Study of the radiative properties of plasma mixtures of interest for ICF chamber design using the ATMED code

JG Rubiano[1,2], MA. Mendoza[1], JM Gil[1,2], R. Rodriguez[1,2], R. Florido[1,2], P. Martel[1,2], E. Minguez[2]

[1] *Departamento de Física, Universidad de Las Palmas de GC, Las Palmas de GC, Spain*

[2] *Instituto de Fusión Nuclear (DENIM), Universidad Politécnica de Madrid, Madrid, Spain*

1. Introduction

The durability and lifetime of refractory metal coatings on the first walls of inertial and magnetic confinement fusion reactors is a key issue for the feasibility of those devices. In the LIFE plant Xe may be used as a target-chamber gas-fill to moderate the first-wall heat-pulse due to x-rays and energetic ions released during target detonation [1, 2]. To study the behaviour of cooling and beam/target propagation through such gas-filled chambers, in this work we present a detailed computation of the radiative properties in a wide range of temperature and density of pure Xe plasmas. Since in the LIFE Plant concept tungsten is a candidate as high-Z material for the first wall coverage of the cavity [3], and Pb is being considered as base material for hohlraums at indirect drive reactors, an analysis of the influence of these materials in the radiative behavior of Xe plasmas is performed studying Xe-W and Xe-Pb plasma mixtures.

2. Computational models.

Due to the wide range on density and temperature conditions two models have been used for simulations. For low density and temperature cases we compute the radiative properties of Xe plasmas using the ABAKO/RAPCAL code [4]. This model determines the non-local thermodynamic equilibrium (NLTE) rate equations, in both stationary and time dependent. It uses several processes well described in several published formulas: for collisional ionization, Lotz formula; for 3-body recombination, the detailed balance; for radiative recombination, the Seaton formula; for collisional excitation, the Van Rogemorter expression; for collisional de-excitation, the detailed balance; for spontaneous decay, the Einstein Coefficient; for electron capture, an ABAKO approximation, and for autoionization, detailed balance. Results demonstrate that with these rate coefficients, the code works well in the corona, and in the Saha limits, and also can work, with thick and thin plasmas. It has been also considered the correction for continuous lowering in the energies at higher densities.

We use the ATMED code for conditions of high density and temperature and to study plasma mixtures [5, 6]. This code has been developed to compute the spectral radiative opacity as well as the Rosseland and Planck means for single element and mixture hot dense plasmas. The code has been developed in the context of the average atom model approximation. The atomic data needed are computed using a Relativistic Screened Hydrogenic Model based on a new set of universal screening constants including j-splitting that were obtained from the fit to a wide database of atomic energies, ionization potentials and transition energies of high quality [7].

The total spectral opacity of plasma κ(ν) is the combination of bound-bound, bound-free, free-free and scattering processes. The line absorption cross section calculation has been computed using a new analytical expression for oscillator strengths based on relativistic screened-hydrogenic wave functions. The lineshape includes natural width, Doppler line broadening and electron collisional broadening. To obtain a more realistic value of the Rosseland mean opacity and additional broadening of the bound-bound transitions has been included by considering the fluctuations of the occupations numbers into the atomic shells. The model can also compute the radiative properties of plasma mixtures, the plasma Equation of State and Shock Hugoniot curves.

3. Results

a) Xe plasmas.

To cover a wide range of temperature and density conditions in the fusion chamber we have perform a simulation of Xe plasmas in a range on temperature between 1 eV and 250 eV. In figure 1 we show the Rosseland Mean Opacity for several densities ranged from 10^{-5} to 10^{-3} g/cm^3. For the low temperature region (1-20 eV) the code ABAKO code has been used because NLTE conditions are expected [1], the rest of computation (30-250 eV) has been carried on by ATMED. As expected the opacity increases with density in one order of magnitude in the whole range and there is a maximum of absorption around 4 eV. Figure 2 shows the multifrequency opacity for 30 eV and several densities as it can be seen the absorption peak area in the EUVL range of 60-120 eV (20-10 nm) is narrowed as the density rises due to the broadening of absorption peaks.

