Radiation losses in FTU

G. Apruzzese,_ L. Gabellieri, H. Kroegler, G. Mazzitelli , L. Pieroni

1 - Introduction

Radiation losses from the FTU plasma are measured (temporally and spatially resolved) with a 16 channel bolometer array, arranged in a pin-hole-camera, which observes the lower half plasma cross-section. The bolometer consists in a metal resistor bridge [**ref.1**]. The total radiated power and the radial profiles of emissivity are calculated by the standard Abel inversion technique , assuming poloidal symmetric emission. The bolometric emission measured in FTU plasmas is fitted utilizing a 1-D impurity transport code with an expression for the anomalous flux with a diffusive term plus a pinch term. The absolute values of the central impurity densities are obtained by x-ray PHA measurements, and are used as input to the code to have a comparison with the experimental results.

For FTU plasmas , the capability of recostructing radial profile is limited by the presence of marfes [**ref.2**], which are characterized by strong poloidally asymmetric radiation. A method has been developed to calculate the radiation emission from marfe, both for deriving the right contribution to the total radiated power and for characterizing the marfe itself.

2 - Radiation losses

PHA soft-X ray diagnostic is routinely used on FTU to give quantitative estimations about heavy (Kα emission lines) and light (bremsstrahlung enhancement) impurity concentration in the plasma. In **Fig.1** the concentrations of nickel, cromium and oxygen (assumed to be the light dominant impurity), measured at the centre of plasma column, are shown versus electronic density for I_p=600 KA. In these discharges with inconel poloidal limiter, Nickel is the dominant metallic impurity especially at low density. Z_{eff} measured by PHA shows a fairly good agreement with bremsstrahlung calculation [**ref.3**].

The data collected by PHA have been utilized as input for a 1-D impurity transport code. The code solves the following equation for each ion of charge Z:

$$\delta n/\delta t + (1/r)\, \delta(r\Gamma_Z)/\delta r = S_Z n_e n_Z - S_{Z-1} n_e n_{Z-1} - \alpha_{Z+1} n_e n_{Z+1} + \alpha_Z n_e n_Z$$

where S is the ionization rate and α the radiative plus dielectronic recombination rate.

For the flux we assume the usual expression:

$$\Gamma_Z = -D\delta n_Z/\delta r + n_Z v_o r/a.$$

where D is the diffusion coefficient and v_o is an inward velocity , these parameters are assumed constant along the minor radius. The total radiated power is one of the outputs of the code and the result is compared with the bolometer measurement.

In this code only one impurity is considered, but generally more impurities are present in the discharge. In this case several code runs are performed, adopting the same values for the diffusion terms, and the results are summed up. For comparison, radiation losses are also calculated under pure coronal equilibrium assumption neglecting diffusion, in this case the radial impurity profile is assumed quite flat [**ref.4**]. Measured electron temperature and density profiles are adopted and a matching is performed to adjust the values at last closed magnetic surface to the data given by Langmuir probes measurements.

Simulations have been executed for a wide range of electron density for discharges in steady state condition and in absence of marfe, to avoid localized radiation source. Bolometer results are reproduced assuming a value of D = 0.3 m-2s-1 for the diffusion coefficient and v_0=-1.5 ms-1 for the inward velocity. These values are consistent with those quoted previous on FTU **[ref.5]**. As an example, in **Fig.2** the total computed emission profiles together with the contribution of single impurities are shown.

In **Tab 1** the total experimental radiation losses are compared with the results obtained from the diffusion code and with the corona equilibrium calculations.

Table 1

shot	**electron density (m-3)**	**Prad Experim. (KW)**	**Prad corona (KW)**	**Prad diffusion (KW)**
7193	0.6exp20	800	370	580
6179	1.4exp20	700	640	740
6242	2.0exp20	480	440	540

Generally good agreement is found for the intermediate and high electron density discharges both for the diffusion as well as for corona calculations. At low density great discrepancy is found with corona calculation while the result from diffusion code is more acceptable. From the data it seems that a dependence of anomalous flux with density must be envisaged and it will be the object of further investigations.

The difference at low electron density between corona and diffusion calculations is due to the role played by oxygen emission. The oxygen emits at the boundary of the plasma and it is strongly dependent from the electron temperature profile at the edge The effect of transport is to displace the emission peak toward the centre with an obvious increase of the radiation losses. This is less important for medium Z impurity wich emits more inside the LCMS.

3 - Non- axysimmetric radiation

The total radiated power and the radial profiles of plasma emissivity are derived by an Abel inversion of the line integrated bolometer signals performed by using the Zernicke technique coupled with the equilibrium reconstruction code (ODIN) [**ref.6]**: the magnetic flux surfaces are taken as surfaces of constant emissivity. The assumption of poloidal simmetry for the plasma emissivity is no more valid in presence of a poloidal asimmetric radiative structure as a marfe. When the marfe is localized inside the view of the bolometric measurement, see **Fig.3**, the corresponding increase of signals is seen as a increase of plasma emission over the plasma cross-section, determining in this way a overestimation of the total radiated power. On the other side if the marfe is localized outside the view, the total radiated power is understimated.

