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1.1 Purpose of FALCON

Understanding the plasma transport properties is one of the most important and challenging objectives of current tokamak research. In spite of intensive effort in recent years {4}, there is still no fully convincing theory, nor a consensus on which of the competing physical processes is dominant. Experimental evidence, and its comparison with theoretical predictions, is thus of prime importance.

While the measurement of *global* energy and particle confinement - and of their scaling with external parameters - is a useful guide for improving experimental performance, *local* transport studies are essential for a meaningful comparison with theory.

The large variety of JET diagnostics provides a comprehensive set of measurements of tokamak plasma parameters.

The FALCON program has been designed to assist the interpretation of these data, and to help assessing their implications for a theory of local transport phenomena in tokamaks. The code is organized in such a way as

- to be *fast* (average CPU time consumption: 5 sec per time slice on the JET IBM computer)
- to be able to access and use data produced by *all diagnostics* and by *all processing codes* routinely run at JET - including information on *data reliability* (eg "validation flags")
- to allow selection of *different sets of input data* chosen among those stored, *for a given pulse*, in the JET data banks
- to use, for those *quantities* that are *not directly measured* (eg internal magnetic geometry, neutral beam and ICRF power deposition), the *best available models* compatibly with the speed of execution .

These features make FALCON a useful tool for *detailed transport analysis for a large number of JET pulses* and for *consistency checks* and *sensitivity studies* .

Using FALCON, one can therefore provide a statistical background that is the necessary complement to transport studies carried out with time-dependent codes, both interpretive (TRANSP) and predictive (JETTO).

1.2 General code flow chart

Figure 1 shows a schematic overall flow chart of the FALCON chain of calculations. While these will be discussed in detail in the following, we wish to emphasize here the *modular structure* of the program.

The individual modules are called, in the sequence shown in Fig 1, by a single control routine. Each of them is independent of the others, meaning that the only connection between them is through COMMON variables.

Besides making the program readily accessible and intelligible, whenever updates are required, this structure gives FALCON a high degree of flexibility. In particular, it makes it possible to use the whole code - or individual modules of it - for special-purpose studies.

As shown in Fig 1, FALCON includes a number of "dummy" routines (*PLAY* routines), called at different stages of the standard chain of calculations. Here, the general user can introduce any kind of non-standard calculation, thereby creating his/her own version of the code.
In this context, FALCON can be used as a "black box"; the only background knowledge required is that of which COMMON blocks are filled with FALCON results at each stage of the standard chain of calculations (Section 9.2).

1.3 Main assumptions

FALCON is a *time slice* analysis program: this means that it does *not* follow the time evolution of a JET discharge by advancing the transport equations in time. The time derivatives appearing in the equations (Section 2) are evaluated from measured data.

A notable example of this *purely interpretive* approach is the absence, in FALCON, of a diffusion equation for the poloidal magnetic field, whose solution requires at least a semi-predictive approach. As a consequence, caution will be required when using FALCON to analyse plasmas that are not in steady-state from the point of view of current penetration.

A number of standard assumptions in the study of tokamak transport underlie FALCON's equations.

First of all, *axisymmetry* is assumed, ie the toroidal angle is seen as an ignorable coordinate along which nothing varies.

Then, plasma parameters such as *temperature (T), density (n) angular rotation frequency (ω) are assumed to be flux-surface quantities*, ie not to have poloidal variations on magnetic flux surfaces. This assumption - justified by the expectation that transport along field lines be many orders of magnitude larger than transport across them - greatly simplifies the diffusive operators in the equations: all local gradients of the main plasma parameters become orthogonal to the flux surfaces.

Furthermore, we assume that *all ion species* in the plasma *have the same temperature* T_i, with the possible exception (in the presence of NBI or ICRF heating) of a suprathermal "fast ion" population (Section 3.1.5).

Finally, it should be stressed that FALCON "borrows" results from several stand-alone codes routinely run at JET. This is, in fact, the main reason for its being a fast - while at the same time sufficiently complete - transport analysis program.
It also implies, of course, that the quality of FALCON's results is strongly dependent on that of IDENTC's (mhd equilibrium), PENCIL's (NBI deposition profiles), etc.

1.4 Limitations

The fact that FALCON relies on other codes, to model certain effects relevant to the investigation of transport, is one of its merits: indeed, it seems desirable to bring results of different, sophisticated stand-alone calculations together, to form a single coherent picture.

There is, however, an associated drawback, best clarified by referring to a specific example. FALCON may use PENCIL results for NBI deposition profiles (obtained with certain assumptions, say, on the electron density profile), and at the same time assume that n_e is different from that used by PENCIL (because, eg, more than one measurement of n_e is available).

That this type of inconsistency may arise is, at present, an inevitable consequence of the FALCON approach. A better coordination of the complex data processing chain at JET will hopefully eliminate its occurrence in the future (see Section 7). For the time being, however, the FALCON user should be aware of this type of drawback, whose effects on the code's results are difficult to assess (but see the discussion in Appendix 9.4).

The treatment of *impurities* (Section 3.1) is also rather primitive in FALCON. Since these can play a significant role in many JET experiments, this limitation must be kept in mind; in particular, sensitivity studies to the plasma composition assumptions are highly advisable.

The *splitting of heat fluxes* into a convective and a conductive component relies on somewhat arbitrary assumptions, notably regarding the poloidal variation of particle fluxes (Section 2.3).

1.6 *Use of FALCON results for transport studies*

Transport analysis with FALCON aims at producing a database of *local inferred fluxes* (of particles, momentum and energy) for a large number of JET experiments. This is a well defined task, since there is general agreement as to which terms in the transport equations are important in determining such fluxes, and FALCON takes them all into account.

The interpretation of measured fluxes in terms of transport theory is, however, susceptible to a variety of approaches. There is no general agreement, in particular, as to which terms in the transport matrix (connecting thermodynamic fluxes and forces) should be retained. For example, conductive heat fluxes need not necessarily be "diagonal", ie simply proportional to local temperature gradients.

The derivation of *transport coefficients* from measured fluxes is, therefore, a somewhat arbitrary procedure.

For this reason, an *interpretation package* (Section 9.3) has been set up as detached from the main FALCON code, and is easily modifiable by each user. This means that the user can freely *introduce new models* for the physical interpretation of measured fluxes, *without having to re-run the code* every time.

In Section 1.4, we have discussed some of the limitations that should be kept in mind when using FALCON results. Some additional general remarks are in order here:

- the radial regions near the centre and the edge of the plasma are usually affected by the largest uncertainties, from the transport interpretation point of view.
  For the central region this is due especially to uncertainties in local geometry and auxiliary heating deposition profiles, as well as to mhd phenomena (sawteeth). For the edge region, it is because of larger errors on the measurements and of the dominant role played by atomic processes.
  Typically, the "safe" radial range for interpretation is $(0.20\text{-}0.40) \leq \rho \leq (0.75\text{-}0.85)$.

- the assessment of "error bars" on transport analysis results (due to the propagation of errors on the input data) remains a major unresolved problem. On the one hand, it is meaningless to quote results without an estimate of the associated error; on the other hand, no satisfactory recipe has yet been found for dealing with the problem in a systematic way.
  FALCON is no exception to this general rule; however, some attempts are made to improve the situation. These are discussed in Appendix 9.4.
  The bottomline is that, in order for the code's results to be dependable, it is necessary to carry out sensitivity studies. These will generally have to be based on iterative runs of the code, for a given plasma, with variations on the input data covering the corresponding uncertainty range.

- FALCON can be run in an "automatic" mode (Section 6.1), in which a default set of assumptions for the input data is consistently adopted.
  The discussion above suggests, however, that the "manual" mode is best suited to transport analysis, and it is the one we recommend. While "automatic" runs for large number of pulses may help identifying general trends, they can also be affected by systematic errors that may be impossible to assess.

A more detailed discussion of these problems, together with a number of illustrative examples, can be found in the companion report {3}.

2.1 *Moment equations*

The well-known fluid moment equations {5} for each plasma component (j= electrons, *thermal* ion species) are the conservation laws for

- particles : $$\frac{\partial}{\partial t} n_j + \nabla \cdot (n_j \mathbf{v}_j) = S_{n_j} \qquad (2.1a)$$

  where $\mathbf{v}$ represents a flow velocity, and S_n the sum of particle sources from ionisation, recombination, charge exchange, neutral beam injection.

- momentum : $$\frac{\partial}{\partial t} (n_j m_j \mathbf{v}_j) + \nabla \cdot (n_j m_j \mathbf{v}_j \mathbf{v}_j) + \nabla p_j + \nabla \cdot \vec{\pi}_j = n_j e_j (\mathbf{E} + \mathbf{v}_j \times \mathbf{B}) + \mathbf{R}_j + \mathbf{S}_{Mj} \qquad (2.1b)$$

  where m_j and e_j are mass and charge of species j, $p = nkT$ is the kinetic pressure, $\vec{\pi}$ represents the stress tensor, $\mathbf{E}$ and $\mathbf{B}$ are electric and magnetic field, $\mathbf{R}$ denotes interspecies friction and $\mathbf{S}_M$ other momentum sources (e.g. neutral beam injection).

- energy : $$\frac{\partial}{\partial t} \left(\frac{1}{2} n_j m_j v_j^2 + \frac{3}{2} p_j \right) + \nabla \cdot \left[\left(\frac{1}{2} n_j m_j v_j^2 + \frac{5}{2} p_j \right) \mathbf{v}_j + \mathbf{q}_j + \mathbf{v}_j \cdot \vec{\pi}_j \right] = S_{Ej} \qquad (2.1c)$$

  where $\mathbf{q}$ represents a local heat flux and S_E is a sum of energy sources (Ohmic heating, auxiliary heating, radiative losses, thermal exchange between species).

In FALCON, we make the assumptions of

local quasi-neutrality $n_e = \sum Z_k n_k$ (2.2) and flux ambipolarity $n_e v_{e,r} = \sum Z_k n_k v_{k,r}$ (2.3)

(k = all ion species including the *non-thermal* ones; Z = charge number) and solve the continuity equation (2.1a) for electrons, main ions and one representative impurity species.

Momentum conservation, Eq (2.1b), is solved for the plasma as a whole, ie summed over all j's (whereby the first two terms on the right hand side disappear, according to (2.2) and (2.3)).

Finally, the energy balance equation (2.1c) is solved for a two-fluid plasma, ie for electrons and for the sum over all ion species.

2.2.2 Formulation of a diffusion equation

As an example of how our transport equations can be formulated in the chosen coordinates, consider the diffusion equation:

$$\nabla \cdot (D \nabla n) = S$$

If we assume that D, n and S are functions of the radial coordiante ρ only, this becomes:

$$\frac{1}{\sqrt{g}} \frac{\partial}{\partial \rho} (\sqrt{g}\, g^{11} D \frac{\partial n}{\partial \rho}) + \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta} (\sqrt{g}\, g^{12} D \frac{\partial n}{\partial \rho}) = S$$

Here, the second term can be eliminated by operating with $\int_0^{2\pi} \sqrt{g} \ \ldots \ d\theta$, yielding

$$\frac{\partial}{\partial \rho} (V' D \frac{\partial n}{\partial \rho} < | \nabla \rho |^2 >) = V' S$$

where

$$V' \equiv \frac{dV}{d\rho} = 2\pi \int_0^{2\pi} \sqrt{g}\ d\theta \tag{2.7}$$

is the differential volume element, and

$$< | \nabla \rho |^2 > \equiv < g^{11} > = \frac{2\pi}{V'} \int_0^{2\pi} \sqrt{g}\ g^{11}\, d\theta \tag{2.8}$$

2.3 *Particle balance*

→ *control switch : none* (always computed)

The particle balance module in FALCON uses, as main experimental input, space- and time-resolved measurements of electron density n_e and effective ionic charge Z_{eff} together with spectroscopic measurements of the edge neutral particle source. The presence of impurities is accounted for by assuming that a single, fully-stripped impurity species (with charge number Z_{imp} assigned as input, and mass number $A_{imp} = 2\,Z_{imp}$) determines the measured Z_{eff}. The presence of a minority population, typically for ICRF heating experiments, is accounted for by assigning as input its species (H, D, ^3He or ^4He) and concentration relative to the electron density.

2.3.1 Electron flux

The flux surface averaged continuity equation for electrons reads

$$\frac{1}{V'}\,\frac{\partial}{\partial t}\,(V' n_e) + \frac{1}{V'}\,\frac{\partial}{\partial \rho}\,[\,V' < \vec{\Gamma}_e \cdot \nabla\rho > \,] = < S_{n_e} > \qquad (2.13)$$

where $\vec{\Gamma}_e \equiv n_e(\mathbf{v}_e - \mathbf{v}_\rho)$ is the local electron flux.

The electron source rate in FALCON is

$S_{n_e} = S_o + S_B$,

where S_o represents ionisation and recombination rates and S_B the neutral beam particle source (provided by the FRANTIC and PENCIL codes, respectively - see Sections 4.1.6-7). The particle source from possible pellet injection is not included, and this implies that caution must be taken when selecting time slices for analysis in pellet experiments.

From Eqs (2.13, 2.11) it follows that the total electron flux through a surface $\rho = constant$ is given by

$$\Gamma^e_{tot}(\rho) = \int_0^\rho [\,< S_{n_e} > - \frac{1}{V'}\,\frac{\partial}{\partial t}\,(V' n_e)]\; V'\, d\rho \qquad (2.14a)$$

2.3.2 Ion fluxes

Making use of the definition of Z_{eff} and of the ambipolarity condition (2.3), it is possible under our assumptions (single fully-stripped impurity species and no impurity source in the plasma) to derive separately, from the observed time evolution of Z_{eff}, a particle flux for main plasma ions (m) and impurity ions (imp). When the minority flux is neglected, one finds:

$$\Gamma^m_{tot}(\rho) = \int_0^\rho \{\,< S_{n_m} > - \frac{1}{V'}\,\frac{\partial}{\partial t}\,[V' \frac{n_e(Z_{imp} - Z_{eff})}{Z_m(Z_{imp} - Z_m)}\,]\}\; V'\, d\rho \qquad (2.14b)$$

and, of course,

$$\Gamma^{imp}_{tot}(\rho) = \frac{1}{Z_{imp}}\,[\Gamma^e_{tot}(\rho) - Z_m \Gamma^m_{tot}(\rho)]. \qquad (2.14c)$$

For the main ion source rate S_{n_m} the same remarks apply as for the electron source. The total ion flux that will be used later (momentum and energy balances) is just

$$\Gamma^{ion}_{tot}(\rho) = \Gamma^m_{tot}(\rho) + \Gamma^{imp}_{tot}(\rho). \qquad (2.14d)$$

2.4 *Momentum balance*

→ *control switch :* ***nmomba*** (0 = off , 1 = on)

We take the toroidal component (multiplying scalarly by $R^2 \nabla\phi$) of Eq (2.1b) summed over all species. After neglecting terms of order m_e/m_i and flux surface averaging, we arrive at the equation for angular momentum conservation :

$$\frac{1}{V'}\frac{\partial}{\partial t}(V'\sum_{ions} m_j n_j < R^2 > \omega) + \frac{1}{V'}\frac{\partial}{\partial \rho}[V' < \sum_{ions} m_j \omega R^2 \vec{\Gamma}_j \cdot \nabla\rho + R^2 \pi^{\phi\rho} >] = \sum_{els,ions} < R^2 \nabla\phi \cdot \mathbf{S}_{Mj} > \tag{2.17}$$

where $\pi^{\phi\rho} \equiv \nabla\phi \cdot \vec{\pi} \cdot \nabla\rho$.

