JET–R(97)15

Implementation of the ICRF Package PION in the Transport Code PRETOR

(Report on the ITER Task D320.1)

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December 1997

ABSTRACT

The ICRF package PION has been interfaced with the transport code PRETOR. The Combined code is intended mainly for studies of ICRF heating of Deuterium Tritium (DT) plasmas in ITER. A brief presentation of the PION code and the interface with PRETOR is given.

1. INTRODUCTION

In order to simulate the behaviour of plasmas heated by Ion Cyclotron Resonance Frequency Waves (ICRF), one must incorporate codes calculating the ICRF power deposition and the distribution function of the resonating ions in a transport code. In principle one can calculate the power deposition with full wave codes [1, 2, 3] or ray tracing codes [4 , 5] and the distribution function with Fokker-Planck codes solving the bounce averaged distribution function. However, such codes require large amounts of CPU time. Furthermore, because of problems with convergence, a physical solutions cannot always be guaranteed. They are therefore not suitable for use in a transport codes. Thus, with today's computer technology one need simpler, but still sufficiently accurate, models of the ICRF related physics. The PION code [6, 7], which calculates the power deposition and the velocity distribution of the resonating ions, is based on simplified models and is relatively fast. Consequently, it is practical to interface it to a transport code. The PION code is used on JET for comparison with experimental results and for evaluation of different heating schemes. For normal plasmas, good agreement between calculated and experimentally measured quantities, such as the fast ion energy content and the fusion yield, has been found [6].

An important feature of the PION code is that the modification of the distribution function caused by the wave particle interaction is taken into account in the power deposition model. This is particularly important for schemes using higher harmonic heating ($\omega = n\omega_{ci}$, $n \geq 2$), like second harmonic tritium heating. For these schemes, the absorption mechanism is a finite Larmor radius effect. As a result, the absorption is very sensitive to high energy tail formation on the distribution function of the resonating ions. To obtain a converged solution to the distribution function it is not sufficient to expand to second order in Larmor radius. For consistency, higher order terms must then also be taken into account in the power deposition calculation.

The PION code has been interfaced with version 2.3E of the transport code PRETOR [8]. This report describes the technical details of the implementation and gives a brief description of the PION code. The combined code is intended mainly for studies of ICRF heating of Deuterium Tritium (DT) plasmas in ITER.

2. BRIEF DESCRIPTION OF THE PION CODE

A fairly detailed description of the PION code can be found in Refs. [6, 7]. Here we will only give a short summary of its main features.

2.1 Power deposition

The power deposition model used in PION is described in Refs.[9, 10], it was obtained by analysing results from the full wave code LION [1]. This analysis revealed that one can think of the wave field as being a superposition of two components, one in the limit of strong absorption and one in the limit weak absorption. For a given Fourier mode with toroidal mode number N, the flux surface averaged Poynting flux could then be written approximately as:

$$P(s) = \int_0^s p_{ICRF}(s')d^3x = \alpha P_1(s) + (1-\alpha)P_2(s), \tag{1}$$

where the function $P_1(s)$ represents the strong absorption component, $P_2(s)$ represents the weak absorption, α is a separation constant and s is a flux surface label,

$$s = \sqrt{\frac{\psi - \psi_0}{\psi_a - \psi_0}}, \tag{2}$$

ψ is the poloidal flux, 0 and a indicate the magnetic axis and the plasma boundary. From $P(s)$ we can obtain the local flux surface averaged power density,

$$p_{ICRF}(s) = \frac{dP(s)}{ds} / \frac{dV}{ds} \tag{3}$$

where V is the volume enclosed by the flux surface.

Furthermore, the separation constant, α, has been found to depend on the single pass absorption coefficient across the mid-plane, a_s, through

$$\alpha = a_s^2(2 - a_s), \tag{4}$$

where

$$a_s = \frac{\omega}{2\pi P_x}\int \mathrm{Im}\left(\vec{E}^* \overleftrightarrow{\varepsilon} \vec{E}\right)dx, \tag{5}$$

$\overleftrightarrow{\varepsilon}$ is the dielectric tensor, P_x is the incoming Poynting flux ($\vec{E}$ is the corresponding electric field), the z axis is along the equilibrium magnetic field and the x axis is in the plane spanned by $\vec{B}_0$ and $\vec{k}$.

The functions $P_1(s)$ and $P_2(s)$ consists of contributions from the different absorbing plasma species, i.e. resonant ion species and electrons,

$$P_1(s) = \sum_j P_{1j}(s), \tag{6}$$

$$P_2(s) = \sum_j P_{2j}(s). \tag{7}$$

For a resonating ion species, the functions $P_1(s)$ and $P_2(s)$ depend on the following quantities:

$$P_{1j} = P_{1j}\left(s, N, \left\langle v_{\|j}^2 \right\rangle\right), \tag{8}$$

$$P_{2j} = P_{2j}\left(s, a(s), F(s)\right), \tag{9}$$

where, $\left\langle v_{\|j}^2 \right\rangle$ is the averaged square velocity of species *j*, *N* is the toroidal mode number, *a*(*s*) is the absorption strength of species *j* along the cyclotron resonance, *F*(*s*) is a function representing the averaged electric wave field strength along the cyclotron resonance in the limit of weak absorption. Thus, P_{1j} depends mainly on the Doppler broadening of the cyclotron resonance whereas P_{2j} depends on the wave field distribution and absorption strength along the cyclotron resonance. The expressions for the direct electron damping, which is due to electron Landau damping (ELD) and Transit Time Magnetic Pumping (TTMP), are more complicated and can be found in Ref. [10].

To calculate the absorption coefficients needed in the model, the WKB approximation is used, i.e.

$$a^j = \int_{-\infty}^{\infty} \left\{ \frac{k_0^2}{|k_\perp|} \mathrm{Im}\left(\varepsilon_{xx}^j\right) \left| \frac{\varepsilon_{xy}}{\varepsilon_{xx} - n_\|^2} \right|^2 + \mathrm{Im}\left(\varepsilon_{yy}^j\right) + \mathrm{Re}\left(\varepsilon_{xy}^j\right) \mathrm{Im}\left[\frac{\varepsilon_{xy}}{\varepsilon_{xx} - n_\|^2} \right] \right\}$$

$$\times \exp\left\{ \int_{-\infty}^{x} 2\,\mathrm{Im}\left[k_\perp(x')\right] dx' \right\} dx \tag{10}$$

where a^j is the contribution from species *j* to the absorption coefficient, $\underline{\varepsilon}^j$ is the contribution from species *j* to the dielectric tensor.