On the FTU tokamak, the marfe radiative emission is observed also by the Hα and the bremsstrahlung diagnostics, both with horizontal and vertical sight lines. Sometimes the marfe is seen by the inner vertical cord of IR interferometer which lies at eighteen cm from inward to the plasma center, when it intercepts the marfe region. The marfe is a toroidally simmetric and poloidally asimmetric band of impurity radiating plasma . Resulting by a radiative thermal instability **[ref.7]**, it is characterized by high electron density and low electron temperature. The formation of the marfe occurs at the inner plasma edge in tokamaks with toroidal or poloidal limiter as FTU. The variable marfe surfaces can be evalutated by the signals of the Hα or bremsstrahlung arrays. In **Fig.4**. it is shown how we estimate the marfe poloidal length, which is taken to correspond to Hα half maximum emission. The width of the marfe in the radial direction is taken approximately between 2-4 cm. Since the marfe is an edge plasma phenomenon, we assume that the bulk plasma properties do not change during the presence of the marfe. This means that the increase of bolometric signals are due only at the formation of the marfe. Taking an average value of the increase only on the integrated line signals which see the central part of the marfe, as described before, the marfe average emission is derived. The marfe total radiated power is then estimated considering its volume.

For this analysis, only discharges with marfes whose central part is seen by the bolometric detectors are examined. These discharges have plasma current Ip = 300-1100 KA and toroidal magnetic field Bt = 6-7 T. Over the electron density range of 0.9-1.9 *10 m-3, the radiation emissivity in the marfe ranges between 2-12 MW/m3 without showing any dependence on the electron density. A clear correlation instead appears with the conduction power, Pohm-Prad, calculated at the time before the marfe onset, as shown in **Fig.5**.

4 - Conclusion

Calculation of total radiated emission in FTU plasma assuming impurity concentrations as obtained from PHA soft x-ray measurements generally agree with the experimental bolometer results, provided that a diffusion coefficient of 0.3 m-2s-1 and a value of -1.5 ms-1 for the inward velocity are assumed in the transport model. Even if the results seem to suggest that a dependence of anomalous flux with density have to be investigated.

The marfe formation is connected with the presence of light impurities in the discharge. During the FTU operation with the poloidal limiter in inconel or in molybdenum, the oxygen is responsible of the marfe onset. We have also observed marfes in discharges dominated by neon (from injection) and silicon (soon after the silanization of the vacuum vessel). The contribution of the marfe radiation to the total plasma radiation is 5-30 % over an electron density range of 0.9-1.9*10m-3. There is evidence of a correlation between the marfe emissivity and the conduction power. An evaluation of the marfe electron density, ne, can be obtained considering that the emissivity is given by the relation $\varepsilon = ne \; ni \; R(T)$ where ni is the impurity density and R(T) is the cooling rate of the impurity. Taking the maximum value of R(T) and considering an approximated value for the impurity fraction, ni/ne, the marfe density is derived. For a plasma with a fraction of 1% of oxygen, as the dominant impurity, the corresponding values of marfe density are between 20-50 % of the line average plasma electron density.

References

/1/ K. F. Mast, J.C. Vallet, C. Andelfinger, P. Betzler, H. Kraus, and G. Schramm, Rew. Sci.Ins. **62** ,(1991) 744

/2/ J.L. Terry, E.S. Marmar, and S.M. Wolfe, Bull. Am. Phys. Soc. **26**, (1981) 886

/3/ G. Bracco, S.E. Segre, V. Zanza et al., accepted for publication in Nuclear Fusion

/4/ V. Pericoli Ridolfini, R. Zagorski, F. Crisanti et al., paper OB7 11th PSI Conf. on Plasma Surface Interactions in Controlled Fusion Device May 94 Japan

/5/ I.Condrea, R. De Angelis, L. Gabellieri, Proceeding of 20th EPS Conference on Controlled Fusion and Plasma Physics July 93 Portugal

/6/ F. Alladio and P. Micozzi, submitted to Nucl. Fusion

/7/ J. Neuhauser, W.Schneider, and R. Wunderlich, Nucl. Fusion **26**, (1986) 1679.

Figure captions

Fig.1: PHA soft x-ray measured impurity concentrations versus line averaged electron density. Heavy ions concentrations are calculated from Kα emission lines.

Fig 2 : Calculated emission density profiles. The continous line is the total power density.

Fig.3: viewing chords of the bolometer array in FTU and a typical position of a marfe.

Fig.4: radial profile of horizontal Hα (a) and bremsstrahlung (b) radiation, before and after the marfe onset.

Fig.5: radiation emissivity in the marfe versus the conduction power, Pohm-Prad.