As said above, we assume that the toroidal angular frequency $\omega \equiv v_{tor}/R$ is a flux surface quantity.

2.4.1 Momentum flux

By integrating Eq (2.17), we obtain the total cross field flux of toroidal angular momentum:

$$M_{\phi,tot} = \int_0^\rho \{ \sum_{els,ions} < R^2 \nabla\phi \cdot \mathbf{S}_{Mj} > - \frac{1}{V'}\frac{\partial}{\partial t}[V' \rho_i \omega < R^2 >] \} V' \, d\rho \tag{2.18}$$

where we have introduced the ion mass density $\rho_i \equiv \sum_{ions} m_j n_j$.

The momentum source rate S_{Mj} includes, in FALCON, only the neutral beam source (see Section 3.3.1).

$M_{\phi,tot}$ can be considered as the main output from the momentum balance calculation. However, we also output one attempt to separate the momentum flux originating from the stress tensor term from that coming from the particle flux. In order to do so, we invoke our assumption (Section 2.3) of constancy of $(\vec{\Gamma} \cdot \nabla\rho)/|\nabla\rho|^2$ on flux surfaces, and write therefore:

$$< m_i \omega R^2 \vec{\Gamma}_j \cdot \nabla\rho > = \frac{\Gamma^i_{tot}}{V' < |\nabla\rho|^2 >} m_i \omega < R^2 |\nabla\rho|^2 > \tag{2.19}$$

Thus, the toroidal momentum cross-field flux originating from the stress tensor term in (2.17) is

$$M_{\phi s} = M_{\phi,tot} - \sum_{j=ions} \frac{\Gamma^j_{tot}}{< |\nabla\rho|^2 >} m_j \omega < R^2 |\nabla\rho|^2 > \tag{2.20}$$

2.4.2 Momentum diffusivity

In order to derive an estimate for a corresponding transport coefficient, we then assume that the cause of this momentum flux is perpendicular viscosity, and *postulate*

$$\pi^{\phi\rho} = - \rho_i \chi_M \frac{\partial\omega}{\partial\rho} |\nabla\rho|^2 \tag{2.21}$$

Thus, we obtain a momentum diffusivity

$$\chi_M = \frac{- M_{\phi s}}{\rho_i \frac{\partial\omega}{\partial\rho} V' < R^2 |\nabla\rho|^2 >} \tag{2.22}$$

2.6 *Energy balance*

→ *control switches : **nebbal** (electrons) **nibbal** (ions)* (0 = off , 1 = on)

Energy balances are evaluated in FALCON for ions and electrons separately.

After flux surface averaging Eq (2.1c) and making the assumption {8} $v_\phi \pi^{\phi\rho} \gg (v_\rho \pi^{\rho\rho}, v_\theta \pi^{\theta\rho})$, we arrive at

$$\frac{1}{V'^{5/3}}\frac{\partial}{\partial t}\left[V'^{5/3} < \frac{3}{2} p_j > \right] + \frac{1}{V'}\frac{\partial}{\partial t}\left[V' < \frac{1}{2} n_j m_j \mathbf{v}_j^2 > \right] + \frac{1}{V'}\frac{\partial}{\partial \rho}\left[V' < (\frac{1}{2} n_j m_j \mathbf{v}_j^2 + \frac{5}{2} p_j)\mathbf{v}_j \cdot \nabla\rho + \omega R^2 \pi_j^{\phi\rho} + \mathbf{q}_j \cdot \nabla\rho > \right] = < S_{Ej} > \tag{2.27}$$

where we have used $v_\phi = v_{tor}$, $R = \omega R^2$.

2.6.1 Total heat fluxes

Summing Eq (2.27) over all *ion* species, we find the net integrated ion heat flux through each surface:

$$Q^i_{tot}(\rho) = \int_0^\rho \{ < S_{Ei} > - \frac{1}{V'^{5/3}}\frac{\partial}{\partial t}\left[V'^{5/3} W_i\right] - \frac{1}{V'}\frac{\partial}{\partial t}\left[V' \frac{1}{2}\rho_i \omega^2 < R^2 > \right] \} V' \, d\rho \tag{2.28}$$

where W_i is the *ion energy density* : $W_i = \sum 3/2 n_j T_j + W_{fast}$ $(j = ions)$, with W_{fast} representing the energy of a minority population of suprathermal ions, and where we have made the approximation $v_i^2 \simeq v_{tor}^2$ when defining the *rotational energy density* : $W_{rot} = 1/2\, \rho_i\, \omega^2 < R^2 >$.

For the electrons, the contribution from directional motion and the presence of a possible suprathermal population are neglected, and we have

$$Q^e_{tot}(\rho) = \int_0^\rho \{ < S_{Ee} > - \frac{1}{V'^{5/3}}\frac{\partial}{\partial t}\left[V'^{5/3} \frac{3}{2} n_e T_e\right] \} V' \, d\rho \tag{2.29}$$

For the source rates, we have for the electrons:

$$S_{Ee}(\rho) = P_\Omega + P^e_{RF} + P^e_{NBI} - P_{e-i} - P_{rad} - P_{ez} \tag{2.30}$$

and for the ions:

$$S_{Ei}(\rho) = P^i_{RF} + P^i_{NBI} + P_{e-i} - P_{c-x} - P_{iz} \tag{2.31}$$

Here the various terms, to be discussed in detail in Sections 3 and 4 below, represent:

P_Ω : Ohmic power density input

P_{e-i} : power density associated with temperature equilibration between electrons and ions (two-fluid approximation)

P_{rad} : radiated power density

$P_{e,iz}$: power density associated with ionisation/recombination processes

P_{c-x} : power density associated with charge-exchange processes

P^i_{NBI} : power density deposited from NBI

P^i_{RF} : power density deposited from ICRF heating, directly or indirectly through slowing down of minority ions.

The total heat fluxes for ions and electrons, Eqs (2.28-29), are the main output of the energy balance calculation.

3.0 Physics modelling

This Section describes the physics assumptions used in FALCON to model those terms in the transport equations for which routine experimental measurements are not available.

Throughout this Section, all the relevant measured profile data (electron density and temperature, ion temperature, effective ion charge, angular rotation velocity, radiated power density profile) are assumed to be available - mapped on a standard flux-surface related 1-D grid.

The acquisition and manipulation of such experimental data, and the definition of the normalized "radial" coordinate ρ , are discussed in detail in Section 4 below.

All physics modelling assumptions in FALCON are controlled by switches and input parameters, whose function will be explained in each subsection. A tabular summary can be found in Section 6.2 .

3.1.5 Non-thermal ion populations

For NBI-induced fast ions, FALCON relies entirely on PPF data (*NBI4/8, NBIP*) : it reads in the hydrogenic *beam gas species* and the *local fast ion particle and energy density* predicted by PENCIL.

Particle and energy density corresponding to ICRF-driven energetic ion populations are accounted for by a Stix-like steady-state treatment of slowing down effects {20}.

3.1.6 Particle source from neutral recycling

The inhomogeneous term in each plasma transport equation contains contributions due to those source rate densities associated with fuelling at the plasma edge, in particular by recycling from intercepted material surfaces. In the absence of neutral beam or pellet injection , this is the sole significant source for plasma particles, charge-exchange energy losses, etc. To describe such effects, FALCON incorporates a version of the *FRANTIC* neutral particle transport estimator {16} , which uses an equivalent cylindrical geometry representation.

Presently edge fuelling, ostensibly by recycling, of a hydrogen isotope majority ion species only is treated. In principle, the diffusion of neutral particles from injected beams (or, if extra appropriate atomic reaction data were added, recycling of other species) could also be calculated. For this, instead, FALCON uses PENCIL results as discussed below.
The principal terms evaluated by *FRANTIC* are the consequent

- *source rate density profile for electrons* (≡ that for main ions), which is used in FALCON's particle balance
- power loss profiles for *charge-exchange* , *electron/ion ionisation* and (less importantly) *radiative recombination* cooling , which are used in FALCON's energy balances

The most significant model approximation involved is an assumption of *complete poloidal symmetry* with regard not only to plasma properties, but also to boundary conditions. This Ansatz may appear inappropriate for discrete limiter or X-point discharges - as in JET - where recycling is certainly highly localised around the neutralising surfaces. However, over the inner plasma region actually of interest in FALCON the neutral particle population comprises predominantly products from some generations of c-x reactions, which act progressively to homogenise and isotropise their distribution. Hence, our approximation may not be so deficient in this context.

3.1.7 Particle source from Neutral Beam Injection

For this, FALCON relies entirely on profiles produced by the on-line version of the PENCIL code (*NBIP.S0* in PPFs). These are input as functions of the Lao-Hirshman coordinate (Section 4.2.1) corresponding to the FAST equilibrium.

With the exception of pellet injection experiments, this term will usually represent the sole significant particle source in the inner plasma; it will therefore determine all results concerning local particle and convective energy fluxes.

In the present set-up of FALCON, it is not possible to perform variations on these PENCIL results. Their mapping onto FALCON's geometry may also be non-trivial, since the underlying FAST and IDENTC equilibria are sometimes significantly different. Furthermore, FALCON may be run using plasma profile data (eg for the electron density) different from those used as input for PENCIL.

The only way to avoid these drawbacks and inconsistencies would be to implement a version of PENCIL into the FALCON chain of calculations. This possibility is being considered (Section 7.2).

3.2.2 Non-inductive current densities

Two *non-inductive* contributions to $j_{//}$ are accounted for in FALCON's current balance: the *neoclassical (bootstrap)* current and the *beam-driven* current. Other possible driven currents (eg due to Ion Cyclotron or to Lower Hybrid RF heating) are at present not included (see Section 7.2).

- For the prediction of the *bootstrap* current, the formulation given in {17} is used:

$$< j_{boot}^{pred} \cdot \mathbf{B} > = F(\psi)\, p_e(\psi)\, [L_{31}^e A_p + L_{32}^e A_{T_e} + L_{32}^i A_{T_i}] \tag{3.4}$$

where $p_e(\psi)$ is the electron pressure and the thermodynamic forces are given by

$$A_p \equiv \frac{\partial}{\partial \psi} \ell n\, p_e + \frac{T_i}{Z\, T_e} \frac{\partial}{\partial \psi} \ell n\, p_i \quad , \quad A_{T_j} \equiv \frac{\partial}{\partial \psi} \ell n\, T_j \tag{3.4'}$$

The dimensionless transport coefficients L_{ab} involve the friction and viscosity matrices {17} . At present, they are modelled assuming the plasma to be in the *banana* collisionality regime. Furthermore, only one ion species with charge number Z is assumed to be present. This inconsistency with the rest of the code will be eliminated in the future by introducing an impurity species explicitly in the model.
An approximated flux-surface-averaged bootstrap current is evaluated as

$$j_{boot}^{pred} = \frac{< j_{boot}^{pred} \cdot \mathbf{B} >}{B_0} \tag{3.4''}$$

- FALCON reads in profiles of the *beam-driven* current density $< j_{b-d}^{pred} >$ as predicted by the PENCIL code (*NBIP.JBDC* in PPFs). These are input as functions of the Lao-Hirshman coordinate (Section 4.2.1) corresponding to the FAST equilibrium.
The same critical remarks apply here as made for the NBI particle and energy sources (Sections 3.1.7 and 3.4.4). However, for the current balance the problems will generally be less serious, in that j_{b-d} is normally a small fraction of the total current density in JET experiments.

3.2.3 Inductive current density

- *Input switch :* ***nohmic***

The modelling of the inductive current density is controlled by the same input switch that controls the Ohmic power calculation (Section 3.4.3).

In all cases, the current density profile from IDENTC is read in. The value of ***nohmic*** will determine whether it is used for the evaluation of $j_{//}^{ind}$, or whether the resistivity model is used instead :

nohmic = 0,1 the inductive current density is defined as the difference between the total current density from IDENTC and the predicted non-inductive currents:

$$j_{//}^{ind} = j_{IDC} - j_{boot}^{pred} - j_{b-d}^{pred} \tag{3.5a}$$

nohmic = 2 the inductive current density is defined as

$$j_{//}^{ind} \equiv \frac{E_{//}}{\eta_{//}} \quad , \text{ assuming } \quad \frac{\partial E_{//}}{\partial \rho} = 0. \tag{3.5b}$$

ie *full resistive current penetration* is assumed. Using the modelled electrical resistivity, this gives the *profile shape* for j^{ind}. Its *magnitude* is determined by imposing that

$$\int j_{//}^{ind}\, dA = I_p^{tot} - \int (j_{boot} + j_{b-d})\, dA \tag{3.5c}$$

A being the cross-sectional area in the poloidal plane.

3.3 *Momentum balance*

For the momentum balance calculation, only momentum input from the neutral beams is included.

The collisional momentum transfer from the fast ions to the bulk plasma is computed by the PENCIL code using a Fokker-Planck treatment. For such a calculation, the momentum injected in the form of banana-trapped particles does not contribute. However, upon ionisation, these particles set up a radial current, due to orbit effects, and thus induce a **j x B** force on the plasma. The question of the definition of the total momentum input to the plasma is thus theoretically complicated (the fraction of banana-trapped particles is furthermore large, for typical JET regimes).