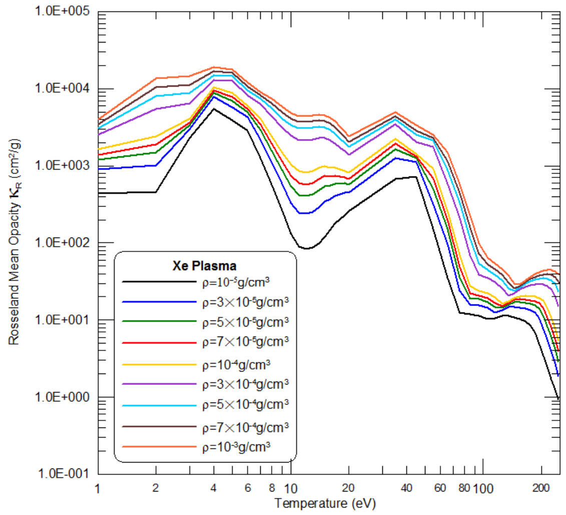

Figure 1. Roseland Mean opacity of a Xe Plasma for several conditions of density and temperature.

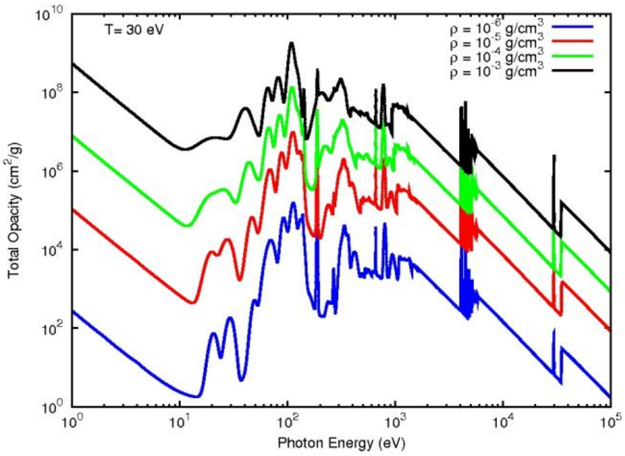

Figure 2. Spectrally resolved opacity of a Xe Plasma for 30 eV and several conditions of density. The plots have been shifted in a factor 50 to a better display.

The emissivity for the same cases than in figure 2 is plotted in figure 3. The average charge state ranges from 17.6 to 10.75 and the N shell is the valence shell. A significant line emission around 11.4 nm is predicted corresponding to inner transition in the n=4 shell and from n=4 to n=5 shells.

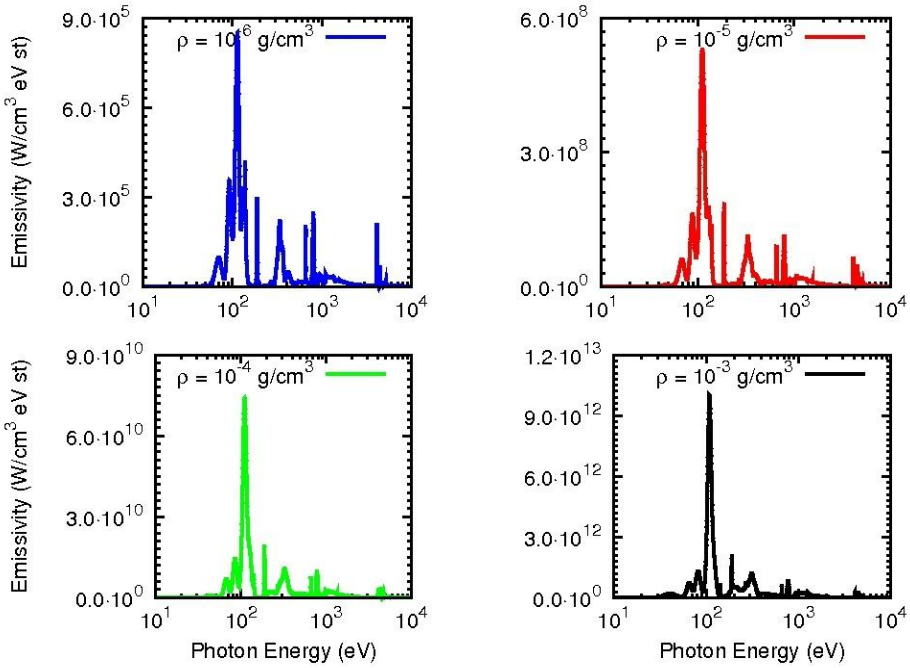

Figure 3. Emissivity for a Xe Plasma for 30 eV of temperature and several conditions of density computed by ATMED.

b) Xe-W and Xe-Pb mixtures.