2.2 Fokker-Planck calculations

The evolution of the velocity distribution function can be described by a Fokker-Planck equation [11],

$$\frac{\partial f}{\partial t} = C(f) + Q(f) \tag{11}$$

where $C(f)$ is a collision operator and $Q(f)$ is a quasi-linear diffusion operator describing wave particle interaction. However, in order to reduce the computing time we do not solve the full 2D distribution function. Instead we solve an approximate equation for the pitch angle averaged distribution function, $F(\mathrm{v})$,

$$\frac{\partial F}{\partial t} = \frac{1}{\mathrm{v}^2}\frac{\partial}{\partial \mathrm{v}}\left[-\alpha \mathrm{v}^2 F + \frac{1}{2}\frac{\partial}{\partial \mathrm{v}}\left(\beta \mathrm{v}^2 F\right)\right] + \frac{1}{\mathrm{v}^2}\frac{\partial}{\partial \mathrm{v}}\left[\mathrm{v}^2 D_{RF}\frac{\partial F}{\partial \mathrm{v}}\right] \tag{12}$$

where

$$D_{RF} = \sum_N K \int_{-1}^{1} \left| J_{n-1}\left(\frac{k_\perp \mathrm{v}}{\omega_{ci}}\sqrt{1-\mu^2}\right) + \frac{E_-}{E_+} J_{n+1}\left(\frac{k_\perp \mathrm{v}}{\omega_{ci}}\sqrt{1-\mu^2}\right)\right|^2 d\mu, \tag{13}$$

n is the harmonic of the cyclotron frequency at which the interaction takes place ($n = 1$ for fundamental heating etc.), K is a constant proportional to $\left|E_+^2\right|$ (the component of the wave electric field rotating in the same directions as the ions), and the collision coefficients α and β can be found in Ref. [9].

In addition to the pitch angle averaged distribution function we also need information about the parallel and perpendicular energy content of the distribution function. In particular, we need $\left\langle \mathrm{v}_{||}^2 \right\rangle$ for the power deposition calculation. We obtain the averaged square parallel velocity with an *ad hoc* formula [10],

$$\left\langle \mathrm{v}_{||}^2 \right\rangle = \frac{\int \mu_{eff}^2 \mathrm{v}^2 F(\mathrm{v}) d\mathrm{v}}{\int \mathrm{v}^2 F(\mathrm{v}) d\mathrm{v}}, \tag{14}$$

where the effective pitch angle is approximated by

$$\mu_{eff}^2 = \frac{1}{3}\frac{1+\left(\frac{\mathrm{v}}{\mathrm{v}_*}\right)^2}{1+\left(\frac{\mathrm{v}}{\mathrm{v}_*}\right)^2+\left(\frac{\mathrm{v}}{\mathrm{v}_*}\right)^4} \tag{15}$$

$v_* = 0.5v_\gamma$, v_γ is a characteristic velocity associated with pitch angle scattering and is defined in Ref.[13]. The ration between v_* and v_γ has been obtained by fitting the expression in Eq. (15) to calculations of μ^2_{eff} made with the 2D Fokker-Planck code BAFIC [14].

The model for the distribution function presented above is sufficient to calculate most of the quantities which are needed as input to the a transport code, such as the collisional power density transfer from resonating ion species to the background ions and electrons, energy density (parallel and perpendicular) of the resonating ion species and fusion reactivity.

In addition to the quantities used as input for the transport code, the Fokker-Planck calculation must also provide parameters which are needed to evaluate the dielectric tensor components used in the power deposition calculation (including finite Larmor radius terms to all orders in the anti-Hermitian part). In order to make the absorption strength in the power deposition calculation consistent with the Fokker-Planck calculation we use a simplified model for the dielectric tensor. This model require three parameters, in addition to $\left\langle v^2_{\|j} \right\rangle$. These parameters are described below.

For each toroidal mode number N the ICRF diffusion tensor, D_{RF}, can be split up in to three components:

$$D^{+}_{RF,N} = K_N \left| J_{n-1}\left(\frac{k_\perp v_\perp}{\omega_{ci}} \right) \right|^2 \tag{16a}$$

$$D^{-}_{RF,N} = K_N \left| \frac{E_-}{E_+} J_{n+1}\left(\frac{k_\perp v_\perp}{\omega_{ci}} \right) \right|^2 \tag{16b}$$

$$D^{c}_{RF,N} = 2K_N \,\mathrm{Re}\left[\frac{E_-}{E_+} J_{n-1}\left(\frac{k_\perp v_\perp}{\omega_{ci}} \right) J_{n+1}\left(\frac{k_\perp v_\perp}{\omega_{ci}} \right) \right] \tag{16c}$$

The power density absorbed due to these components by species j from a wave mode with toroidal mode number N can be written as

$$p^j_{\sigma,N} = 2\pi m \int_0^\infty \frac{1}{v^2} \frac{\partial}{\partial v} \left(v^3 D^\sigma_{RF,N} \right) F_j v^2 dv\,, \quad \sigma = +, -, \text{ and c.} \tag{17}$$

We can now define the following factors, which are used in the power deposition calculations,

$$\gamma^j_{+,N} = \frac{p^j_{+,N}}{p^{j,Maxw.}_{+,N}},\ \gamma^j_{-,N} = \frac{p^j_{-,N}}{p^{j,Maxw.}_{-,N}} \text{ and } \gamma^j_{c,N} = \frac{p^j_{c,N}}{p^{j,Maxw.}_{c,N}}, \tag{18}$$

where the superscript *Maxw.* indicate the power absorbed by a Maxwellian distribution function with the same density as the actual distribution function and with a temperature $n_j kT = \frac{1}{2} m \langle v_{||,j}^2 \rangle$. Thus, the factors in Eq.(18) represents the ratio between the actual absorbed power density and the power density that would be absorbed by a Maxwellian distribution function.

2.3 Dielectric tensor

Let us now turn to how the three factors in Eq.(18) are used to calculate the dielectric tensor elements. Neglecting the parallel electric wave field, the local absorbed power can be written as

$$p_{RF}^j = \frac{\omega}{2\pi} \mathrm{Im}\left(\vec{E}^* \vec{\vec{\varepsilon}} \vec{E}\right) = \frac{\omega}{2\pi} \left\{ E_+^2 \left[\mathrm{Im}\left(\varepsilon_{xx}^j + \varepsilon_{yy}^j\right) - 2\,\mathrm{Re}\,\varepsilon_{xy}^j \right] + \right.$$

$$\left| E_-^2 \right| \left[\mathrm{Im}\left(\varepsilon_{xx}^j + \varepsilon_{yy}^j\right) + 2\,\mathrm{Re}\,\varepsilon_{xy}^j \right] +$$

$$\left. 2\,\mathrm{Re}\left(E_+ E_-^*\right) \mathrm{Im}\left(\varepsilon_{xx}^j - \varepsilon_{yy}^j\right) \right\}, \qquad (19)$$

where $\vec{\vec{\varepsilon}}^j$ is the contribution from species *j* to the dielectric tensor. Thus, in order for the absorption strength in the power deposition calculation to be consistent with that of the Fokker-Planck calculation the following relations must hold,