3.3.1 Momentum source

- *Controlling switch : **nnbi*** { if NBI is off, the momentum source will be set to **0.** }

In FALCON we do *not* use the PENCIL results, except for the purpose of comparison. Instead, we make the assumption that the entire mechanical momentum input is transferred to the plasma. Thus we have in Eq. (2.17):

$$R^2 \nabla\phi \cdot \mathbf{S}_M = R^2 \nabla\phi \cdot \sum S_b m_b \mathbf{v}_b$$

where S_b is the local beam ionisation source rate, m_b is the beam ion mass and $\mathbf{v}_b$ is the injection velocity. The sum is over different beam components: full energy E_b, 1/2 E_b and 1/3 E_b. Since

$$R^2 \nabla\phi \cdot \mathbf{v}_b = R_{\tan} |\mathbf{v}_b|$$

where $R_{\tan}$ is the beam tangency radius (minimum distance between beam trajectory and torus axis), and neglecting differences in local deposition for the different (atomic) components, we write

$$R^2 \nabla\phi \cdot \mathbf{S}_M = R_{\tan} m_b S_B \sum |\mathbf{v}_b| \qquad (3.7)$$

- *Experimental data used*

Beam ion mass, injection energy and injected power are read in from the *NBI4/8* PPFs, for each of the 16 injectors. For the tangency radius, an average is taken between the two typical values of the present JET injectors ($R_{\tan}$ = 1.18 , 1.85 m).

The fraction of power in each energy component is given by the following table (measured values):

injected species	*injection energy (keV)*	*power fraction in %*		
		full	*half*	*third*
H	70/80	70	25	5
	110	40	30	30
D	80	75	15	10
	140	65	20	15
He	any	100	-	-

3.4.3 Ohmic heating

- *Controlling switch : **nohmic*** (default value = 2)

The modelling of the local power input to the electrons due to Joule effect heating is controlled by the same input switch that also controls the modelling of the current density profile (Section 3.2.3).

The local Ohmic power density is defined as

$$P_\Omega(\rho) = <\mathbf{j}\cdot\mathbf{E}> \tag{3.9}$$

Here, the r.h.s. can be evaluated in different ways, depending on the value of ***nohmic*** :

nohmic = 0 FALCON relies entirely on results from the mhd equilibrium calculation: following ref. {7} , we write

$$<\mathbf{j}\cdot\mathbf{E}> = \frac{<\mathbf{j}\cdot\nabla\phi>\ <\mathbf{E}\cdot\mathbf{B}>}{F(\psi)\ <1/R^2>} \tag{3.10}$$

In terms of ρ and of the poloidal and toroidal flux, the parallel electric field is here

$$<E_{//}B> = F(\rho)<\frac{1}{R^2}>[\dot{\psi}_0 + \rho^2(\dot{\psi}_b - \dot{\psi}_0) - \frac{1}{2\pi\, q_\psi}\dot{\phi}] \tag{3.10'}$$

while

$$<\mathbf{j}\cdot\nabla\phi> = \frac{2(\psi_b - \psi_0)}{\mu_0}\frac{1}{V'}\frac{\partial}{\partial\rho}[\rho\, V' <\frac{g_{22}}{g}>] \tag{3.10''}$$

nohmic = 1 the total, flux-surface-averaged current density from IDENTC is used, together with the resistivity model, to write

$$<\mathbf{j}\cdot\mathbf{E}> = \eta_{//}\, j_{//}^{ind}\ \ j_{IDC} \tag{3.11}$$

where $j_{//}^{ind}$ has been evaluated using this same switch selection, ie as *difference between j_{IDC} and the predicted bootstrap and beam-driven currents* (Eq (3.5)).

nohmic = 2 no use is made of results from IDENTC: we write

$$<\mathbf{j}\cdot\mathbf{E}> = \eta_{//}\, j_{//}^{ind}\ \ (j_{//}^{ind} + j_{boot}^{pred} + j_{b-d}^{pred}) \tag{3.12}$$

where $j_{//}^{ind}$ has been evaluated using this same switch selection, ie assuming *steady-state from the point of view of resistive diffusion (with the chosen resistivity model)* as shown in Section 3.2.3 .

3.4.5 Ion Cyclotron Resonance heating

- *Controlling switch : **nicrf*** { = **0** → ICRF module ***off***, = **1** → ICRF module ***on*** }
- *Input parameters : **kminio, conmin, naconf(j) , tmin0, rfpeff***

No on-line calculation of RF power deposition profiles is currently available in the JET data banks. Full wave or ray-tracing codes that compute ICRH deposition profiles, with associated Fokker-Planck codes, are far too cumbersome for routine use in transport analysis. Therefore, a simplified model (*ICRDEP* {19}) - based on a parametrisation of results from the full wave code LION - has been included in FALCON. The package includes:

calculation of *spectrum* of RF waves (fraction of coupled power in each $k_{//}$)

evaluation of *absorption coefficients* - for *fundamental minority* and *2nd harmonic majority* heating, with a rough estimate of the power absorbed via mode conversion - for a number of $k_{//}$-values (typically, 10 cover the entire spectrum with sufficient accuracy)

calculation of deposition profile on the minority species, using the absorption coefficients to weight results obtained in the limit of *strong and weak single-pass absorption*

estimate of *local power redistribution from the minority to background electrons and ions*, and of the fast ion pressure profile, based on the simplified approach formulated by Stix {20} .

The physics modelling in ICRDEP does *not* include direct electron heating effects via mechanisms such as transit time or Landau damping. In certain heating scenarios at JET, these effects may well be important. Also, the absence of a Fokker-Planck solver to follow the slowing down of energetic minority ions may represent a severe limitation.

- ICRDEP uses all of FALCON's plasma profiles and an equivalent cylindrical geometry (Section 4.2.1). The *frequency and coupled power* for each of the 8 ICRF antennas is read in from PPFs (*RF#.FR , RF#.CP* , where # = *1D, 2B, ... ,7D, 8B*). The meaning of the other input parameters is the following:

  kminio minority species (see Section 3.1.4)

  conmin minority concentration (see Section 3.1.4)

  naconf (1, ... ,8) status and polarity of each of JET's present ICRF antennas:
  = **0** → *antenna off*
  = **1** → *antenna in* monopole *configuration*
  = **2** → *antenna in* dipole *configuration*
  Note that *the ICRDEP calculation will be repeated for each of the antennas assigned as* "on", and the results will be added to give the total deposition profile.

  tmin0 ratio between the "temperature" of the energetic minority population and the background ion temperature (used in the estimate of the Doppler broadening of the resonance). Typical measurements indicate that this ratio is ~ **10.**

  rfpeff in order to speed up the ICRDEP calculation, when *more ICRF antennas are in the same configuration and frequency* the user can assign only one of them as "on", and multiply its coupled power by a factor ***rfpeff*** > ***1.*** .

When the ICRF modelling is included in FALCON's calculations, ICRDEP consumes half of the CPU time required for execution (~ 5 sec on JET's IBM computer). Thus, as soon as results from stand-alone ICRF deposition calculations become available in PPFs, FALCON will be modified to optionally use them, by-passing its ICRDEP module.
The drawback of such an option is (as discussed above for NBI) that inconsistencies may occur, and that it is impossible to perform sensitivity studies on the RF deposition profiles.

In this respect, it is important to stress that *any* prediction of the effect of ICRH on the plasma will depend sensitively on the assumed *local minority concentration*, which is usually *not measured.* Its assignment, therefore, is generally going to be little more than a guess, and this makes sensitivity studies - at least on this parameter - all the more necessary.

related measurements. An input switch allows the user to impose that no further calculations be performed if the measured data are not consistent

Nearly all experimental data relevant to transport studies are stored in the PPF data bank system. However, a small number of high-level processing results (mhd equilibria from IDENTC, radiation profiles from bolometer measurements, ion temperature profiles from NPA, electron density profiles from Abel inversion of interferometer data) are currently available only in dedicated nomad2 databases (Section 4.3). The data acquisition package in FALCON can retrieve data from all these databases.

4.1.1 Different types of input data

Two types of experimental data are input to FALCON:
i) those used directly in the evaluation of transport fluxes (eg electron temperature profile), and
ii) those used only for consistency checks or, more generally, for comparison with FALCON results (eg plasma energy content from magnetic measurements).
The former will be discussed in detail in Sections 4.2-4.3, the latter in Section 4.4.

For a complete run of FALCON, one needs first of all results from

- *a sequence of mhd equilibrium calculations*, covering the time interval within a given pulse to which the time slices selected for analysis belong

Furthermore, the following measurements should be available as a function of time (ideally, with a sampling rate such that there be several measured points between neighbouring FALCON time slices):

- *electron and ion temperature profiles*
- *electron density and effective ionic charge profiles*
- *angular rotation frequency profile*
- *radiated power density profile*

The code can also run (employing additional user-controlled assumptions) in the absence of spatially-resolved measurements of T_i, Z_{eff}, ω or P_{rad} (see Sections 4.3.2/4/5/6) .

4.1.2 Priority lists

Since many of the plasma parameters needed as input for FALCON are routinely measured by more than one diagnostic at JET, the code has input switches (***nx...***) that allow the user to select *manually*, for each run, which diagnostic should be used as data source (Sections 4.2-4.3).

When, however, the default values are assigned to these switches (***nx...*** = ***0***, eg for *automatic* runs), then FALCON will select its own input, based on built-in *priority lists*. The code will use the first data source, in each priority list, which is *available and reliable* (Section 4.1.3).

There is one such priority list for each of the main input quantities, as shown in Sections 4.2-4.3 below. Priority lists may be a function of the *plasma regime* being analyzed, since important diagnostics can measure only under particular operating conditions (eg charge-exchange spectroscopy uses active neutral beams at JET, and will provide data only during NBI heating).

FALCON's priority lists are based on a somewhat arbitrary judgment on the degree of reliability of present JET diagnostics. When new information on this - or new diagnostics ! - become available, built-in priority lists are re-assessed (this requires straightforward changes to the standard program). However, in "testing mode" (Section 6.6) the user may already introduce *ad hoc* modifications to the standard priority lists, according to the needs of special-purpose calculations.

4.2 *Magnetic geometry*

For the magnetic geometry, FALCON uses results from the IDENTC code {10}, by accessing results either from the automatic on-line version of the code (stored under DDA name *IDC#* in PPFs) or from the manually validated IDENTC database in nomad2.

The magnetic field is represented as

$$\mathbf{B} = F(\psi)\,\nabla\phi + \nabla\psi \times \nabla\phi \tag{4.1}$$

where the first term is the toroidal field (ϕ is the toroidal angle) and the second term is the poloidal field. $\psi(R,z)$ is the poloidal flux function, given in the midplane by

$$\psi(R,0) = \psi_0 + \int_{R_0}^{R} B_{pol}\, R\, dR \quad , \quad \text{so that} \quad B_{pol} = \frac{1}{R}\,|\nabla\psi| \ . \tag{4.2}$$

The paramagnetic function

$$F(\psi) \equiv R\, B_{tor} \tag{4.3}$$

expresses the deviation of the toroidal magnetic field from a vacuum field ($B_{tor}^{vac} \sim 1/R$). Normally (for $\beta_{pol} < 1$), the plasma is paramagnetic, ie the field is higher than the vacuum field.

Assuming an axisymmetric tokamak with not too large toroidal plasma flow, the cross-field force balance gives a non-linear equilibrium equation known as the Grad-Shafranov equation :

$$\Delta^{\times}\psi = -\mu_0 R^2 \frac{dp}{d\psi} - F\frac{dF}{d\psi} \qquad \text{with} \qquad \Delta^{\times} \equiv R^2\,\nabla\cdot\frac{\nabla\psi}{R^2} = \frac{\partial^2\psi}{\partial R^2} - \frac{1}{R}\frac{\partial\psi}{\partial R} + \frac{\partial^2\psi}{\partial z^2} \tag{4.4}$$

where $p(\psi)$ is the plasma pressure, R is the major radius of the point in question, z its height above the midplane. The r.h.s. of the G-S equation is essentially the toroidal current density

$$j_\phi(R,\psi) = R\,\frac{\partial p}{\partial\psi} + \frac{F}{\mu_0 R}\frac{\partial F}{\partial\psi} \tag{4.5}$$

With a specified current density, the solution of Eq (4.4) is in principle straightforward. In the context of data interpretation, however, the relevant problem is an *inverse* one: external magnetic measurements, and other experimental information, are used to deduce properties of the current density. It is well-known {11} that this inverse problem is normally ill-posed; therefore, a method based on parametric optimization of the current density profile is instead commonly used. The parametric form for the current density used in IDENTC is

$$j_\Phi = \frac{\lambda}{\mu_0}\left[\delta\,\frac{R}{R_0}A(\psi_n) + (1-\delta)\,\frac{R_0}{R}B(\psi_n)\right] \tag{4.6}$$

where $R_0 = 2.96\ m$ is the geometric centre of the JET vacuum vessel, λ and δ are fitting parameters and ψ_n is the normalized poloidal flux:

$$\psi_n \equiv \left|\frac{\psi - \psi_0}{\psi_b - \psi_0}\right| \ , \qquad \text{with} \quad \psi_0 = \psi(\text{magnetic axis}) \ , \ \psi_b = \psi(\text{boundary}) \tag{4.6'}$$

The functions $A(\psi_n)$ and $B(\psi_n)$, normalized and dimensionless, represent the terms $dp/d\psi$ and $dF^2/d\psi$, respectively, in Eq (4.4). In IDENTC they are usually parametrized as

$$A(\psi_n) = 1 - \psi_n + a_1(1-\psi_n)^2 \quad , \quad B(\psi_n) = 1 - \psi_n + b_1(1-\psi_n)^2 \tag{4.6''}$$

Thus, in total four parameters (λ , δ , a_1 , b_1) are used to parametrize the current density profile. These four parameters are then chosen so as to reproduce, in an optimal least square sense, the externally measured quantities {11} .

The main IDENTC output used by FALCON is the flux map $\psi_{ij} = \psi(R_i, z_j)$. From it, using the FLUSH routines {12}, FALCON reconstructs numerically the metric coefficients (Section 2.2) and all other required geometrical quantities, based on the flux surface representation of Eq (2.4) .

4.2.2 Sources of equilibrium data

- *Subroutines :* ***GETIDC , GEOMET***
- *Main control switch :* ***nequil***

  Two types of IDENTC results are presently available at JET:
  i) an automatic, on-line version of the code is run at 50 time slices during each pulse (this is generally sufficient for the purpose of FALCON's calculations) ;
  ii) a manual, more complete and carefully validated version is run frequently - but not for every pulse .

  nequil = 1 results from the manual version of IDENTC, stored in a dedicated nomad2 database, are used.

  nequil = 2 results from the on-line IDENTC, stored in PPFs, are used. FALCON will first look for the more recent version (*IDC2*). If this is not available, *IDC1* data will be accepted as input.