In the operation of a fusion reactor the xenon atmosphere in the fusion chamber can be contaminated by tungsten impurities from the first wall and with debris form the targets varying its radiative properties.

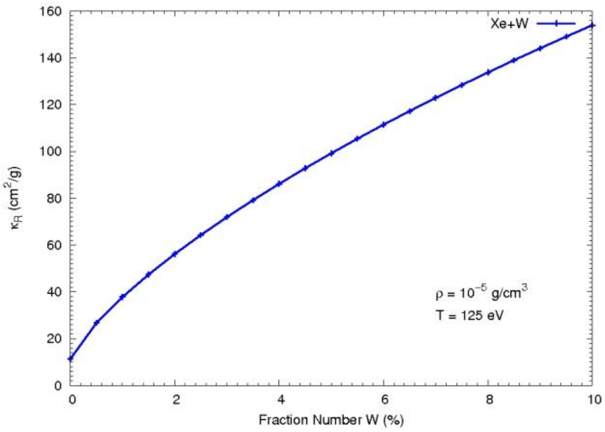

Figure 4. Roseland Mean opacity of a Xe-W Mixture Plasma for several fraction number of W at 125 eV and 10^{-5} gcm^{-3} computed by ATMED.

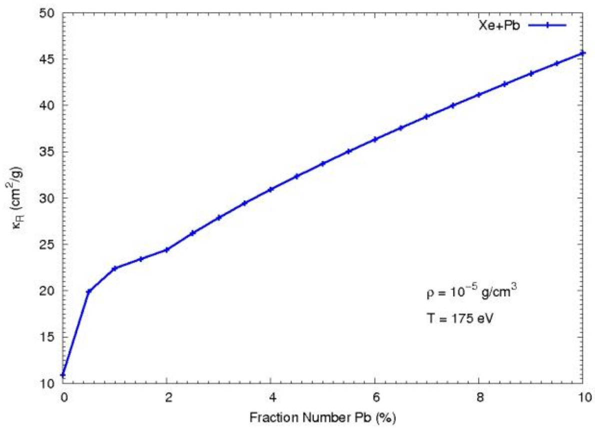

Figure 5. Roseland Mean opacity of a Xe-Pb Mixture Plasma for several fraction number of W at 175 eV and 10^{-5} gcm^{-3} computed by ATMED.

Figure 4 shows the Rosseland mean opacity of for a Xe-W mixture for several concentrations of tungsten from 0 to 10% at 125 eV and 10^{-5} g/cm^3. A significant increment of the opacity with the proportion of tungsten is obtained. An amount of a 2% of W increases the opacity in a factor 4 in relation to pure Xe plasma. Similar behavior is shown in figure 5 for a Xe-Pb mixture.

Acknowledgements

This work has been supported by Spanish Ministry of Science and Innovation Grant No. ENE2009-11208 and the “Keep in Touch” Project of the European Union.

References.

[1] R Miles et al. Challenges Surrounding the Injection and Arrival of Targets at LIFE Fusion Chamber Center. LLNL-JRNL-464793. (2011).

[2] M. A. Rhodes, J. Kane, G. Loosmore, J. DeMuth, and J. Latkowski. Proc. SPIE 7916, 791604 (2011).

[3] A. Hassanein, V. Morozov. Fusion Engineering and Design 63-64, pp. 609-618 (2002).

[4] R Florido, R Rodríguez, J M Gil, J G Rubiano, P Martel, D Suarez, M Mendoza and E Mínguez. Phys. Rev. E **80** 056402 (2009).

[5] JG. Rubiano, M. Mendoza, J. Gil, R. Rodríguez, R. Florido, P. Martel and E. Mínguez, 37th EPS Conference on Plasma Physics, P5.405 (2010).

[6] M.A. Mendoza, J G. Rubiano, J. Gil, R. Rodríguez, R. Florido, P. Martel and E. Mínguez, 37th EPS Conference on Plasma Physics, P4.410 (2010).

[7] M. Mendoza, J. Rubiano, J. Gil, R. Rodríguez, R. Florido, P. Martel and E. Mínguez, High Energy Density Physics, 7, 169 - 179 (2011).