics. It would be premature at this stage to judge which of the variety of magnetic and inertial fusion concepts will ultimately succeed commercially. This fact should not discourage use of the best available concepts in the design and construction of needed fusion test facilities.

10. DESCRIPTION OF REQUIRED RESOURCES FOR PROJECT EXECUTION

Stage I/Phase I.1. 12 man/month, total financial resources 291000; **INFLPR** 5 man/month, material resources: Nd:YAG lasers Surellite II („Continuum USA"), Radiofrequency generator and experimental set-up with two chambers for laser-irradiation of target, able t generate fluxes of charged particles in order to estimate their drift velocity; UV and VIS diagnostics systems, ADAS atomic package programs for spectroscopy, Cowan and R-matrix codes for atomic structure calculations of optical allowed and forbidden transitions in charged atomic systems;1.1/90000;**UB** 4 man/month, participation EPS2006 and COST workshops, 1.1/106200 ; 14.1/2000 ; 14.2/2400 ; 14.3/4600,**UPB** 3 man/month;achievement of computer systems and part of research specific systems ,1.1/70.400 ;7.1/3600 ;7.2/4000 ;7.3/1.700

Stage II/ Phase 2.1 ; 19 man/month ;total financial resources156.600 ; **INFLPR** 12man/month ; achievement computer system and biro tics; uses UV-VIS spectroscopic system, Oscilloscope Tektronix TDS724A, experimental set-up with two targets ADAS, Cowan, R-matrix.codes;1.1/58200,7.2/3600,7.3/1700;**UB** 4man/month, uses Personal workstation xw9300,Sistem Athlon2400+,1.1/43200; **UPB** 3man/month, 1.1/32400.

Stage II/PhaseII. 2:19 man/month, total finance 261.000;**INFLPR** 12 man/month, achievement computer systems in part for web services, attends EPS 2007, workshops, stage of works at CELIA Bordeaux France and QUB Belfast:1.1/104.000,7.1/6100,14.1/5400,14.2/16200,14.3/3300.**UB** 4 man/month, 2 research stages at the Universities Paris VI and York,UK. 1.1/63000;14.1/2000;14.2/2400,14.3/4600.**UPB** 3 man/month, stages at LULI Palaiseau Farce, 1.1/41.000,7.1/3000,14.1/2000,14.2/6000,14.3/2000

Stage II/Phase II. 3. 19 man/month, 208.800; **INFLPR** 12 man/month, will acquire computer system or part of it, stages at the University Milan for experiments on drift velocity of charged articles, .1/94100, 7.2/3600, 14.1/3400, 14 .2/3600,14.3/3.300;**UB** 4 man/month, stages at the University Paris IV and University of York UK,1.1/48600,14.1/2000,14.2/2400,14.3/4600;**UPB** 3 man/month, achievement of computer systems and birotics.1.1/40.000,7.2/3200.

Stage III/Phase III. 1: 22 man/month, total estimate 471.600; **INFLPR** 15 man/month, 1.1/270000, **UB** 4 man/month, research stages 1.1/101700,14.1/3000,14.2/3600,14.3/6900, **UPB** 3 man/month and stages at our collaborators from abroad 1.1/70.000,14.1/6400,14.2/3000,14.3/7000.

Please find enclosed attached documents in copy, of our international collaboration in this field of work.