  No results from the FAST code are used in FALCON's main calculations. Some are, however, read in and used for comparisons and consistency checks (Section 4.4).

- *Priority list (* ***nequil = 0*** *) :* ***1 / 2***
- *Other associated switches :* ***ndvldt*** can be used optionally to *neglect the time derivative of volume elements* in the transport equations:

  ndvldt = 0 it is assumed that $\partial V'/\partial t = 0$.

  ndvldt = 1 (default value), $\partial V'/\partial t$ - evaluated by differencing over neighbouring time slices - is retained in the equations

  It is advisable to neglect $\partial V'/\partial t$ when the interval between time slices being analyzed is much longer than the typical spacing between equilibria.
  When the default option is used, one should expect $1/V'\ \partial/\partial t\ (V'f)$ to differ from $\partial f/\partial t$ by less than 10 % .

- *Input parameter for time-smoothing :* ***none (nearest available time always taken)***
- *Other associated input parameters :* *none*
- *mhd equilibrium not available ?* ***FALCON will not run***

4.3.1 Electron temperature profile

- *Subroutines : XINPTE , XMAPIN*
- *Main control switch : **nxte***

  FALCON can use electron temperature profiles measured either by the Electron Cyclotron Emission (based on the conversion of the 2nd-harmonic X-mode ECE spectrum through the spatial distribution of the total magnetic field) or by the LIDAR Thomson scattering diagnostic (based on the scattering of a laser beam crossing the plasma at the midplane), depending on the value of the control switch ***nxte*** :

  nxte = 1 the T_e-profile from ECE stored in PPFs (*ECM1.PRFL*) is used. The corrections to the vacuum magnetic field are computed using a simple analytical formula {15}. The measurement is taken along a horizontal line of sight, 13 cm below the midplane, and is time-integrated over a $\Delta t \sim 15$ *msec*

  nxte = 2 the T_e-profile from LIDAR in PPFs (*LIDR.TE*) is used. The measurement is virtually instantaneous. Present sampling frequencies are low (≤ 1 *Hz*)

  nxte = 3 FALCON reads in the ECE calibrated spectrum stored in PPFs (*ECM1.CSPC*), and converts frequencies to locations using the local value for the total magnetic field as determined by IDENTC (Section 4.2). The difference with respect to option ***nxte = 1*** can be significant (shift of the profile in real space $\sim 10 - 15$ *cm*)

  In all cases, the experimental profiles enter the mapping routine ***XMAPIN*** as functions of the midplane major radius R .

- *Priority list (**nxte = 0**) : **3 / 2 / 1***
- *Other associated switches : **ntemap*** can be used optionally to *impose that the position of the peak in the T_e-profile coincide with that of the magnetic axis* as determined by IDENTC:

  ntemap = 0 (default value), the measured profile is left unchanged

  ntemap = 1 the profile is artificially "stretched" by the x-coordinate transformation:
  $R \rightarrow R_0 + (R - \hat{R})\,(R_b - R_0)/(R_b - \hat{R})$,
  where $\hat{R} = R$(peak in measured T_e) and $R_0 = R$(magnetic axis from IDENTC)
  .

- *Input parameter for time-smoothing : **dtte***

  { When LIDAR data are used, FALCON will automatically reset ***dtte = 0.*** , and in particular $dT_e/dt = 0.$, due to the low sampling rate of the present system. Thus, transport analysis with FALCON should use LIDAR profiles only if the plasma is close to *steady-state* }

- *Other associated input parameters : **rxtrap***

  The measurement of T_e near the plasma edge is largely uncertain, and ECE can give spuriously large values due to the overlap of different harmonics. We have introduced a parameter that enables to replace the edge profile by an extrapolation of the inner data:

  rxtrap = 0. (default value) the measured data remain unchanged

  rxtrap > 0. (typically, $R_{xtrap} \sim 4.0\ m$) near the edge ($R > R_{xtrap}$) , the data are replaced by a T_e-profile, with constant gradient = ∇T_e (measured at $R = R_{xtrap}$) .

- *Measured profile not available ? **FALCON will not run***

4.3.3 Electron density profile

- *Subroutines : XINPNE , XMAPIN*
- *Main control switch : **nxne***

  FALCON can use electron density profiles measured either by the Far InfraRed interferometer (FIR) or by the LIDAR Thomson scattering diagnostic. In the former case, up to 8 signals (corresponding to integrated measurements of n_e along different vertical lines of sight) can be available. From them, using various mathematical algorithms, several density profiles are deduced.

  nxne = 1 the on-line estimate of a two-parameter parabolic fit to the FIR signals (in PPFs: *NEX.AX/GAM/WAL*) is used. The fit has the form

  $$n_e(x) = (n_{e0} - n_{eb})\,(1 - x^2)^\gamma + n_{eb} \qquad (4.10a)$$

  where x is the flux surface label of the Lao-Hirshman representation (Section 4.2.1) *based on the FAST equilibrium* .

  nxne = 2 the density profile from LIDAR (in PPFs: *LIDR.NE*) is used. The x-coordinate is the real-space midplane major radius.

  nxne = 3 the on-line Abel inversion of FIR signals (in PPFs: *NEPR.PRFL*) is used. The calculation is based on the on-line IDENTC equilibrium results, and the x-coordinate is the real-space midplane major radius.

  nxne = 4 the result of a manually validated Abel inversion of FIR signals (stored in a dedicated nomad2 database) is used. This is more accurate than the on-line version; in particular, it may use spline interpolation rather than polynomial fitting.

  nxne = 5 the on-line estimate of a three-parameter fit to the FIR signals (in PPFs: *NFT.AX/PFT/QFT/WAL*) is used. The fit has the form

  $$n_e(x) = (n_{e0} - n_{eb})\,(1 - x^2)\,(1 + px^2 + qx^4) + n_{eb} \qquad (4.10b)$$

  and is more general than the one above; in particular, it can describe features such as localized central peaking and non-monotonicity. Again, x is the Lao-Hirshman coordinate *based on the FAST equilibrium* .

- *Priority list (**nxne = 0**) : **4 / 5 / 3 / 2 / 1***
- *Other associated switches : none*
- *Input parameter for time-smoothing : **dtne***
  When LIDAR profiles are used, FALCON will automatically reset ***dtne = 0.*** , implying in particular that $dn_e/dt = 0.$, due to the low sampling rate of the present LIDAR system. Thus, transport analysis with FALCON should use LIDAR profiles only if the plasma is close to a *steady-state.*
- *Other associated input parameters : none*
- *Measured profile not available ? **FALCON will not run***

4.3.5 Toroidal rotation velocity profile

- *Subroutines : XINPMOM , XMAPIN*
- *Main control switch : **nxangv***

  The same diagnostic that measure impurity ion temperatures (Section 4.3.2) can also measure the plasma angular rotation frequency ω , through the analysis of the Doppler shift of various identified impurity radiation lines.
  CXRS can provide spatially-resolved measurements of ω , while X-ray crystal spectroscopy only gives the value near the magnetic axis.

  nxangv = 1 the ω-profile from CXRS (in PPFs: *CXSM.ANGF*) is used.

  nxangv = 2 the single-point measurement from X-ray crystal (in PPFs: *XCS.CHO*) is used.

- *Priority list (**nxangv** = 0) : 1 / 2*
- *Other associated switches : none*
- *Input parameter for time-smoothing : **dtangv***
- *Measured profile not available ?*
  FALCON will assume a simple parabolic shape : $\omega(\rho) = \omega^{exp}\,(1 - \rho^2)$
- *No experimental data available ?*
  FALCON will set** $\omega(\rho) = 0.$ **, and by-pass the momentum balance calculation
- *Other associated input parameters : none*

4.4 *Consistency checks on input data*

In principle, transport analysis should be performed only if a set of *internally consistent* experimental data is available. If the measurements are contradictory, it may be impossible to decide which data should be used as input to FALCON.

The consistency check subroutine ***CONCHK*** has been introduced into FALCON in order to:

i) stop the execution (optionally) whenever pre-set criteria on the consistency of data used for the main calculations are not met

ii) issue warning messages whenever striking inconsistencies are identified in experimental data, even when these are not explicitly used in FALCON

The routine has been devised in order to meet FALCON's immediate requirements, given that no other program presently at JET carries out systematic consistency checks, and is by no means completely satisfactory. It is hoped that in the near future a stand-alone facility will be created, and that special PPFs containing results of systematic, on-line consistency checks will become available (Section 7.2). FALCON will then use that information (even before the main input data are read in) to decide whether a given time slice can be analyzed, and possibly to set additional constraints on the built-in priority lists.

The following checks are carried out in FALCON:

agreement between measured *loop voltage* and that deduced by FALCON

agreement between FALCON's estimate of the *plasma energy content* and of its *time derivative* and the values deduced from magnetic measurements

agreement between FALCON's estimate of the *D-D neutron yield* and the measured data

4.4.1 Experimental data used

The following scalar quantities stored in PPFs are read in by FALCON in order to carry out consistency checks:

V_{loop} : the FAST estimate of the loop voltage at the plasma boundary (*MG2.VSU*)

W_{tot} , $\dot{W}_{tot}$: the values deduced from the diamagnetic loop measurement (*MG3.WPD*) and from the equilibrium calculations of the on-line IDENTC (*IDC2.WP*) and of FAST (*MG2.WP*) , as well as PENCIL's estimate of perpendicular and parallel energy in the fast-ion population generated by NBI (*NBIP.WPET* and *NBIP.WPAT*)

Y_{D-D} : the measured total D-D reaction rate (*TIN.RDD* $\equiv 2\ Y_{D-D}$) and PENCIL's estimate of the neutron yield from beam-target reactions (*NBIP.YBNS*)

- The *input parameter for time-smoothing* of these data is : ***dtscal*** .

Note that in particular the loop voltage from FAST usually displays large oscillations; therefore, a careless choice of ***dtscal*** may easily make the corresponding consistency check meaningless.

5.0 FALCON output

This Chapter describes the standard output from the FALCON program.

Additional output can be stored in FALCON's user PPFs by using the program in "testing mode" (Section 6.6).

One utility for the manipulation of FALCON output in connection with transport analysis is described in Appendix 9.3.

Some of the techniques that can be routinely used to interpret the results, and to assess their sensitivity to uncertainties in the experimental data and in the physics modelling assumptions, are described in Appendix 9.4.

5.2 *Listed output*

- *Controlling switch :* ***noutp***
- *IBM output file :* ***JETuid.FALCON.PRINT***

A comprehensive selection of FALCON output for each code run can be optionally sent to an IBM file (*JETuid.FALCON.PRINT*, if the code is run by the user JETuid), as well as to user PPFs.

This listed output includes scalar quantities and profiles, and is structured as follows:

1. pulse and time(s) analyzed - then, for each time slice :
2. consistency check results
3. geometry information / IDENTC profiles
4. experimental profiles used as input
5. particle balance
6. current and momentum balance
7. global (electrons + ions) power balance
8. ion power balance
9. electron power balance
10. sequence number of user PPF created by the run

If more than one pulse was analyzed in the run, the sequence above is repeated in the listed output for each pulse.

The sections concerning FALCON's balances include each individual term in the (integrated) transport equations, as well as the inferred local fluxes.

- An example of listed output is found in Section 9.5 below (test case).

The production of a listed output is controlled by the input switch ***noutp*** :

noutp = 0 (default) listed output only contains *pulse #(s), time(s) and sequence #(s) of created PPFs*
Note that this is the standard output for "automatic" runs (Section 6.1)

noutp = k > 0 a complete listed output is sent to ***JETuid.FALCON.PRINT***.
For radial profiles, only every ***k***-th point will be printed
Thus, in order to get a list of the entire radial range, ***k*** = 1 should be selected

current balance

CIDC flux-surface-averaged current density from IDENTC (A/m^2)

CURD "resistive" current density (A/m^2)

CBOO bootstrap current density (A/m^2)

CBEA beam-driven current density from PENCIL (A/m^2)

VLOP local loop voltage (V)

QPSI q-profile

momentum balance

MSRC momentum source rate (N/m^2)

MFLX total momentum flux (Nm)

MVIS viscous momentum flux (Nm)

WROT rotational energy density($J/m3$)

electron and ion energy balances

POHM Ohmic power (W)

PE(I)NB NBI power to electrons(ions) (W)

PE(I)RF ICRF power to electrons(ions) (W)

PRAD radiated power (W)

PCX charge-exchange loss power (W)

PEI e-i thermal exchange power (W)

WE(I)DT time derivative of electron(ion) kinetic energy (W)

QTOT total (e + i) integrated heat flux (W)

QCDE(I) integrated specific electron(ion) conductive heat flux (W)

QCVE(I) integrated specific electron(ion) convective heat flux (W)

QVIS integrated viscous heat flux (W)

FCDE(I) specific electron(ion) conductive heat flux (W/m^2)

FCVE(I) specific electron(ion) convective heat flux (W/m^2)

CHIE(I) specific electron(ion) thermal conductivity (m^2/s)

The input to the code is summarized in three vectors:

switches and input parameters

SCON input control switches

SMOD physics modelling switches

PARM other input parameters

6.1 Computer Requirements

To run FALCON the user should have *a userid for the JET IBM* and *authority to create user PPFs*. Both of these points can be clarified with the Data Management Group (room K1/0/38).

All files relevant to the running of FALCON (e.g. executable load module and ISPF panels) are maintained under a single userid - **JETBHO** To gain access to the controlling clist the user should update his/her dataset START.CLIST so that the dataset 'JETBHO.GRPLIB.CLIST' is allocated (see Fig. 6.1). Some datasets may need to be created by the user in particular modes of running the code - these will be mentioned at appropriate places further on in this chapter.