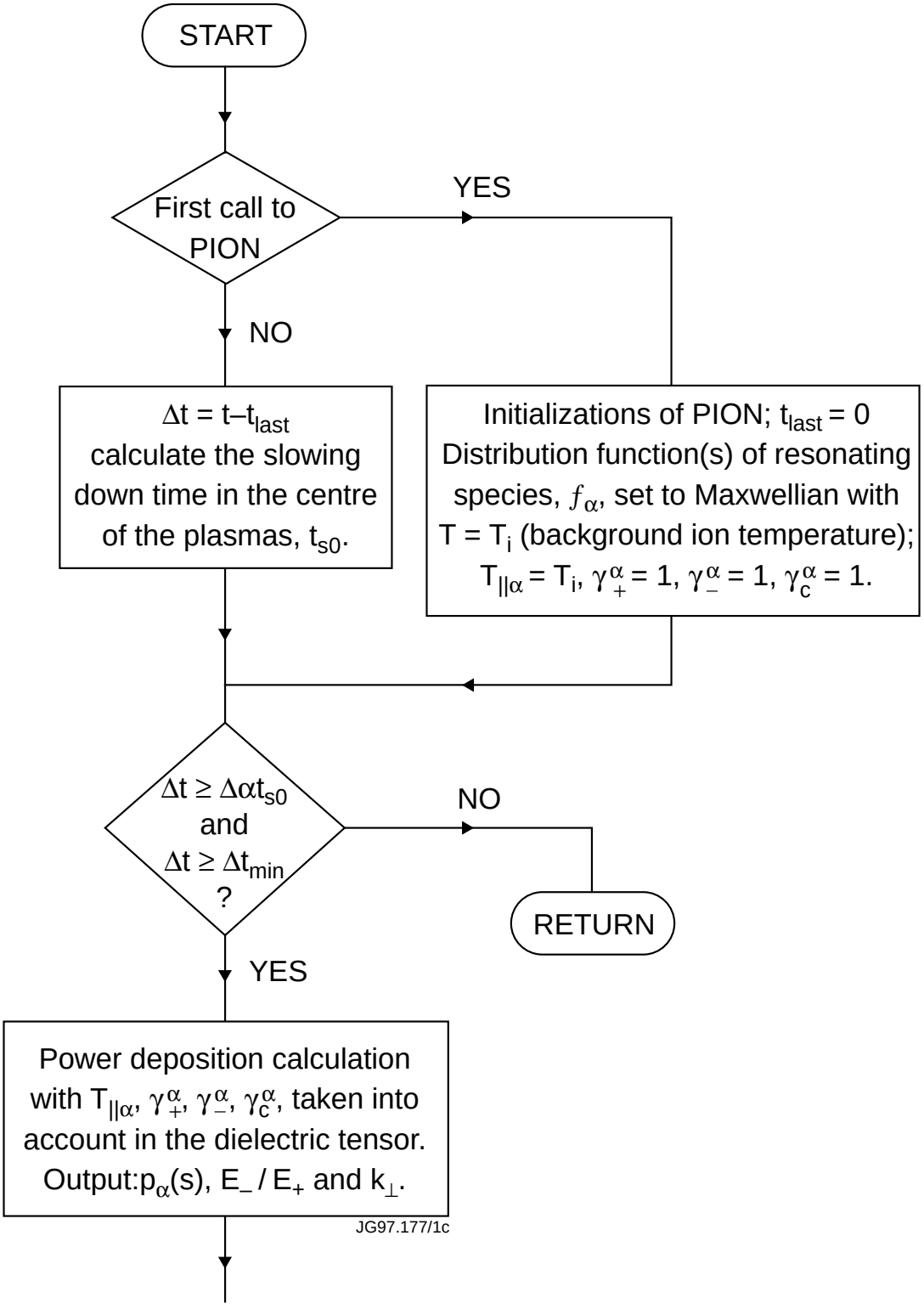
$$\mathrm{Im}(\varepsilon_{xx}^j + \varepsilon_{yy}^j) - 2\,\mathrm{Re}(\varepsilon_{xy}^j) = \gamma_{+,N}^j \left[\mathrm{Im}(\varepsilon_{xx}^{j,\,Maxw.} + \varepsilon_{yy}^{j,\,Maxw.}) - 2\,\mathrm{Re}(\varepsilon_{xy}^{j,\,Maxw.}) \right] \qquad (20a)$$

$$\mathrm{Im}(\varepsilon_{xx}^j + \varepsilon_{yy}^j) + 2\,\mathrm{Re}(\varepsilon_{xy}^j) = \gamma_{-,N}^j \left[\mathrm{Im}(\varepsilon_{xx}^{j,\,Maxw.} + \varepsilon_{yy}^{j,\,Maxw.}) + 2\,\mathrm{Re}(\varepsilon_{xy}^{j,\,Maxw.}) \right] \qquad (20b)$$

$$\mathrm{Im}(\varepsilon_{xx}^j - \varepsilon_{yy}^j) = \gamma_{c,N}^j \left[\mathrm{Im}(\varepsilon_{xx}^{j,\,Maxw.} - \varepsilon_{yy}^{j,\,Maxw.}) \right] \qquad (20c)$$

From the above equations one can find the anti-Hermitian parts of the dielectric tensor, $\mathrm{Im}(\varepsilon_{xx}^j)$;$\mathrm{Im}(\varepsilon_{yy}^j)$ and $\mathrm{Re}(\varepsilon_{xy}^j)$, in terms of the gamma factors and the known expressions for the Mawellian contributions to the dielectric tensor. These expressions for the anti-Hermitian part are somewhat lengthy and we omit them here, for the details see Ref. [7]. With the method described above we can easily calculate the exact corrections to the anti-Hermitian part of the dielectric tensor. Corrections to the Hermitian parts are more difficult to calculate and we use a simple approximation in PION [7].

2.4 Flow chart



All the subroutines and common block variables which are part of the PION code are listed in Appendix.

3. INTERFACE BETWEEN THE PRETOR CODE AND THE PION CODE

The PRETOR code is written in C whereas the PION code is written in FORTRAN. It is, however, relatively easy to communicate data between C and FORTRAN. The interface between PRETOR and PION consists of a number of FORTRAN subroutines, two of which are called from PRETOR. These subroutines are described below.

1. Initialisation routine called by PRETOR.

```
subroutine init_pion( s_max        , s_a          , s_R          ,
&                     s_PadHF      , s_frac       , s_frequency  ,
&                     s_minority_Z , s_minority_M , s_main_Z     ,
&                     s_main_M     , s_imp_Z      , s_imp_M      ,
&                     s_nb_antenna , s_nb_strap   , s_phase      ,
&                     s_init)
```

This subroutine stores data, which normally do not change during the simulation, in a common block. Consequently, this subroutine is called at the beginning of the simulation and then only if ICRF related quantities, like the wave frequency, change during the simulation. The parameters are as follows,

s_max : Number of grid points on which input quantities from PRETOR, like temperature and densities, are given.

s_a : Minor radius of the plasma in the outer mid-plane [m].

s_R : Major radius [m].

s_PadHF : ICRF power [MW].

s_frac : n_{res} / n_{fuel}, where n_{res} is the density of the resonating species and n_{fuel} is the density of fuel ions (i.e. normally the hydrogenic species).

s_frequency: : Wave frequency [MHz].

s_minority_Z : Atomic charge of the resonating species.

s_minority_M : Atomic mass of the resonating species.

s_main_Z : Atomic charge of the main ion species.

s_main_M : Atomic charge of the main ion species.

s_imp_Z : Atomic charge of the impurity species.

s_imp_M : Atomic mass of the impurity species.

s_nb_antanna : Number of ICRF antennas.

s_nb_straps : Number of straps in an antenna.

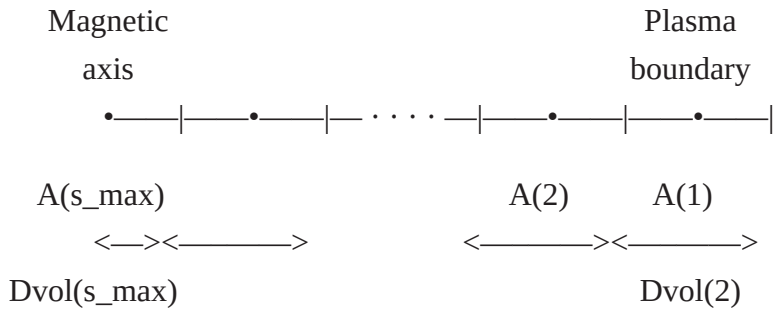
s_phase(i, j) : Double precision matrix; Phase of the current of strap *j* in antenna *i*.