The FALCON job runs in batch, in class F if one shot is being analysed and in class H if more than one shot is being analysed. The average C.P.U. time for one time slice is 5 seconds but this rises to 11 seconds if the option to run the ICRF package is included.

```
PROC 0 DEBUG
/*********************************************************************/
/* AUTHOR     : LA HOPKINS ... 21.07.86                              */
/*                                                                   */
/* FUNCTION   : EXAMPLE START.CLIST TO ALLOCATE FALCON LIBRARIES     */
/*                                                                   */
/* PARAMETERS: DEBUG     USED IN TESTING CLIST                       */
/*                                                                   */
/* USED BY    :                                                      */
/*                                                                   */
/* UPDATE RECORD                                                     */
/* YYMMDD INITS DESCRIPTION                                          */
/*********************************************************************/

/*********************************************************************/
/* SET DEBUGGING OPTIONS                                             */
/*********************************************************************/

IF &DEBUG = DEBUG THEN CONTROL   MSG   SYMLIST   CONLIST   LIST
                  ELSE CONTROL   MSG NOSYMLIST NOCONLIST NOLIST NOFLUSH

/*********************************************************************/
/* CALL JETSTART                                                     */
/*********************************************************************/

EXEC 'JETLIB.LIB.CLIST(JETSTART)'                    +
            '&DEBUG                                  +
            MYCLIB(''''''JETBHO.GRPLIB.CLIST'''''')  +
            '

END
```

Figure 6.1

6.3 *Selection Panels*

When the **FALCON** command is invoked without the **AUTO** parameter, some ISPF selection panels are displayed to enable the user to input values for control switches, physics parameters and shot and time slice values. If the switch to control the running of the ICRF package is set as **on (nicrf = 1)** an extra panel is displayed relating to specific ICRF input parameters.
The panels appear in the following sequence:

```
------------------------ FALCON CONTROL SWITCHES ---------------------------
  MAIN CONTROL SWITCHES :
   ion energy balance switch ------------ 1     - nibbal
   el. energy balance switch ------------ 1     - nebbal
   current    balance switch ------------ 1     - ncurba
   momentum   balance switch ------------ 1     - nmomba
   stepsize used in output of arrays ---- 2     - noutp

  EXP. INPUT DATA SWITCHES :
   equilibrium source ------------------- 2     0     - nequil,ndvldt
   ppf switch 2 ------------------------- 3     0     - nxte,ntemap
   ppf switch 4 ------------------------- 5     - nxne
   ppf switch 5 ------------------------- 0     - nxti
   zeff switch  ------------------------- 1     - nxzef
   radiation switch --------------------- 0     - nxprad
   plasma rot. vel. switch -------------- 0     - nxangv
   consistency checks on exp. data  ----- 0     - nconsi

  PHYSICS MODELLING SWITCHES :
   ohmic package ------------------------ 2     1     - nohmic,nresis
   NBI modelling / ICRF modelling  ------ 1     1     - nnbi, nicrf
   neutral modelling -------------------- 1     - nneutr
```

Figure 6.2 - First submission panel

```
--------------------------- FALCON PARAMETERS ----------------------------

   Atomic mass of main ions ------------- 02.00  - am
   Atomic charge of main ions ----------- 01.00  - zp
   Minority species --------------------- 1       - kminio
   Rel. minority conc. (nmin/ne) -------- 00.05  - conmin
   Impurity charge number --------------- 06.00  - zi
   start radius(Te) for extrapolation --- 04.00  - rxtrap
   parm. used in calculation of Ti ------ 01.00  - ammag
   Coeffs. for ZEFF profile ------------- 00.00  00.00   - czeff1,czeff2
   parms. used in calculation of Prad --- 00.80  00.20 - rhorad,wrad
   Coeff. for particle pinch velocity --- 00.50  - alfinw


  DT FOR TIME SMOOTHING :
                        (NB: if dt=0.0, corresponding time derivatives
                             are set to zero in FALCON)
               te ---- 0.5000          ti ---- 0.5000
               ne ---- 0.5000        zeff ---- 0.5000
             prad ---- 0.5000        angv ---- 0.5000
          scalars ---- 0.5000
```

Figure 6.3 - Second submission panel

To proceed from one panel to the next the **< ENTER >** key should be pressed. Pressing the PF3 key returns the user to the previous panel. Continuous pressing of this key returns the user to ISPF option 6 without submitting FALCON. *The < ATTN > key should never be pressed.* The correct formats for all the panel input fields are shown in the accompanying figures.

On the FALCON JOB SUBMISSION panel pulse number and time slices to be analyzed can be entered. The user has the choice of inputting *discrete, arbitrarily spaced time slices* or *a combination of first time slice, last time slice and time interval between time slices.* If values are entered for both options then the latter option is the one which FALCON uses.

If an invalid format is used when entering a variable on a panel then a warning message is displayed in the top right corner after the < ENTER > key is pressed. The user cannot proceed to the next panel until this error is corrected.

If the option **AUTO** is chosen when executing FALCON, then only the FALCON JOB SUBMISSION panel is displayed and if the option **FILE(name1)** is chosen then all the panels except this one are displayed. Using both these two options results in no panels being displayed, and the batch job is submitted as soon as the commands are entered.

Input switches and parameters appearing in the submission panels are described below :

(*) indicates switches that may have associated input parameters

```
                FALCON CONTROL SWITCHES
                =======================

MAIN CONTROL SWITCHES

 nibbal = 0/1   ion       energy balance not computed/computed

 nebbal = 0/1   electron  energy balance not computed/computed

 ncurba = 0/1   current   energy balance not computed/computed

 nmomba = 0/1   momentum  energy balance not computed/computed

 noutp  = 0     no formatted output
          n > 0    formatted output - results printed every n mesh  points
```

```
PHYSICS MODELLING SWITCHES

   nohmic = 0     current density computed from flux map in FALCON
            1     current density from IDENTC used
            2     current density from full resistive diffusion used

   nresis = 0/1   Spitzer/neoclassical resistivity used

   nnbi   = 0/1   NBI  module  off/on

(*) nicrf  = 0/1   ICRF module  off/on

   nneutr = 0/1   recycling neutral diffusion calculation  off/on
```

```
                FALCON PARAMETERS
                =================

   am       atomic mass (amu) of background ion species

   zp       atomic charge     of background ion species

   kminio   atomic mass (amu) of minority   ion species

   conmin   relative concentration of minority ion species (nmin/ne)

   zi       atomic charge     of impurity   ion species


   rxtrap   midplane R beyond which Te is to be linearly extrapolated

   ammag    exponent that determines the shape of Ti relative to Te :
            Ti(rho)/Ti0 = ( Te(rho)/Te0 ) ** ammag
            --> only if Ti-profile is not available

   czeff1   parameters that determine the shape of Zeff-profile :
   czeff2      Zeff(rho) = Z'* exp(- (rho-czeff2)**2/czeff1**2 )
            Z' is such that line-averaged Zeff matches visible Brems-
            strahlung measurement.
            --> only if Zeff-profile is not available and czeff1.ne.0
            ( if czeff1=0. , radially uniform Zeff is assumed )

   rhorad   parameters that determine the shape of Prad-profile :
   wrad      Prad(rho) = P'* (0.1 + exp(- (rho-rhorad)**2/wrad**2 ) )
            P' is such that volume integral of Prad matches BOLO.TOPO
            --> only if Prad-profile is not available  ( nxprad=3 )

   alfinw   coefficient for particle pinch velocity


   dtTe,dtTi,dtne    time smoothing intervals (sec) for input data
   dtZeff,dtPrad     acquisition and evaluation of time derivatives
   dtangv,dtscal     (Te,Ti,ne,Zeff,Prad,angular velocity and scalar
                      parameters (Vloop etc) respectively)
```

6.4 *Default Setting Of Switches And Input Parameters*

The following default values are assigned to input switches and parameters if the AUTO option is chosen:

```
CONTROL SWITCHES
nibbal - 1      nebbal - 1      ncurba - 1      nmomba - 0
noutp  - 0      nequil - 2      ndvldt - 0      nxte   - 0
ntemap - 0      nxne   - 0      nxti   - 0      nxzef  - 0
nxprad - 0      nxangv - 0      nconsi - 1      nohmic - 2
nresis - 1      nnbi   - 1      nicrf  - 0      nneutr - 1

INPUT PARAMETERS
am     - 02.00      zp     - 01.00      kminio - 1
conmin - 00.03      zi     - 07.00      rxtrap - 00.00
ammag  - 01.00      czeff1 - 00.00      czeff2 - 00.00
rhorad - 00.90      wrad   - 00.10      alfinw - 01.00

ICRF PARAMETERS
naconf(1:8) - 0     tmin0  - 10.00      rfpeff - 01.00
```

```
-------------------- MAIN SELECTION PANEL FOR FALCON PLOTS --------------------

 Select and press ENTER:

                    PPF UID ===> JETBHO        blank - Public PPF

                PPF SEQ NO ===> 0              0     - Latest


                      SHOT ===> 19739

                      TIME ===> 50.00          blank - List available

         CONTROL FILE MEMBER ===> PFALC



          *** No. of Shot-times currently selected:  0      ***

         PF3:  Quit and submit            PF4:  Quit without submit
```

Figure 6.6

```
------------------------------ TIME POINT TABLE -----------------  ROW 1 OF 1
COMMAND ===>                                                  SCROLL ===> CSR

 The following time points are available in FALC for

                          PPF UID: JETBHO
                             SHOT: 19739
                           SEQ NO: 0

--------------------------------------------------------------------------------

 Select required time points with  S

      46.50
      50.00
****************************** BOTTOM OF DATA  ********************************
```

Figure 6.7

```
//*********************************************************************/
//*                                                                   */
//* JCL TO COMPILE AND LINK  play  ROUTINES FOR THE FALCON CODE       */
//*                                                                   */
//*********************************************************************/
//*
//  JOB  (,),'JETuid',MSGCLASS=X,TIME=(1),PRTY=7,
//       MSGLEVEL=(1,1),NOTIFY=JETuid
/*JOBPARM  LINECT=64,L=100
/*ROUTE PRINT RM8
/*JOBPARM POINT=9
//*
//*
// EXEC F77CL,PRINT=X,FTN=77,
//    PARM.C='LC(60),LANGLVL(77),X,NOMAP,NOSF,NOSRCFLG,ICA',
//    REGION.C=1500K,
//    PARM.L='LET,LIST,MAP,NOXREF,ICA'
//C.SYSLIB   DD  DSN=JETBHO.FALCOM.FORT,DISP=SHR
//C.SYSIN    DD  DSN=JETuid.falcupd.fort(play),DISP=SHR
//L.SYSLIB   DD
//           DD DSN=SYS1.VSF2FORT,DISP=SHR
//           DD DSN=JETSPN.F.LOAD,DISP=SHR
//           DD DSN=JETLIB.PPFLIB.LOAD,DISP=SHR
//           DD DSN=JETLIB.LIB.LOAD,DISP=SHR
//           DD DSN=SYS6.HSL.LOADV,DISP=SHR
//           DD DSN=SYS6.NAG.D12.LOADV,DISP=SHR
//           DD DSN=SYS6.LOAD,DISP=SHR
//           DD DSN=SYS1.PPLIB,DISP=SHR
//           DD DSN=SYS1.ESVVLIB,DISP=SHR
//           DD DSN=SYS5.NOMAD2.DEFAULT.LOAD,DISP=SHR
//L.SYSLMOD  DD DSN=JETuid.falcon.load(name2),DISP=SHR
//L.SYSUT1   DD UNIT=TEMP,SPACE=(1024,(200,100))
//L.LOAD     DD DSN=JETBHO.FALCON.LOAD,DISP=SHR
//L.SYSIN    DD *
   ENTRY MAIN
   INCLUDE LOAD(RUN)
//*
```

Figure 6.8

7.2 *Future plans*

A number of developments are envisaged for FALCON in the foreseeable future :

- first of all, the *interface to JET experimental data* will have to be regularly updated, owing to the continuous evolution of JET diagnostics and data bank structure. Such changes will generally be transparent to the user, in that the standard FALCON load module will always contain the latest version of the input package.
  It is hoped, in fact, that a future rationalization of the JET data processing chain will make the FALCON data acquisition package much simpler than it presently is, and that all remaining inconsistencies will be eliminated in the process

- concerning the *selection of time slices* to be analyzed with FALCON for any given pulse, an interface is being prepared to the standard TIMESLICE program {24}, so that its output can be used optionally as an alternative to the present manual selection

- as soon as an on-line program for *consistency checks* become available, with results stored in PPFs, FALCON will be re-organized as to use such results as a filter for its input selection, and the built-in consistency check module will be eliminated

- concerning the *modelling of auxiliary heating*, there are plans to

  implement a version of PENCIL directly into the FALCON module, so as to allow an evaluation of NBI deposition profiles independent of that in PPFs - in particular, for the purpose of sensitivity studies and in order to remove inconsistencies in the data used as input for PENCIL and FALCON calculations

  introduce, conversely, the option of reading PPF data for ICRF deposition profiles (an on-line program is being installed as part of JET's processing chain), as an alternative to the internal ICRDEP calculation

  introduce a model for lower hybrid current drive, which should be available by the time the JET system becomes operational

- concerning the *interpretation of FALCON results*, more effort will be devoted to the understanding of the propagation of uncertainties across the code calculations, in the spirit of Appendix 9.4. For the purpose of statistical analysis of the results, an interface will be established between the FALCON database and SAS utilities available at JET

7.3 *Acknowledgments*

We wish to thank A Taroni, W M Stacey, W H Houlberg, G C Cordey, M L Watkins, M Keilhacker for useful discussions on physics issues relevant to the FALCON program.

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Last but not least, we thank S A Hutchinson and L A Hopkins for their substantial help during the preparation of this document.

{24} R Frost, *TED, the Time Slice Editor User Guide*, JET internal report DMG/PUD/004/05

9.1 *Detailed flowcharts of individual FALCON modules*

The following pages provide deatils of the function of each of the subroutines called in the various FALCON modules. The general flowchart of the code, reproduced below from Chapter 1, clarifies the role of each of the modules.