2. Main interface between PRETOR and PION.

```
subroutine pion_rf_power_(GPRFD_min      , GPRFD_main      ,
&                         GPRFD_imp      , GPRFD_e         ,
&                         GPRF_fast_ion  , GPRF_fast_e     ,
&                         GPRF_e         , GWRF_fast       ,
&                         GWRF_parallel  , GPRF_fusion     ,
&                         Te             , ne              ,
&                         Ti             , ni              ,
&                         np             , dVol            ,
&                         F_func         , Rin             ,
&                         Rout           , psi_pol         ,
&                         PRFD_MIN       , PRFD_MAIN       ,
&                         PRFD_IMP       , PRFD_E          ,
&                         PRF_FAST_ION   , PRF_FAST_E      ,
&                         PRF_E          , RF_NFAST        ,
&                         RF_WFAST       , RF_WPARALLEL    ,
&                         RF_FUSION      , DT              )
```

This subroutine is called by PRETOR at every time step and outputs the ICRF deposition profile calculated by PION. In particular, it gives the total electron and ion heating. In the case of the electrons, the total heating is the sum of the direct electron heating, i.e. TTMP/ELD , and the collisional power transfer from the resonating ions to the electrons. The total ion heating is just the collisional power transfer from the resonating ions. In addition to these, a number of other quantities are also calculated, e.g. the stored energy of the resonating ions and the non-thermal fusion reactivity.

All profile quantities are given on the PRETOR grid, which is such that for a quantity given by a vector A: A(1) is the value at the plasma boundary and A(s_max) is the value on the magnetic axis, i.e at the centre of the cells shown below. However, the volume elements , dVol, are the volumes between the cells, see below.



The parameters are given below.

Input variables.

Te	: Real vector; electron temperature profile [Kev].
ne	: Real vector; electron density profile [10^{19} m^{-3}].
Ti	: Real vector; ion temperature profile [KeV].
ni	: Real vector; ion density profile, excluding impurities, [10^{19} m^{-3}].
np	: Real vector; impurity density profile [10^{19} m^{-3}].
dVol	: Real vector; plasma volume enclosed by a cell, see above.
F_func	: Real vector; $F = 5RB_\varphi$ where R is the major radius and B_φ is the toroidal magnetic field [T].
Rin	: Real vector; major radius in the inner midplane [m].
Rout	: Real vector; major radius in the outer midplane [m].
psi_pol	: Real vector; poloidal flux, Psi_pol(0) = 1 and Psi_pol(s_max) = 0, [a.u].
DT	: Time step [s].

Output variables.

GPRFD_min	: ICRF power absorbed by the minority ions [W].
GPRFD_main	: ICRF power absorbed by the majority ions [W].
GPRFD_imp	: ICRF power absorbed by the impurity ions [W].
GPRFD_e	: ICRF power absorbed by the electrons (via TTMP/ELD) [W].
GPRF_fast_ion	: Collisional power transferred to the bulk ions [W].
GPRF_fast_e	: Collisional power transferred to the electrons [W].
GPRF_e	: Total power to the electrons (GPRFD_e + GPRF_fast_e) [W].

GWRF_fast : Energy stored in the fast ions [J].

GWRF_parallel : Parallel energy stored in the fast ions [J].

GPRF_fusion : Fusion reactivity [1/s].

PRFD_min : Real vector; ICRF power density absorbed by the minority ions [Wm^{-3}].

PRFD_main : Real vector; ICRF power density absorbed by the main ion species [Wm^{-3}].

PRFD_imp : Real vector; ICRF power density absorbed by the impurity ions [Wm^{-3}].

PRFD_e : Real vector; ICRF power density absorbed by the electrons (via TTMP/ELD) [Wm^{-3}].

PRF_fast_ion : Real vector; collisional power density transferred to the bulk ions [Wm^{-3}].

PRF_fast_e : Real vector; collisional power density transferred to the electrons [Wm^{-3}].

PRF_e : Real vector; total power to the electrons (PRFD_e + PRF_fast_e) [Wm^{-3}].

RF_Nfast : Real vector; fast ion density [m^{-3}].

RF_Wfast : Real vector; energy density stored in the fast ions [J m^{-3}].

RF_Wparallel : Real vector; parallel energy density stored in the fast ions [J m^{-3}].

RF_fusion : Real vector; fusion reactivity density [1/s].

The subroutine pion_rf-power calls the subroutine PICNTL which first calls a routine that determines if it is necessary to make a new PION calculation. If it is necessary then routines which maps the PRETOR data on to the grid used by PION are called and finally the main PION routine, PIONT, is called. The criterion for when it is necessary to make a new PION calculation is: $\Delta t \geq \alpha t_s$ and $\Delta t \geq \Delta t_{\text{min.}}$, where Δt is the time from the last PION calculation, t_s ion-electron slowing down time in the centre of the plasma, the parameter a can be set by the user and should normally be of the order 0.1 to 0.2, $\Delta t_{\text{min.}}$ is the minimum time between calculations and is also set by the user. It is necessary to use this procedure since the computation time would be far too long if PION where to be called at every PRETOR time step. The first condition ensures that calculations are only carried after a fraction of the time on which the distribution function characteristically evolves. In some cases it might be impracticable to call PION as often as this and a minimum time between PION calculations can therefore be specified, reasonable results are

often obtained with $\Delta t_{min.} \sim 0.1$ to 0.2 seconds. It should, however, be remembered that to closely follow the evolution of the distribution function $\Delta t_{min.}$ should not be a too large fraction of the ion-electron slowing down time.

4. HOW TO RUN THE PRETOR VERSION WHICH INCLUDES PION

The PRETOR/PION version can at present only be run for either ITER or JET. It is envisaged that an updated power deposition package will be installed in PION in the near future, which will make PION more flexible. However until this has been done PION power depositions should be used only for ITER or JET.

In addition to the normal data input to PRETOR, there is specific input related to PION. In the file name.rf, where "name" is a name that can be freely chosen, parameters giving to the number of antennas, the number of straps per antenna and the phasing of the straps is set. The structure of the file should be:

NA NS

PH(1, 1) PH(1, 2) PH(1, 3) PH(1, 4)

PH(2, 1) PH(2, 2) PH(2, 3) PH(2, 4)

•

•

•

PH(NA, NS)

LANT

NTORIN

A D WT

where NA (≤ 4)is the number of antennas, NS (≤ 4) is the number of current straps in an antenna, PH(1, 1) is the phase in degrees of the current in strap one of antenna one, PH(1, 2) is the phase in degrees of the current in strap two of antenna one etc.

For ITER simulations there is an option: by setting LANT to zero the power deposition is calculated for a single toroidal mode number, NTORIN, only; by setting LANT to one, an antenna spectrum calculation will be carried out and the power deposition for the whole spectrum is calculated. When LANT is set to one, the parameters A, D and WT are used in the antenna spectrum calculation, where A is the distance from an antenna conductor to the back wall, D is the distance between the centres of two neighbouring conductors in an antenna and WT is the width of the antenna conductors. A, D and WT should be given in metres. This option has been introduced since the design of the ITER antenna is not finalised yet.

Most ICRF related quantities, viz. the wave frequency; the atomic charge of the main resonating species; the atomic mass of the main resonating species and the density fraction of the main resonating ion species, can be changed by pressing the button “Parameters” on the PRETOR widget and then choosing “PION: RF parameters”. To change the RF power one must, however, chose “Additional powers” instead of “PION: RF parameters”.

Under the heading “PION: RF parameters” there is also a button called “use PION”. When this button is switched on PION is called at every PRETOR time step and, as discussed before, an algorithm in PION decides if a new power deposition calculation is needed. However, if the button is switched off one can still launch a PION run by pressing the PION button on the main PRETOR widget. This is useful if one want to make a fast simulations without calling PION too often (PION calculations slow down PRETOR considerably).

The parameters, a and $\Delta t_{\text{min.}}$,which determines the frequency by which PION is called (see section 3.) are set in the file pion.dat. Furthermore, a parameter, called LW below, should be set to either 0 or 1. If LW is set to 1 then information concerning details about the power deposition calculation is written to standard output. LW should therefore normally be set to zero. The structure of the file pion.dat should be:

$\alpha \quad \Delta t_{\text{min.}}$

LW

5. CONCLUSIONS

The ICRF package PION has been interfaced with the transport code PRETOR. The main aim with the combined code is to study ICRF heating of DT plasmas in ITER. The PION code is particularly suited for this task since, in addition to being relatively fast, it takes into account the influence of the distribution function of the resonating ion species on the power deposition. This is particularly important for second harmonic heating of tritium, which is one of the main ICRF heating scenarios for DT plasmas.

ACKNOWLEDGEMENT

This work was carried out under NET contract: NET/94-875.

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APPENDIX I

List of subroutines and COMMON variables in PION

The code consist of seven major program blocks, viz.,

(1) picntl.f: This block is called by the interface routine pion_rf_power. It maps the PRETOR data on the grid used by PION and determines if it necessary to do a new PION calculation. When a new PION calculation is necessary it calls the main PION block, i.e. pion.f

(2) pion.f: This block controls the calculation. The input data is processed; the antenna spectrum, power deposition and Fokker-Planck calculations are called and output data is written.
It also contains some routines used by the other blocks.

(2) spect.f: Calculates the antenna spectrum.

(3) dep.f: Calculates the ICRH power deposition profile for the resonating ion species and the electrons.

(3) acoef.f: Calculation of single pass ion cyclotron absorption coefficients at different radii along the cyclotron resonance, these are used in dep.f.

(5) fplt.f: Time dependent Fokker-Planck calculation of the velocity distribution(s) of the resonating ion species.

(6) piaux.f Auxiliary routines: matrix inversion, spline fitting and spline evaluation, elliptic integrals, plasma dispersion function.

INDEX OF SUBROUTINES

The subroutines in pion.f, spect.f, dep.f, acoef.f and fplt.f are listed below.

**********PIONT**********

********** SPECT **********

SPECT(2)	ANTENNA SPECTRUM	SP.2.01
JY(3)	FORIER TRANSFORMED SQUARED ANTENNA CURRENT	SP.2.02
KSI(3)	KSI=ALPHA+I*BETA	SP.2.03
XCUT(3)	FIND CUT-OFF POS. AND ELEC. DENS AT THE CUT-OFF	SP.2.04
KXPRIM(4)	X-DERIVATIVE OF PERP. WAVE NUMBER AT THE CUT-OFF	SP.2.05
AIRY(3)	AIRY FUNCTIONS	SP.2.06
APRIM(3)	DERIVATIVES OF AIRY FUNCTIONS	SP.2.07

********** DEP **********

DEP	ICRH-POWER DEPOSITION PROFILE	DP.2.01
P1CF(2)	CYCLORTRON ABSORPTION PROFILE FOR STRONG DAMPING	DP.2.02
P2CF(3)	CYCLORTRON ABSORPTION PROFILE FOR WEAK DAMPING	DP.2.03
P1EF(2)	ELECTRON ABSORPTION PROFILE FOR STRONG DAMPING	DP.2.04
P2EF(3)	ELECTRON ABSORPTION PROFILE FOR WEAK DAMPING	DP.2.05
WEIGHT(7)	WEIGHT COEFFICIENTS	DP.2.06
WIDTH(3)	WIDTH OF CYCLOTRON ABSORPTION FOR STRONG DAMPING	DP.2.07
S1C(1)	S1	DP.2.08
FFUNC(2)	CALIBRATION FUNCTION FOR CYCLOTRON DAMPING	DP.2.09
ALOC(6)	LOCAL ABSORPTION COEFFICIENTS	DP.2.10
HFUNC(2)	CALIBRATION FUNCTION H FOR ELECTRON ABSORPTION	DP.2.11
PENORM(4)	NORMALISED LOCAL ELECTRON ABSORPTION	DP.2.12
GFUNC(2)	CALIBRATION FUNCTION G FOR ELECTRON ABSORPTION	DP.2.13
ACE0(10)	SINGLE PASS ABSORPTION COEFF. AT THE MID PLANE	DP.2.14
AEOC(5)	ELEC. ABS. COEF. OUTSIDE THE CRL AT THE MIDPLANE	DP.2.15
AMODC0(6)	MODE CONVERSION ABS. COEFF. AT THE MID PLANE	DP.2.16
AWKB3(5)	ABS. COEFF. FOR SINGLE PASS OF CLR AT THE M. P.	DP.2.17
CRDIS 0(4)	DISTANCE BETWEEN CUT OFF AND RES. AT THE M. P.	DP.2.18
AELOC(4)	LOCAL ELECTRON ABSORPTION COEFFICIENT	DP.2.19
KPERPM(12)	PERPENDICULAR WAVE NUMBER AT THE MID PLANE	DP.2.20
DIELM(8)	LUKE WARM DIELECTRIC TENSOR AT THE MID PLANE	DP.2.21
ALPHAM(6)	2ND ORDER CORR. FACT. TO THE D. T. AT THE M. P.	DP.2.22
DIRESM(8)	RESONANT PART OF THE D. T. AT HARMONICS > 2.	DP.2.23
DIELCM(6)	HIGER ORDER CORRECTIONS TO THE DIEL. TENSOR.	DP.2.24

AHELDIC(4)	ANTI HERMITIAN DIELECTRIC TENSOR CONTRIB. FROM EL.	DP.2.25
TRAP(4)	TRAPETS INTEGRATION	DP.2.26

********** ACOEF **********

ACOEF(10)	SINGLE PASS ABS. COEFF. AT DIFFERENT RADII	AC.2.01
CRDIST(6)	DISTANCE BETWEEN CUT-OFF AND RESONANCE	AC.2.02
AMODC(5)	MODE CONVERSION ABSORPTION COEFFICIENT	AC.2.03
ACYCLO(10)	SINGLE PASS CYCLOTRON ABSORPTION COEFFICIENTS	AC.2.04
AWKB1(12)	WKB CALCULATION OF CYCLOT. ABS. COEFF. I	AC.2.05
AWKB2(12)	WKB CALCULATION OF CYCLOT. ABS. COEFF. II	AC.2.06
KPERP1(9)	PERPENDICULAR WAVE NUMBER I	AC.2.07
KPERP2(12)	PERPENDICULAR WAVE NUMBER II	AC.2.08
DIEL1(9)	LUKE WARM DIELECTRIC TENSOR I	AC.2.09
DIEL2(9)	LUKE WARM DIELECTRIC TENSOR II	AC.2.10
ALPHAR(7)	2ND ORDER CORRECTION FACTORS FOR DIEL. TENSOR	AC.2.11
DIRESM(6)	RESONANT PART OF D. T. AT HARMONICS > 2	AC.2.12
DIELC(6)	HIGHER ORDER CORRECTION TO THE DIEL TENSOR	AC.2.13
ZFUNC(3)	PLASMA DISPERSION FUNCTION	AC.2.14