INPUT: pulse #(s) and time(s)

module	*function*	*COMMON blocks*	*testing routine*
XINPUT	read switches and input parameters acquire experimental data from PPFs	COMPRM,COMSWT COMEXP	PLAY1
EQUIL	mhd equilibrium reconstruction	CMGEOM	PLAY2
MAPROF	map exp profiles onto geometry	COMMAP	PLAY3
MODEL	ion density profiles auxiliary power deposition calculations neutral diffusion calculation	CMIOND COMBEA,CMICRF COMFRA	PLAY4
BALANC	particle, current, momentum, energy balances	COMELE,COMIBL COMOHM,COMMOM	PLAY5
CONCHK	consistency checks		PLAY6
OUTPUT	output local fluxes		PLAY7

OUTPUT: local fluxes

Figure 1

Modules called sequentially by FALCON's CONTROL routine.
The variables in each COMMON block are set exclusively within the corresponding module.
The *PLAY* routines, for use with the code in "testing" mode, are called at the end of each module (ie after the corresponding COMMON blocks have been filled).

module EQUIL

subroutine	*function*
INEQU	initialize (set to zero) COMMON variables
SWITIN	re-initialize switches (where appropriate)
MESHDF	define FALCON's radial mesh
EQSEL	select equilibrium data to be used
METRIC	calculate metric coefficients and flux surface averages
XLAO	construct radial labels for Lao-Hirshman representations (IDENTC and FAST)
CURDEN	construct toroidal current density profile
MAGPAR	evaluate magnetic parameters (q , ℓ_i , B_{pol})

Figure 3 - Flow chart for FALCON's module EQUIL

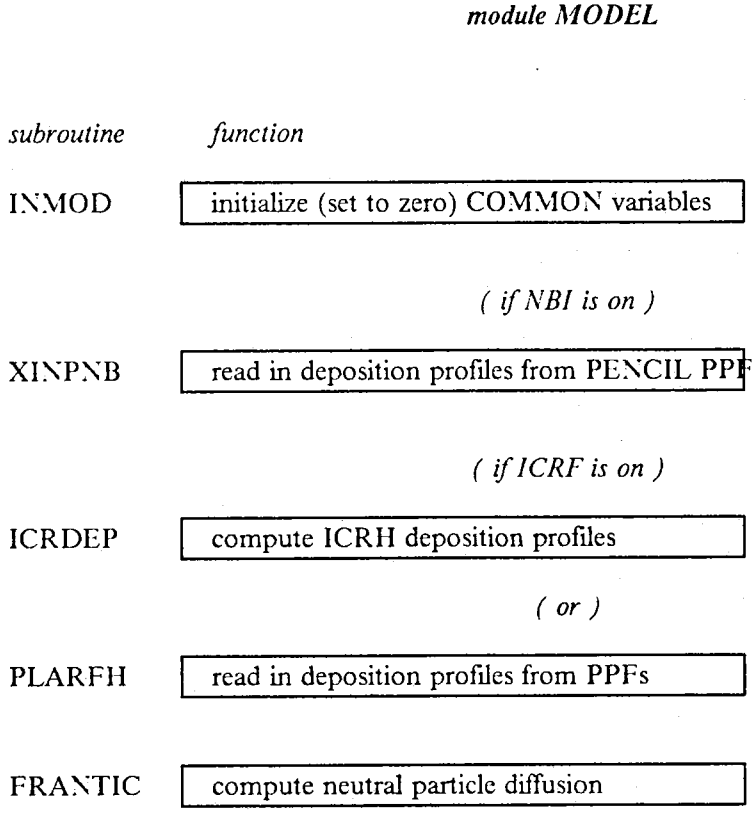


Figure 5 - Flow chart for FALCON's module MODEL

module OUTPUT

subroutine	*function*
NOMLOAD	create output dataset to load nomad database
FALCOUT	write output to FALCON.PRINT
PPFOUT	create *FALC* PPF containing FALCON results

Figure 7 - Flow chart for FALCON's module OUTPUT

9.2.1 COMMON blocks set in module XINPUT

Common include module : COMPRM

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : COMPRM (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define basic FALCON commons. Must be INCLUDED before any C
C            other INCLUDED common.                                   C
C                                                                     C
C---------------------------------------------------------------------C
C                                                                     C
C  The indices used here have the meaning:                            C
C                                                                     C
C         NTS   - Time point label                  (DIM = LI2)       C
C         NTOK  - Good time point label             (DIM = LI2)       C
C                                                                     C
C     COMMON / COMPRM / - Basic FALCON variables                      C
C                                                                     C
C  TSL   (NTS)   - Time points selected                               C
C  TSLOK (NTOK)  - Time points successfully processed                 C
C  DTPHA (NTS)   - Time interval to previous current phase "node"     C
C  ICRPHA(NTS)   - Time slice phase with respect to ICRF heating      C
C                  ( 0 = before , 1 = during , 2 = after heating )   C
C  NBIPHA(NTS)   - Time slice phase with respect to NBI  heating      C
C  ICMODE(NTS)   - Confinement mode flag                              C
C  MONST (NTS)   - Monster flag                                       C
C  PELLT (NTS)   - Last pellet time                                   C
C  NPELL (NTS)   - Number of previous pellets                         C
C  PELLS (NTS)   - Maximum pellet size                                C
C  PELLV (NTS)   - Maximum pellet speed                               C
C  PELLP (NTS)   - Maximum pellet penetration                         C
C  ISQPPF        - Seq. number of last written PPF                    C
C  NR            - Number of radial points in FALCON mesh             C
C  IREF          - Current shot number                                C
C  NTIME         - Total number of times selected for current shot    C
C  NTOK          - Number of current time slice successfully processed C
C  NTS           - Number of current time slice                       C
C  FILE          - Shot list processing flag                          C
C  AUTO          - Default switch setting flag                        C
C                                                                     C
C     COMMON / COMSIG / - Signal names for main FALCON data           C
C                                                                     C
C  CHTE          - List of signals for Te                             C
C  CHTI          - List of signals for Ti                             C
C  CHZEFF        - List of signals for Zeff                           C
C  CHANGV        - List of signals for Angv                           C
C  CHPRAD        - List of signals for Prad                           C
C  CHNEX         - )                                                  C
C  CHNE          - ) List of signals for ne                           C
C  CHNFT         - )                                                  C
C                                                                     C
C     COMMON / CONST /  - Frequently used constants                   C
C                                                                     C
C  PAI / TWOPAI  - pi / 2*pi                                          C
C  ECHRG         - Electron charge (C)                                C
C  POWLIM        - Heating phase on threshold (W)                     C
C  LAMBDA        - Coefficient for convective heat flux (5/2)         C
C                                                                     C
C     COMMON / RWORK /  - Work space                                  C
C                                                                     C
C  RWORK(...)    - Work space                                         C
C                                                                     C
C*********************************************************************C
C
C Basic array dimensions
C ======================
C
      PARAMETER (LI1  = 21)
      PARAMETER (LI2  = 20)
      PARAMETER (NV   = 100)
      PARAMETER (NS   = 1)
      PARAMETER (LBUF = 38000)
C
C Basic FALCON variables
C ======================
C
      COMMON / COMPRM /
     R    TSL     , TSLOK  , DTPHA  ,
     R    PELLT   , PELLS  , PELLV  , PELLP   ,
     I    NBIPHA  , ICRPHA , ICMODE , MONST   ,  NPELL ,
     I    ISQPPF  , NR     , IREF   , NTIME   ,  NTOK  ,  NTS   ,
     L    FILE    , AUTO
C
      DIMENSION
     R    TSL   (LI2)  ,  TSLOK (LI2)  ,  DTPHA (LI2)  ,
     R    PELLT (LI2)  ,  PELLS (LI2)  ,
     R    PELLV (LI2)  ,  PELLP (LI2)  ,
     I    NBIPHA(LI2)  ,  ICRPHA(LI2)  ,
     I    ICMODE(LI2)  ,  MONST (LI2)  ,  NPELL (LI2)
C
      LOGICAL FILE  ,  AUTO
C
C Signal names for main FALCON data
C =================================
C
      PARAMETER (LTE  = 3)
      PARAMETER (LTI  = 7)
      PARAMETER (LNE  = 5)
      PARAMETER (LPR  = 3)
      PARAMETER (LZF  = 6)
      PARAMETER (LAV  = 4)
C
      COMMON / COMSIG /
     C    CHTE    , CHTI    , CHZEFF  , CHANGV  ,
```

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : COMSWT (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define common associated with control switches           C
C                                                                     C
C-------------------------------------------------------------------C
C                                                                     C
C     COMMON / COMSWT / - Control switches                            C
C                                                                     C
C  NCURBA         - Current         balance off/on switch           C
C  NMOMBA         - Momentum        balance off/on switch           C
C  NOUTP          - Formatted output every NOUTP th radial point    C
C  NLOAD          - PPF/Nomad load  control        switch           C
C  NEQUIL         - Equilibrium source switch                       C
C  NDVLDT         - dV/dt effects off/on switch                     C
C  NXTE           - Electron temperature source switch              C
C  NTEMAP         - Electron temperature mapping off/on switch      C
C  NXNE           - Electron density source switch                  C
C  NXTI           - Ion temperature source switch                   C
C  NXZEFF         - Zeff source switch                              C
C  NXPRAD         - Radiation source switch                         C
C  NXANGV         - Tor. ang. velocity source switch                C
C  NCONSI         - Consistency checks off/on switch                C
C  NOHMIC         - Ohmic power modelling switch                    C
C  NRESIS         - Resistivity modelling switch                    C
C  NNBI           - Neutral beam modelling off/on switch            C
C  NICRF          - ICRF modelling off/on switch                    C
C  NNEUTR         - Neutral recycling modelling off/on switch       C
C  INCURBA                                                          C
C    to           -   Values of above switches at input             C
C  INNEUTR                                                          C
C  ITLMAP         - LIDAR temperature mapping switch                C
C  INLMAP         - LIDAR density     mapping switch                C
C  IDCDDA         - PPF source ('IDC1','IDC2',..) available         C
C                                                                     C
C*********************************************************************C
C
C
C Common associated with control switches
C ========================================
C
      COMMON / COMSWT /
     I    NCURBA  ,  NMOMBA  ,  NOUTP   ,  NLOAD   ,
     I    NEQUIL  ,  NDVLDT  ,  NXTE    ,  NTEMAP  ,
     I    NXNE    ,  NXTI    ,  NXZEFF  ,  NXPRAD  ,
     I    NXANGV  ,  NCONSI  ,  NOHMIC  ,  NRESIS  ,
     I    NNBI    ,  NICRF   ,  NNEUTR  ,
     I    INCURBA ,  INMOMBA ,  INOUTP  ,
     I    INEQUIL ,  INXTE   ,  INTEMAP ,
     I    INXNE   ,  INXTI   ,  INXZEFF ,  INXPRAD ,
     I    INXANGV ,  INCONSI ,  INOHMIC ,  INRESIS ,
     I    INNBI   ,  INICRF  ,  INNEUTR ,
     I    ITLMAP  ,  INLMAP  ,
     C    IDCDDA
C
      CHARACTER*4 IDCDDA
```

```
C  XZEFF (K,NTS,M)- Zeff profile                                          C
C  XRZEFF(K,NTS,M)- Zeff x vector                                         C
C  XPRAD (K,NTS,M)- Radiation profile                                     C
C  XRPRAD(K,NTS,M)- Radiation x vector                                    C
C  XANGV (K,NTS,M)- Toroidal angular frequency profile                    C
C  XRANGV(K,NTS,M)- Toroidal angular frequency x vector                   C
C  PSCXSM(K,NTS)  - Psi vector for CXSM data                              C
C  PSCXS4(K,NTS)  - Psi vector for CXS4 data                              C
C  XETLID(K,NTS)  - Error on Te(LIDAR)      ( Max(TEU-TE,TE-TEL) )        C
C  XEDLID(K,NTS)  - Error on ne(LIDAR)      ( Max(NEU-NE,NE-NEL) )        C
C  XCHLID(K,NTS)  - Chi**2 for LIDAR fit                                  C
C  XETCXM(K,NTS)  - Error on Ti(CXSM)       ( Max(TIU-TI,TI-TIL) )        C
C  XETCX4(K,NTS)  - Error on Ti(CXS4)       ( Max(TIU-TI,TI-TIL) )        C
C  XEACXM(K,NTS)  - Error on Av(CXSM)       ( Max(AVU-AV,AV-AVL) )        C
C  XEACX4(K,NTS)  - Error on Av(CXS4)       ( Max(AVU-AV,AV-AVL) )        C
C  TIOHCX(K)      - First Ti-profile measured by CXRS                     C
C  ETOHCX(K)      - Error on TIOHCX                                       C
C  RHTOCX(K)      - rho-grid corresponding to TIOHCX                      C
C  ZFOHCX(K)      - First Zeff-profile measured by CXRS                   C
C  RHZOCX(K)      - rho-grid corresponding to ZFOHCX                      C
C                                                                         C
C     COMMON / COMNMR / - # of points in input data arrays                C
C                                                                         C
C  NUMIDC         - Number of radial points in selected IDENTC profs.     C
C  NPSI           - Number of radial points in PPF IDENTC profiles        C
C  NRTOCX         - # of (non-zero) radial points in TIOHCX               C
C  NRZOCX         - # of (non-zero) radial points in ZFOHCX               C
C  NUMRTE(NTS,M)  - Number of raw data points in el. temp. profile        C
C  NUMRNE(NTS,M)  - Number of raw data points in el. dens. profile        C
C  NUMRTI(NTS,M)  - Number of raw data points in ion temp. profile        C
C  NUMRZF(NTS,M)  - Number of raw data points in Zeff    profile          C
C  NUMRPR(NTS,M)  - Number of raw data points in radiation profile        C
C  NUMRAV(NTS,M)  - Number of raw data points in ang freq profile         C
C  NRCXSM(NTS)    - Number of raw data points in CXSM psi                 C
C  NRCXS4(NTS)    - Number of raw data points in CXS4 psi                 C
C                                                                         C
C     COMMON / COMDDT / - Time derivatives of input expt data             C
C                                                                         C
C  XDTEDT(K,NTS,M)- d(XTE   )/dt                                          C
C  XDNEDT(K,NTS,M)- d(XNE   )/dt                                          C
C  XDTIDT(K,NTS,M)- d(XTI   )/dt                                          C
C  XDZFDT(K,NTS,M)- d(XZEF  )/dt                                          C
C  XDAVDT(K,NTS,M)- d(XANGV )/dt                                          C
C                                                                         C
C*************************************************************************C
C
C Common associated with input parameters
C ========================================
C
      COMMON / COMINP /
     R    AMAIN   , ZMAIN   , AMINO   , ZMINO   , CONMIN  ,
     R    AIMPU   , ZIMPU   , AFAST   , ZFAST   ,
     R    RXTRAP  , AMMAG   , CZEFF1  , CZEFF2  ,
     R    RHORAD  , WRAD    , ALFINW  ,
     R    DTTE    , DTTI    , DTNE    , DTZEFF  ,
     R    DTPRAD  , DTANGV  , DTSCAL  , DTICRF  , DTNBI
C
C Common associated with input scalar data
C =========================================
C
      COMMON / COMISC /
     R    CURR    , BTMAG   , BTMADT  , YOHMG2  ,
     R    VSU     , VSUDT   , VAX     , XLIMG2  ,
     R    WPMG3   , WPDMG3  , DWMHDT  , DWDIDT  ,
     R    TUCMG2  , TAUMG3  ,
     R    DENAV   , RAXLAO  , ROLAO   , RHOLAO  ,
     R    ELAO    , R2LAO   , BTIMG2  , AVLNEX  ,
     R    DNEXDT  , EC2TVL  , DTVLDT  , YTOKIN  ,
     R    HALTAU  , HALFLL  , HALFLW  , HALREC  ,
     R    TINRDD  , POWNIH  , PNB080  , PNB140  ,
     R    PWNIDT  , GASNBI  , PINIen  , PINIpw  ,
     R    POWLHC  , POWRFH  , PWRFDT  , AFREQ   , ARFPOW  ,
     R    CR0IDC  , EFLIDC  , XLIIDC  , WPIDC   , WIDCDT  ,
     I    NACONF(8)
C
      DIMENSION
     R    CURR   (LI2)  , YOHMG2 (LI2) , BTMAG  (LI2) , BTMADT (LI2) ,
     R    VSU    (LI2)  , VSUDT  (LI2) , VAX    (LI2) , XLIMG2 (LI2) ,
     R    WPMG3  (LI2)  , WPDMG3 (LI2) , DWMHDT (LI2) , DWDIDT (LI2) ,
     R    TUCMG2 (LI2)  , TAUMG3 (LI2) ,
     R    DENAV  (LI2)  , RAXLAO (LI2) , ROLAO  (LI2) , RHOLAO (LI2) ,
     R    ELAO   (LI2)  , R2LAO  (LI2) , BTIMG2 (LI2) , AVLNEX (LI2) ,
     R    DNEXDT (LI2)  , EC2TVL (LI2) , DTVLDT (LI2) , YTOKIN (LI2) ,
     R    HALTAU (LI2)  , HALFLL (LI2) , HALFLW (LI2) , HALREC (LI2) ,
     R    TINRDD (LI2)  , POWNIH (LI2) , PNB080 (LI2) , PNB140 (LI2) ,
     R    GASNBI (2)    , PINIen (16,LI2)  , PINIpw (16,LI2) ,
     R    PWNIDT (LI2)  , POWLHC (LI2) ,
     R    POWRFH (LI2)  , PWRFDT (LI2) , AFREQ (8,LI2) ,
     R    ARFPOW (8,LI2), CR0IDC (LI2) , EFLIDC (LI2) , XLIIDC (LI2) ,
     R    WPIDC  (LI2)  , WIDCDT (LI2)
C
C Commons associated with input profile data
C ===========================================
C
      COMMON / COMIPR /
     R    AEIDC   , AR2IDC  , AR0IDC  ,
     R    AXNIDC  , XTE     , XRTE    ,
     R    XNE     , XRNE    , XTI     ,
     R    XRTI    , XZEFF   , XRZEFF  , XPRAD   ,
     R    XRPRAD  , XANGV   , XRANGV  , PSCXSM  ,
     R    PSCXS4  , XETLID  , XEDLID  , XCHLID  ,
     R    XETCXM  , XETCX4  , XEACXM  , XEACX4  ,
     R    TIOHCX  , ETOHCX  , RHTOCX  , ZFOHCX  ,
     R    RHZOCX
C
      DIMENSION
     R    AEIDC (NV,LI2)     , AR2IDC(NV,LI2)     ,
     R    AR0IDC(NV,LI2)     , AXNIDC(NV)         ,
     R    XTE   (NV,LI2,LTE) , XRTE  (NV,LI2,LTE) ,
     R    XNE   (NV,LI2,LNE) , XRNE  (NV,LI2,LNE) ,
```