********** FPLT **********

FPLTO(11)	CONTROL THE FOKKER-PLANK EQUATION	FP.0.01
CONST(4)	CONSTANTS AND INITIALISATIONS	FP.1.01
BIINIT	INITIALIZE THE INTEGRALS OF BESSEL FUNCTIONS	FP.1.02
RFCONS	INITIAL NOMALIZTION CONSTANT IN THE RF-OP.	FP.1.03
INITF(7)	INITIAL VELOCITY DISTRIBUTION	FP.2.01
ADVAN(8)	EVOLUTION OF VEL. DIS. DURING A TIME STEP	FP.2.02
INMOM(4)	MOMENTS OF THE INITIAL VELOCITY DISTRIBUTION	FP.2.03
SOLVE(6)	SOLVE THE DISCRETIZED F.-P. EQUATION	FP.2.04
VELMOM(3)	VELOCITY SPACE MOMENTS	FP.2.05
POWTRF(4)	COLLISIONAL POWER TRANSFER	FP.2.06
COEFF(1)	FOKKER-PLANCK COEFFICIENTS	FP.2.07
CCOEF(1)	COLLISION COEFFICIENTS	FP.2.08
CTERM(8)	LOCAL TERMS IN THE COLLISION OPERATOR	FP.2.09
RFCOEF(1)	RF-OPERATOR COEFFICIENTS	FP.2.10
PSTAT(3)	STATIONARY BULK VELOCITY DISTRIBUTION	FP.2.11
PDABSC(4)	ABSORBED RF-POWER	FP.2.12

ENHFAC(3)	ENHANCEMENT FACTORS GAMMA	FP.2.13
TPAR(3)	AVERAGED SQUARE PARALLEL VELOCITY	FP.2.14
DENSC(2)	NORMALIZE PV TO THE RIGHT DENSITY	FP.2.15
DERIV(3)	NORMALIZED DERIVATIVES OF VEL. SPACE MOMENTS	FP.2.16
TBULK(1)	NORMALIZED BULK TEMPERATURE	FP.2.17
ADJV(5)	EXTEND OR SHORTEN THE VELOVITY RANGE	FP.2.18
CONV1(5)	CONVERT LOG(F) TO P=F*V**2/F(0)	FP.2.19
CONV2(5)	CONVERT P=F*V**2/F(0) TO LOG(F)	FP.2.20
RFDIFV(1)	CREATE A VECTOR CONTAINING THE RF-DIFF. CONST.	FP.2.21
RFDIFF(2)	RF-DIFFUSION CONSTANT	FP.2.22
RFDN(4)	CONTRIBUTIONS TO THE RF-DIFFUSION CONSTANT	FP.2.23
BESI1(3)	INTEGRALS OVER BESSEL FUNCTIONS I	FP.2.24
BESI2(3)	INTEGRALS OVER BESSEL FUNCTIONS II	FP.2.25
GSTIX(1)	FUNCTION G(X)	FP.2.26
HUSIG(9)	FUSION CROSS SECTION	FP.2.27

**********PIAUX**********

ELLIPF(3)	Elliptic integrals of first and second kind.
ERRMSG(5)	Prints error messages from PION.
ERROR(2)	Error function in the complex plane.
RQBEQS(3)	Solves a cubic equation with real coefficients.
BESSEL(7)	Bessel functions.
DGTTRF(7)	LU factorization of a real tridiagonal matrix.
XERBLA(3)	Error handler for LAPACK routines.
DGTTRS(11)	Solution of systems of algebraic equations, using LU factorization computed by DGTTRF.
BINTK(8)	Produces B-spline coefficients for interpolation.
BNFAC(6)	Help routine for BINTK (LU factorization).
BNSLV(6)	Help routine for BINTK (solves an equation system).
BSPVN(9)	Help routine for BINTK (calculates value of nonzero basis functions).
FDUMP	Dummy routine.
I1MACH	Returns integer machine dependent constants.
J4SAVE(3)	Global parameters needed by error handling routines.
XERABT(2)	Aborts program execution and prints error message.
XERCTL	Dummy routine.
XERPRT(2)	Prints error messages.
XERROR(4)	Processes an error.
XERRWV(10)	Processes error messages.

XERSAV(5)	Records an error has occured.
XGTUA(2)	Returns unit nunmber(s) to which error messages are being sent.
BVALU(8)	Evaluates the B-representation of a B-spline at given point for the function value or its derivaties.
INTERV(15)	Help routine for BVALU.
QAGE(17)	Help routine for BVALU (Approximation of a given definite integral).
QK15(7)	Help routine for BINTK (Evaluate definite integral of a function f and of abs(f)).
QK31(7)	Help routine for BINTK (Evaluate definite integral of a function f and of abs(f)).
QK41(7)	Help routine for BINTK (Evaluate definite integral of a function f and of abs(f)).
QK51(7)	Help routine for BINTK (Evaluate definite integral of a function f and of abs(f)).
QK61(7)	Help routine for BINTK (Evaluate definite integral of a function f and of abs(f)).
QSPRT(7)	Ordering routine.
R1MACH(1)	Returns single precission machine dependent signals.
RF(4)	Complete elliptic integral of the 1st kind.
XERCNT(6)	Dummy routine.
XERHLT(1)	Abort program execution and print error message.
XERMSG(5)	Processing of diagnostic message.
XERPRN(4)	Print an error message.
XERSVE(7)	Record that an error has occured.
RD(4)	Complete elliptic integrals of the second kind.