9.2.2 COMMON blocks set in module EQUIL

Common include module : CMGEOM

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : CMGEOM (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define commons associated with EQUILIBRIUM package       C
C                                                                     C
C-------------------------------------------------------------------C
C                                                                     C
C  The indices used here have the meaning:                            C
C                                                                     C
C         I      - Flux surface rad. coordinate label (DIM = LI1)     C
C         K      - Expt. radial coordinate label      (DIM = NV)      C
C         ITH    - Flux surface pol. coordinate label (DIM = NPTHMX)  C
C                                                                     C
C     COMMON / CMGEOM / - Main geometry common                        C
C                                                                     C
C  RMINOR         - Minor radius = AVRAD of last surface (m)         C
C  ROMA           - R coord. of magnetic axis (m)                    C
C  ZOMA           - Z coord. of magnetic axis (m)                    C
C  ELONG          - Elongation from IDENTC                           C
C  BTOR           - Btot at magnetic axis (=BTOT(1))                 C
C  SHASHI         - Shafranov shift (ROMA - 2.96m) (m)               C
C  INTIND         - Internal inductance                              C
C  PSIB           - Unnormalised psi of boundary (Wb)                C
C  PSI0           - Unnormalised psi of magnetic axis (Wb)           C
C  PSI0(B)DT      - d(PSI0(B))/dt (Wb/s)                             C
C  DELPSI         - Unnormalised psi range/2/pi (Wb)                 C
C  QAXIS          - Safety factor on axis from IDENTC                C
C  QWALL          - Safety factor at edge from IDENTC                C
C  BTN            - Beta parameter in J phi from IDENTC              C
C  LMB            - Lambda parameter in J phi from IDENTC            C
C  AN  (2)        - AN coefficients  in J phi from IDENTC            C
C  BN  (2)        - BN coefficients  in J phi FROM IDENTC            C
C  RHO   (I)      - Falcon flux surface coord = SQRT(normalised psi) C
C  DRHO  (I)      - Rho backward difference                          C
C  AVRAD (I)      - Equivalent cylindrical radius (m)                C
C  RMAJL (I)      - R in equatorial plane to left  of mag. axis  (m) C
C  RMAJR (I)      - R in equatorial plane to right of mag. axis  (m) C
C  DAREA (I)      - differential area (m**2)                         C
C  TAREA (I)      - integrated   area (m**2)                         C
C  DVOL  (I)      - differential volume (m**3)                       C
C  VOLUM (I)      - integrated   volume (m**3)                       C
C  ASPRAT(I)      - <Inverse aspect ratio>                           C
C  EPS112,32,34   - <Inverse aspect ratio ** 1/2 , 3/2 , 3/4 >       C
C  ROONR2(I)      - < (ROMA/R)**2 >                                  C
C  ROONR (I)      - < ROMA/R >                                       C
C  AOFRHO(I)      - Area of flux tube (m**2)                         C
C  VPRIME(I)      - dV/drho (m**3)                                   C
C  DJACDT(I)      - (1./VPRIME)*d(VPRIME)/dt (1/s)                   C
C  GRDRO2(I)      - < gradrho**2 > (1/m**2)                          C
C  G22SQG(I)      - VPRIME*G22G                                      C
C  RTG22G(I)      - < sqrt(g22/g) > ( g - covariant metric tensor )  C
C  G22G  (I)      - < g22/g >                                        C
C  RINV2 (I)      - < 1/R**2 > (1/m**2)                              C
C  RAV   (I)      - < R >      (m)                                   C
C  R2AV  (I)      - < R**2 >   (m**2)                                C
C  R2AVDT(I)      - d(< R**2 >)/dt  (m**2/s)                         C
C  R2G11 (I)      - < R**2*ginv11 > ( ginv-contravariant metric tensor )C
C  BAV   (I)      - < B >  (total B-field) (T)                       C
C  BINAV (I)      - < 1/B >  (1/T)                                   C
C  B2AV  (I)      - < B**2 > (T**2)                                  C
C  BIN2AV(I)      - < 1/B**2 >  (1/T**2)                             C
C  B0ONB2(I)      - < B0/B**2 >  ( B0 - vacuum B-field at R0 )       C
C  BPOL  (I)      - < Bpol >    (T)                                  C
C  BPOL2 (I)      - < Bpol**2 > (T**2)                               C
C  PHITOR(I)      - Toroidal flux (Wb)                               C
C  PHIDOT(I)      - d(PHITOR)/dt  (Wb/s)                             C
C  QPSI  (I)      - d(PHITOR)/d(PSI) as computed in FALCON           C
C  PSIA  (I)      - Unnormalised psi (Wb)                            C
C                                                                     C
C  BTOT  (I)      - Btot profile in equatorial plane (right)  M      C
C  CDIDC (I)      - Current density profile                   A      C
C  QIDC  (I)      - Q profile                                 P       C
C  PIDC  (I)      - Pressure profile                          P       C
C  FIDC  (I)      - Paramagnetic function                     E       C
C  VIDC  (I)      - Loop voltage                              D       C
C  BZIDC (I)      - Bz profile in equatorial plane                    C
C  XLAOI (I)      - X Lao from IDENTC                                 C
C  EIDC  (I)      - Ellipticity function E                            C
C  R2IDC (I)      - Triangularity function R2                         C
C  ROIDC (I)      - Shift function R0                                 C
C  XLAOF (I)      - X Lao from FAST                                   C
C                                                                     C
C  ACDIDC(K)      - Current density profile (A/m**2)                  C
C  AQIDC (K)      - Q profile                                 R       C
C  APIDC (K)      - Pressure profile  (Pa)                    A       C
C  AFIDC (K)      - Paramagnetic function (T m)               W       C
C  AVIDC (K)      - Loop voltage          (V)                         C
C  APSIN (K)      - Psi (absolute) vector  (Wb)                       C
C                                                                     C
C  ICFIG          - Plasma configuration (1-Lim,2-IW,3-SN,4-DN)       C
C                                                                     C
C     COMMON / SURF /   - Flux surface points common; set by SURFLX   C
C                                                                     C
C  F     (ITH,I) - Distance from mag. axis                            C
C  THETA (.,.,.) - Poloidal angle                                     C
C  DFDRHO(.,.,.) - df/d(rho) at (f,theta)                             C
C  DFDTHE(.,.,.) - df/d(theta) at (f,theta)                           C
C  RC    (.,.,.) - R coordinate                                       C
C  ZC    (.,.,.) - Z coordinate                                       C
C  BR    (.,.,.) - R comp. of B field                                 C
C  BZ    (.,.,.) - Z comp. of B field                                 C
C  NPTH          - Number of poloidal points per surface              C
```

9.2.3 COMMON blocks set in module MAPROF

Common include module : COMMAP

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : COMMAP (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define commons associated with experimental data         C
C            mapped onto the FALCON mesh at a given time slice        C
C                                                                     C
C---------------------------------------------------------------------C
C                                                                     C
C  The indices used here have the meaning:                            C
C                                                                     C
C        K      - Expt. x-coordinate label          (DIM = NV)       C
C        I      - Flux surface rad. coordinate label (DIM = LI1)     C
C        M      - Diagnostic label                  (DIM = various)  C
C                                                                     C
C     COMMON / COMRHOs / - rho-vectors for raw input data             C
C                                                                     C
C  XRHOTE(K,M)   - rho-grid for input Te-data                         C
C  XRHOTI(K,M)   - rho-grid for input Ti-data                         C
C  XRHONE(K,M)   - rho-grid for input ne-data                         C
C  XRHOZF(K,M)   - rho-grid for input Zeff-data                       C
C  XRHOPR(K,M)   - rho-grid for input Prad-data                       C
C  XRHOAV(K,M)   - rho-grid for input omega-data                      C
C                                                                     C
C     COMMON / COMEXPF / - Data used by FALCON                        C
C                                                                     C
C  TELE  (I)     - Electron temperature profile                       C
C  DELE  (I)     - Electron density profile                           C
C  TION  (I)     - Ion temperature profile                            C
C  PRADD (I)     - Radiation density    profile                       C
C  XANGFR(I)     - Angular velocity     profile                       C
C  RHOION(I)     - Plasma mass profile                               C
C  ZEFF  (I)     - Zeff profile                                       C
C  PRFNEX(I)     - reconstructed ne-profile from NEX parameters       C
C  PNEXDT(I)     - reconstructed d/dt( ne ) from NEX parameters       C
C  PRFNFT(I)     - reconstructed ne-profile from NFT parameters       C
C  PNFTDT(I)     - reconstructed d/dt( ne ) from NFT parameters       C
C                                                                     C
C     COMMON / COMDDTF / - Time derivatives of FALCON data            C
C                                                                     C
C  DTEDT (I)     - d(TELE  )/dt                                       C
C  DNEDT (I)     - d(DELE  )/dt                                       C
C  DTIDT (I)     - d(TION  )/dt                                       C
C  DZFDT(I)      - d(ZEFF  )/dt                                       C
C  DAVDT (I)     - d(XANGFR)/dt                                       C
C                                                                     C
C*********************************************************************C
C
C
C Common associated with rho-grids
C ================================
C
      COMMON / COMRHOs /
     R    XRHOTE  ,  XRHOTI  ,  XRHONE  ,
     R    XRHOZF  ,  XRHOPR  ,  XRHOAV
C
      DIMENSION
     R    XRHOTE(NV,LTE),   XRHOTI(NV,LTI),   XRHONE(NV,LNE),
     R    XRHOZF(NV,LZF),   XRHOPR(NV,LPR),   XRHOAV(NV,LAV)
C
C
C Common associated with data used by FALCON
C ==========================================
C
      COMMON / COMEXPF /
     R    TELE    ,  DELE    ,  TION    ,  PRADD   ,
     R    XANGFR  ,  ZEFF    ,
     R    PRFNEX  ,  PNEXDT  ,  PRFNFT  ,  PNFTDT
C
      DIMENSION
     R    TELE  (LI1),  DELE  (LI1),  TION  (LI1),  PRADD (LI1),
     R    XANGFR(LI1),  ZEFF  (LI1),
     R    PRFNEX(LI1),  PNEXDT(LI1),  PRFNFT(LI1),  PNFTDT(LI1)
C
C
C Time derivatives of data used by FALCON
C =======================================
C
      COMMON / COMDDTF /
     R    DTEDT   ,  DNEDT   ,  DTIDT   ,  DZFDT   ,  DAVDT
C
      DIMENSION
     R    DTEDT(LI1), DNEDT(LI1), DTIDT(LI1), DZFDT(LI1), DAVDT(LI1)
```