INDEX OF COMMON VARIABLES

1.1 GENERAL PHYSICS VARIABLES

COMMON/COMDAT/

ACHARG(10)	ATOMIC CHARGES OF ION SPECIES.	RA 1.1
AMASS(10)	ATOMIC MASSES OF ION SPECIES.	RA 1.1
B0	MAGETIC FIELD AT MAGNETIC AXIS (T).	R 1.1
DENSE0	ELECTRON DENSITY AT THE MAGN. AXIS (M-3)	R 1.1
DENSI0(10)	DENSITIES OF ION SPECIES AT MAGN. AXIS (M-3)	RA 1.1
FREQM	WAVE FREQUENCY (HZ)	R 1.1
OMCE0	ELECTRON CYCLOTRON FREQUENCY AT MAGN. AXIS (S-1)	R 1.1
OMCI0(10)	ION CYCLOTRON FREQUENCY AT MAGN. AXIS (S-1)	RA 1.1
OMEGA	WAVE ANGULAR FREQUENCY (S-1)	R 1.1
OMPE0	ELECTRON PLASMA FREQUENCY AT MAGN AXIS (S-1)	R 1.1
OMPE02	OMPE0**2	R 1.1
OMPI0(10)	ION PLASMA FREQUENCIES AT MAGN. AXIX (S-1)	RA 1.1
OMPI02(10)	OMPI0**2	RA 1.1
RMAJOR	MAJOR RADIUS (M)	R 1.1
SOHM	FLUX SURFACE LABEL AT RESONANCE	R 1.1
TE0	ELECTRON TEMPERATURE AT MAGN. AXIS (KEV)	R 1.1
TI0(10)	ION TEMPERATURES AT MAGN. AXIS (KEV)	RA 1.1
VTE0	ELECTRON THERMAL VELOCITY AT MAGN. AXIS (M/S)	R 1.1
VTI0(10)	ION THERMAL VELOCITIES AT MAGN. AXIS (M/S)	RA 1.1
XMAX	OUTER MINOR RADIUS (M)	R 1.1
XMIN	INNER MINOR RADIUS (M)	R 1.1
XR	MINOR RADIUS AT RESONANCE (M)	R 1.1
IS(10)	POINTER TO RESONANT ION SPECIES	IA 1.1
MAINRI	POINTER TO MAIN RESONATING ION SPECIES	I 1.1
NRES	NUMBER OF RESONATING ION SPECIES	I 1.1
NHARM1	OMEGA=NHARM1*OMCI(MAINRI)	I 1.1
NHARMI(MDR)	OMEGA=NHARM(I)*OMCI(I) FOR RESONATING SPECIES I	IA 1.1
NHRES(4)	NHRES(I), IS THE NO. OF ION SPEC. RES. AT HARM.	IA 1.1
NRSPEC	NUMBER OF ION SPECIES	I 1.1

1.2 ANTENNA DATA.

COMMON/COMANT/

APHI(MDA, NDST)	PHASE OF STRAPS FOR DIFFERENT ANTENNAS	RA 1.2
APOW(MDA)	ANTENNA POWER (A.U)	RA 1.2
A	ANTENNA WALL DISTANCE (M)	R 1.2
B	ANTENNA PLASMA BOUNDARY DISTANCE (M)	R 1.2
C	DISTANCE BETWEEN STRAP PAIRS (M)	R 1.2
D	DISTANCE BETWEEN A PAIR OF STRAPS	R 1.2
GAMMA	DENSITY GRADIENT AT THE PLASMA EDGE (DN/DX)/N	R 1.2
WT	WIDTH OF THE ANTENNA CUNDUCTORS (M)	R 1.2
NANT	NUMBER OF ANTENNAS	I 1.2

1.3 INPUT DATA SPECIFIC TO THE FOKKER-PLANCK CALCULATION

COMMON/COMFPD/

PRF	RF-POWER	R 1.3
TAUEV(10)	ENERGY CONFINEMENT TIME OF ION SPECIES	RA 1.3
IBV(10)	POINTER TO SECOND REACTING FUSION SPACIES	RA 1.3
NFUSV(10)	DETERMINES FUSION REACTION	RA 1.3

1.4 MESH

COMMON/COMMES/

S(MDS)	FLUX SURFACE LABEL AT CALCULATION POINTS	R 1.4
NMAX	NUMBER OF TOROIDAL MODE NUMBERS TO BE CALC.	I 1.4
NSURF	NUMBER OF FLUX SURFACES	I 1.4
NST	CACULATION FOR +-NTOR=0,NST,...,NMAX*NST	I 1.4

1.5 PROFILES

COMMON/COMPRO/

BINP(NSM1)	MAGNETIC FIELD AT THE LOW FIELD SIDE (T)	RA 1.5
BOUTP(NSM1)	MAGNETIC FIELD AT THE HIGH FIELD SIDE (T)	RA 1.5
BP(102)	MAGNETIC FIELD AT EQUDISTANT R POINTS (T)	RA 1.5
DENP(NSM1)	NORMALISED DENSITY PROFILE	RA 1.5
DXB	DISTANCE BETWEEN POINTS IN BP (M)	R 1.5

DXS	DISTANCE BETWEEN POINTS IN SXP (M)	R 1.5
RPP(NSM1)	MAJOR RADIUS AT THE LOW FIELD SIDE (M)	RA 1.5
RQP(NSM1)	MAJOR RADIUS AT THE HIGH FIELD SIDE (M)	RA 1.5
SP(NSM1)	FLUX SURFACE LABEL	RA 1.5
TEXP(NSM1)	NORMALIZED ELEC. TEMP. PROFILE	RA 1.5
TIXP(NSM1)	NORMALIZED ION TEMP. PROFILE	RA 1.5
VPRIMP(NSM1)	D(VOLUME)/DS	RA 1.5
XBP(102)	R-POINTS FOR BP	RA 1.5
XSP(102)	R-POINTS FOR CONVERTING R TO S	RA 1.5
QSP(102)	SAFTY FACTOR PROFILE	RA 1.5
NPS	NUMBER OF POINTS WHERE INPUT PROFILES ARE GIVEN	I 1.5

1.6 PLASMA DISPERSION FUNCTION.

COMMON/COMZFC/

CZRE(161)	REAL PART OF PLAMA DISP. FUNC. Z	RA 1.6
CZIM(161)	IMAGINARY PAR OF PLAMA DISP. FUNC. Z	RA 1.6
DELTA	Z IS GIVEN AT -NZMAX*DELTA,...,NZMAX*DELTA	RA 1.6
NZMAX		I 1.6

2.1 VELOCITY DISTRIBUTION.

COMMON/COMDIS/

FLOGA(MDR,MDS,MDV)	LOG(F)	RA 2.1
VA(MDR,MDS,MDV)	VELOCTIES (M/S)	RA 2.1
NVM(MDR,MDS)	NUMBER OF VELOCITY POINTS	IA 2.1

2.2 NON MAXWELLIAN CORRECTION FACTORS

COMMON/COMNMC/

GAMCIA(102,MDR,MDNT)	CORRECTION FACTOR GAMMAC	RA 2.2
GAMLIA(102,MDR,MDNT)	CORRECTION FACTOR GAMMA+	RA 2.2

GAMRIA(102,MDR,MDNT)		
	CORRECTION FACTOR GAMMA-	RA 2.2
SD(102)	FLUX SURFACE LABEL	RA 2.2
TZNA(102,MDR)		
	PARALLEL ENERGY (KEV)	RA 2.2

2.3 VARIABLES USED INTERNALLY IN FPLT.

COMMON/COMFPL/

ACHB	ATOMIC CHARGE OF SECOND SPECIES IN FUS. RACTION	D 2.3
ACHR	ATOMIC CHARGE OF RESONATING SPECIES	D 2.3
AMASSB	ATOMIC MASS OF SECOND SPECIES IN FUS. RACTION	D 2.3
ACHR	ATOMIC MASS OF RESONATING SPECIES	D 2.3
CLOG	COULOMB LOGARITHM	D 2.3
CLRAT(10)	RATIO BETWEEN ION-ION AND ION-EL. COL. LOG.	D 2.3
CM(10)	MASS RATIO BETWEEN ION SPEC. AND RES. ION SPEC.	DA 2.3
CME	MASS RATIO BETWEEN ELEC. AND RES. ION SPEC.	D 2.3
CN(10)	DENS. RATIO BETWEEN ION SPEC. AND RES. ION SPEC.	DA 2.3
CNE	DENS. RATIO BETWEEN ELEC. AND RES. ION SPEC.	D 2.3
CRF	CONSTANT IN RF-OPERATOR	D 2.3
CT(10)	TEMP. RATIO BETWEEN ION SPEC. AND RES. ION SPEC.	DA 2.3
CTE	TEMP. RATIO BETWEEN ELEC. AND RES. ION SPEC.	D 2.3
CUTP	BELOW CUTP THE DISTRIBUTION NEED NOT BE CALC.	D 2.3
C1	CONSTANT IN COLLISION OPERATOR	D 2.3
DENSIB	DENSITY OF SECOND SPECIES IN FUS. REAC. (CM-3)	D 2.3
DENSIR	DENSITY OF THE RESONATING ION SPECIES (CM-3)	D 2.3
DPERR	ALLOWABLE ERROR ON THE ABSORBED POWER	D. 2.3
DPNORM	NORMALISATION CONSTANT FOR ADJUSMENT OF RF-POW.	D 2.3
DPRF	ABSORBED RF-POWER (W/CM-3)	D 2.3
FC(202,2)	PART OF RF-OP. RELATED TO THE CROSS TERM	DA 2.3
FL(202,2)	PART OF RF-OP. RELATED TO E+	DA 2.3
FR(202,2)	PART OF RF-OP. RELATED TO E-	DA 2.3
OMCIR	CYCLOTRON ANGULAR FREQUENCY OF RESONATING SPEC.	D 2.3
TIB	TEMP. OF SECOND SPEC. ION FUSION REAC. (KEV)	D 2.3
TIR	TEMP. OF THE RESONATING ION SPECIES (KEV)	D 2.3
TS	ION-ELECTRON SLOWING DOWN TIME (S)	D 2.3
TSI	ION-ION SLOWING DOWN TIME (S)	D 2.3
VT	THERMAL VELOCITY OF RES. ION SPEC. (CM/S)	D 2.3

WEIGHT(3,MDNT)		
	WEIGHT FACTOR DETERMINING E+,E- AND CROSS TERM	DA 2.3
XN(MDNT)	K(PERP)/OMCI FOR RES. SPEC.	DA 2.3
XSTAR	V(GAMMA)/VT	D 2.3
Y0	F(V=0) FOR MAXWELL DISTRIBUTION	D 2.3
EPS1	LOCATION OF TURNING POINT OF THE FAST IONS	D 2.3
CPSI	PITCH ANGLE VARIABLE FOR THE FAST IONS	D 2.3
QS	SAFTY FACTOR	
	D 2.3	
S1	LOCATION OF THE TURNING POINT OF THE FAST IONS	D 2.3
NIB	SECOND SPECIES IN FUSION REACTION I	2.3
NIR	RESONATING ION SPECIES	I 2.3
NFUS	FUSION REACTION	I 2.3
NHARM	HARMONIC AT WHICH INTERACTION TAKES PLACE	I 2.3
NMAX	NUMBER OF TOROIDAL MODE NUMBERS	I 2.3
NST	STEP BETWWEN TOROIDAL MODE NUMBERS	I 2.3
NXMARG	NUMBER OF VEL. POINTS TO ADD IF VEL. GRID INSUF.	I 2.3
NS1	THE NUMBER OF THE FLUX SURFACE	I 2.3

3.1 OUTPUT FROM SPECT

COMMON/COMSPO/

PN(MDNT)	NORMALISED ANTENNA SPECTRUM	RA 3.1

3.2 OUTPUT FROM DEP

COMMON/COMDPO/

ACARR(MDS,MDNT,MDR)		
	SINGLE PASS ABSORPTION COEFFICIENTS FOR IONS	RA 3.2
ECLRA(MDS,MDNT,MDR)		
	AVERAGED RE(E+*CONJ(E-))/|E+|	RA 3.2
ERLRA(MDS,MDNT,MDR)		
	AVERAGED (|E-|/|E+|)**2	RA 3.2
MCRAT(MDNT)		
	FRACTION OF POWER GOING TO MODE CONVRSION	RA 3.2
PAVET(MDS)	NORMALISED FLUX SURFACE AVERAGED POYNTING FLUX TO THE ELECTRONS	RA 3.2

PAVIT(MDS,MDR)
NORMALISED FLUX SURFACE AVERAGED POYNTING FLUX TO THE ION SPECIES RA 3.2

PAVT(MDS) NORMALISED FLUX SURFACE AVERAGED POYNTING FLUX RA 3.2

PDAVET(MDS) NORMALISED POWER DENSITY ABS. BY THE ELECTRONS RA 3.2

PDAVI(MDS,MDNT,MDR)
NORMALISED POWER DENSITY ABS. BY THE RESONANT ION SPECIES FOR A TOROIDAL MODE NUMBER RA 3.2

PDAVIT(MDS,MDR)
NORMALISED POWER DENSITY ABS. BY THE RESONANT ION SPECIES (SUMMED OVER NTOR) RA 3.2

WKXRA(MDS,NTOR,MDR)
AVERAGED PERPENDICULAR WAVE NUMBER (M-1) RA 3.2

3.3 OUTPUT FROM FPLT

COMMON/COMFPO/

DRAT(MDR,MDS)
RATIO BETWEEN BULK AND TOTAL DENS. OF RES IONS RA 3.3

EB(MDR,MDS) TEMP. OF BULK IONS OF RES. ION SPECIES (KEV) RA 3.3

FUSD(MDR,MDS)
FUSION REACTION RATE DENSITY (CM-3 S-1) RA 3.3

FUST(MDR) FUSION REACTION RATE (S-1) RA 3.3

PDRF(MDR,MDS)
RF-POWER DENSITY ABS. BY RES. ION SPECIES (W/M3) RA 3.3

PDTE(MDR,MDS)
POWER DENSITY COLLISIONALLY TRANSFERRED FROM RESONATING IONS TO THE ELECTRONS (W/M3) RA 3.3

PDTI(MDR,MDS)
POWER DENSITY COLLISIONALLY TRANSFERRED FROM RES. IONS TO THE BACKGROUND IONS (W/M3) RA 3.3

PTE(MDR) POWER TRANSF. FROM RES. IONS TO ELECTRONS (W) RA 3.3

PTI(MDR) POWER TRANSF. FROM RES. IONS TO BACKG. IONS (W) RA 3.3

PRFI(MDR) POWER ABSORBED BY RESONATING ION SPECIES RA 3.3

W(MDR) ENERGY CONTENT OF RES. ION SPECIES (J*M-3) RA 3.3

WZ(MDR) PARALL. ENERGY CONT. OF RES. ION SPECIES (J*M-3) RA 3.3

WFAST(MDR) FAST ENERGY CONTENT OF RESONATING IONS (J) RA 3.3

WZFAST(MDR)	FAST PARALLEL ENERGY CONT. OF RES. IONS (J)	RA 3.3
WD(MDR,MDS)	ENERGY DENSITY OF RES. ION SPECIES (J*M-3)	RA 3.3
WDZ(MDR,MDS)	PARALLEL ENERGY DENS. OF RES. ION SPEC. (J*M-3)	RA 3.3
WDF(MDR,MDS)	FAST ENERGY DENSITY OF RES. ION SPECIES (J*M-3)	RA 3.3
WDZF(MDR,MDS)	PARALLEL FAST ENERGY DENSITY OF RESONATING ION SPECIES (J*M-3)	RA 3.3