Common include module : COMBEA

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : COMBEA (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define FALCON common associated with NB power deposition C
C                                                                     C
C-------------------------------------------------------------------C
C                                                                     C
C  The indices used here have the meaning:                            C
C                                                                     C
C         I      - Flux surface rad. coordinate label (DIM = LI1)     C
C                                                                     C
C     COMMON / COMBEA / - Neutral beam data from PENCIL               C
C                                                                     C
C  YBNS           - Beam-plasma D-D neutron production rate (s-1)     C
C  YPNS           - Plasma-plasma D-D neutron production rate (s-1)   C
C  PSBEAM(I)      - < Electron source rate >  (flux surf aver) (1/m**3) C
C  CURBEA(I)      - < Beam induced current >  (A/m**2)                C
C  WPEBEA(I)      - < Perp. energy density of fast ions >    (Jm-3)   C
C  WPABEA(I)      - < Parallel energy density of fast ions > (Jm-3)   C
C  WPEDOT(I)      - d/dt < Perp. energy density of fast ions > (Wm-3) C
C  WPADOT(I)      - d/dt < Para. energy density of fast ions > (Wm-3) C
C  WFNB  (I)      - Wfast from NBI (J)                                C
C  WFNBDT(I)      - d (Wfast from NBI) / dt  (W)                      C
C  YBNBEA(I)      - <   Beam-plasma D-D neutron emissivity >  (m-3 s-1) C
C  YPNBEA(I)      - < Plasma-plasma D-D neutron emissivity >  (m-3 s-1) C
C  MOMELE(I)      - Momentum input to electrons from beams   (N/m**2)  C
C  MOMION(I)      - Momentum input to ions      from beams   (N/m**2)  C
C  PNBIED(I)      - Power density deposited on electrons     (W/m**3)  C
C  PNBIID(I)      - Power density deposited on ions          (W/m**3)  C
C  PNBIE (I)      - Integrated power deposited on electrons  (W)       C
C  PNBII (I)      - Integrated power deposited on ions       (W)       C
C                                                                     C
C*********************************************************************C
C
C
C Neutral beam related data from PENCIL
C ====================================
C
      COMMON / COMBEA /
     R    YBNS    , YPNS    , PSBEAM  , CURBEA  ,
     R    WPEBEA  , WPABEA  , WPEDOT  , WPADOT  ,
     R    WFNB    , WFNBDT  ,
     R    YBNBEA  , YPNBEA  , MOMELE  , MOMION  ,
     R    PNBIED  , PNBIID  , PNBIE   , PNBII
C
       DIMENSION
     R    PSBEAM(LI1)     , CURBEA(LI1)     ,
     R    WPEBEA(LI1)     , WPABEA(LI1)     ,
     R    WPEDOT(LI1)     , WPADOT(LI1)     ,
     R    WFNB  (LI1)     , WFNBDT(LI1)     ,
     R    YBNBEA(LI1)     , YPNBEA(LI1)     ,
     R    MOMELE(LI1)     , MOMION(LI1)     ,
     R    PNBIED(LI1)     , PNBIID(LI1)     ,
     R    PNBIE (LI1)     , PNBII (LI1)
C
       REAL
     R    MOMELE  , MOMION
```

Common include module : CMICRF

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : CMICRF (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define FALCON common associated with RF power deposition C
C                                                                     C
C-------------------------------------------------------------------C
C                                                                     C
C  The indices used here have the meaning:                            C
C                                                                     C
C         I      - Flux surface rad. coordinate label (DIM = LI1)     C
C         NTW    - Tor wave number index              (DIM = 0:100)   C
C                                                                     C
C     COMMON / CMICRF / - ICRDEP results                              C
C                                                                     C
C  WFRF  (I)      - Total fast ion energy (Stix) (J)                  C
C  WF2H  (I)      - Fast ion energy from 2nd-harm heating (J)         C
C  WFRFDT(I)      - d(Fast ion energy (Stix))/dt   (W)                C
C  PRFED (I)      - RF power density deposited on electrons  (W/m**3) C
C  PRFID (I)      - RF power density deposited on ions       (W/m**3) C
C  P2HD  (I)      - 2nd harm RF power dens deposited on ions (W/m**3) C
C  RRICRF(I)      - Non-thermal reaction rate from ICRF (sec-1)       C
C  SPECTT(NTW)    - RF antenna spectrum (NTW = tor wave #  0:100)     C
C  PRFE  (I)      - Integrated RF power depos. profile on electrons (W) C
C  PRFI  (I)      - Integrated RF power depos. profile on ions (W)    C
C                                                                     C
C*********************************************************************C
C
C
C ICRDEP results
C ==============
C
      COMMON / CMICRF /
     R    WFRF    , WF2H    , WFRFDT  , PRFED   , PRFID   ,
     R    P2HD    , RRICRF  , SPECTT  , PRFE    , PRFI
C
       DIMENSION
     R    WFRF(LI1), WF2H  (LI1), WFRFDT (LI1), PRFED(LI1), PRFID(LI1),
     R    P2HD(LI1), RRICRF(LI1), SPECTT(0:100),PRFE (LI1), PRFI (LI1)
```

Common include module : COMOHM

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : COMOHM (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define FALCON commons associated current balance.        C
C                                                                     C
C---------------------------------------------------------------------C
C                                                                     C
C  The indices used here have the meaning:                            C
C                                                                     C
C         I      - Flux surface rad. coordinate label (DIM = LI1)     C
C                                                                     C
C     COMMON / COMOHM / - Current balance results                     C
C                                                                     C
C  EFIELD(I)     - < Toroidal electric field (resistive) >           C
C  CURPHI(I)     - < Interp. toroidal current density >              C
C  CPARAB(I)     - < Interp. current density*magnetic field >        C
C  EPARAB(I)     - < Interp. electrical field*magnetic filed >       C
C  CRBOOT(I)     - < Pred. bootstrap current density*magnetic field > C
C  TCBOOT        - Pred. total bootstrap current                     C
C  CBEAM (I)     - < Pred. beam induced current density*mag. field > C
C  TCBEAM        - Pred. total beam induced current.                 C
C  RESTCD(I)     - < Resistive current density >                     C
C  COULOG(I)     - Coulomb logarithm                                 C
C  RESIST(I)     - Pred. electrical resistivity                      C
C  ETANEO(I)     - Neoclassical resistivity                          C
C  ETASPI(I)     - Spitzer resistivity                               C
C  STARNU(I)     - electron collisionality parameter nu*e            C
C  FNUEE (I)     - e-e collision frequency (s-1)                     C
C  FTRAP (I)     - fraction of trapped particles                     C
C  VLOOP (I)     - Loop voltage (resistive)                          C
C                                                                     C
C*********************************************************************C
C
C
      COMMON / COMOHM /
     R    EFIELD  ,  CURPHI  ,  CPARAB  ,  EPARAB  ,
     R    CRBOOT  ,  TCBOOT  ,  CBEAM   ,  TCBEAM  ,
     R    RESTCD  ,  COULOG  ,
     R    RESIST  ,  ETANEO  ,  ETASPI  ,  STARNU  ,
     R    FNUEE   ,  FTRAP   ,  VLOOP
C
      DIMENSION
     R    EFIELD(LI1),  CURPHI(LI1),  CPARAB(LI1),  EPARAB(LI1)    ,
     R    CRBOOT(LI1),  CBEAM (LI1),  RESTCD(LI1),  COULOG(LI1)    ,
     R    RESIST(LI1),  ETANEO(LI1),  ETASPI(LI1),  STARNU(LI1)    ,
     R    FNUEE (LI1),  FTRAP (LI1),  VLOOP (LI1)
```

Common include module : COMMOM

```
C
C*********************************************************************C
C                                                                     C
C   MODULE : COMMOM (INCLUDE)                                         C
C                                                                     C
C FUNCTION : Define FALCON commons associated with the momentum       C
C            balance.                                                 C
C                                                                     C
C---------------------------------------------------------------------C
C                                                                     C
C  The indices used here have the meaning:                            C
C                                                                     C
C         I      - Flux surface rad. coordinate label (DIM = LI1)     C
C                                                                     C
C     COMMON / COMMOM / - Momentum balance variables                  C
C                                                                     C
C  WROT  (I)     - (ion) rotational energy (J)                       C
C  WROTDT(I)     - d(WROT)/dt   (W)                                  C
C  MFLUX (I)     - Cross-field momentum flux  (N m)                  C
C  MSFLUX(I)     - Momentum flux due to perp viscosity only  (N m)   C
C  QVISC (I)     - (Ion) heat loss associated with momentum flux (W) C
C  TORMOM(I)     - Angular momentum density input rate (N/m2)        C
C  PENCTM(I)     - Same, as coming from PENCIL PPFs                  C
C  DIFMOM(I)     - Momentum diffusivity   (m2/s)                     C
C  PLAPOT(I)     - Plasma potential       (V)                        C
C  ANGMOM(I)     - Total angular momentum (N m s)                    C
C  ANGMDT(I)     - d/dt(Total angular momentum)  (N m)               C
C  RATMOM(I)     - Total angular momentum input rate  (N m)          C
C  TAUMOM(I)     - Global momentum confinement time   (s)            C
C                                                                     C
C*********************************************************************C
C
C
      COMMON / COMMOM /
     R    WROT    ,  WROTDT  ,
     R    MFLUX   ,  MSFLUX  ,  QVISC   ,
     R    TORMOM  ,  PENCTM  ,  DIFMOM  ,  PLAPOT  ,
     R    ANGMOM  ,  ANGMDT  ,  RATMOM  ,  TAUMOM
C
      DIMENSION
     R    WROT  (LI1),  WROTDT(LI1),
     R    MFLUX (LI1),  MSFLUX(LI1),  QVISC (LI1),
     R    TORMOM(LI1),  PENCTM(LI1),  DIFMOM(LI1),  PLAPOT(LI1),
     R    ANGMOM(LI1),  ANGMDT(LI1),  RATMOM(LI1),  TAUMOM(LI1)
C
      REAL
     R    MSFLUX  ,  MFLUX
```

9.4 *Errors on results / Sensitivity analysis*

The aim of FALCON is to create *a database of local fluxes inferred from JET experimental data,* based on detailed local transport analysis of (hundreds of) discharges.

This ambitious effort would remain pointless if reliable estimates of the uncertainty associated with FALCON's results were not available. Any interpretation of the code's results must take into account "error bars" on the inferred fluxes.

These are determined primarily by uncertainties in the experimental input data, and partly also to the physics modelling assumptions made when the code is run.

Multiple runs of FALCON - with variations of the input profiles and of other input parameters within the respective range of uncertainty - can of course allow an empirical determination of the sensitivity (spread in the results).

However, often it is not practical to run the code iteratively so many times as required by a proper sensitivity assessment.

Each user will then probe (somewhat subjectively) the space of possible parameter variations. This element of subjectivity will propagate to the general FALCON database, and may bias subsequent analyses.

As a first step towards a systematic and objective assessment of error bars on transport analysis results, we use the known simple dependence of the rate of energy equipartition between species (P_{e-i}) on the major plasma parameters, to assess *analytically* (within the database) the propagation of its uncertainty to the heat fluxes.

It is important to realize that in tokamak plasmas (particularly at medium/high density) P_{e-i} often plays a dominant role in determining the local energy fluxes (and thermal conductivities *a fortiori*), when one wants to study ion and electron transport separately.

Our exercise produces two *flags* labelling - *for any given pulse, time slice and radial position* - local electron and ion heat fluxes (Q_e , Q_i), and telling whether their separation is meaningful, in the light of the uncertainty on P_{e-i} .

Depending on the plasma regime, it may turn out that the inferred Q_e , Q_i are both dependable, or that only one of them is, or that both are unreliable. In the latter case, the only result that can be meaningfully interpreted is the *total* heat flux (local sum over electrons and ions).

Obviously, the heat fluxes are affected by other uncertainties, independent of P_{e-i} . Those are not so easily investigated analytically, and their assessment will remain, for the time being, limited to the more primitive (iterative) treatment.

As discussed in Section 3.4.2, the interspecies power transfer due to unequal temperatures is represented - following conventional collisional theory - by

$$P_{e-i}(\rho) = 7.63 \cdot 10^{-34}\, \ell n\, \Lambda_e\, [Z]\, n_e^{\,2}\, \frac{T_e - T_i}{T_e^{\,3/2}}$$

where *SI* units have been used with temperatures in eV , $\ell n\, \Lambda_e$ is the Coulomb logarithm and

$[Z] \equiv \frac{1}{n_e} \sum_{ions} \frac{n_j Z_j^2}{A_j}$ where Z and A are charge and mass number, respectively .

9.5 *Test case: "manual" run*

The following 15 pages contain a reproduction of the listed output in the standard file *'JETuid.FALCON.PRINT'* resulting from a "manual" run based on switches and parameters appearing in the submission panels reproduced in Section 6.3.

```
================================================
FALCON transport analysis for JET pulse #   19739
================================================

Time slice #     1  is  t =   46.500

Time slice #     2  is  t =   50.000
```

```
**********************************************
*  Time loop:   time slice # =  1   t = 46.500  *
**********************************************


Time slice checking routine
***************************

- WARNING(TSLCHK) : CXSM.PSI  is zero-valued --> CXSM data cannot be used for this time

- WARNING(TSLCHK) :   50 zero-valued data points eliminated for LIDRTE

- WARNING(TSLCHK) :   50 zero-valued data points eliminated for LIDRNE

- WARNING(TSLCHK) :   41 zero-valued data points eliminated for NEPRPRFL

- WARNING(TSLCHK) :    1 zero-valued data points eliminated for CXS1TI

- WARNING(TSLCHK) :   63 zero-valued data points eliminated for BRADPROF


Equilibrium reconstruction (EQUIL)
**********************************

------------------------------------------------------------------------

* FLUSH *  FOR PULSE NUMBER    :   19739
              TIME  REQUESTED :   46.500
              TIME  FOUND     :   46.235

  SPLINE APPROXIMATION USED
       NPX,NPY  =   19  19
       MX,MY    =   11  11  (INTERIOR KNOTS)
       NC       =  225      (NUMBER OF COEFFICIENTS)
       NPP      =  144
  WINDOW
       RW. (CM) =    153.600   448.100
       ZW. (CM) =   -231.450   231.450

  MAGNETIC AXIS
       XP0 (CM) =    308.000
       YP0 (CM) =      0.180
       FP0      =     -0.001
  BT         (G) =  31248.3
  DPSI      (WB) =      8.877
  SIGMA          =      0.00009
  IGO            =      5
  ERROR CODE     =      0

------------------------------------------------------------------------


- WARNING(EQSEL) : Time derivatives of equilibrium quantities set to zero
                   as previous FALCON equilibrium time point is too far

* FLUPX *  NO X-POINT FOUND

  PLASMA BOUNDARY (AXIS VALUES)
       R,Z (CM) =    412.972     0.180
       FBFL     =    1.00000
       ABFL(CM) =    104.972

  CLOSED SURFACE NEAR VESSEL (AXIS VALUES)
       R,Z (CM) =    420.257     0.180
       FMAFL    =    1.10179
       AMAFL    =    1.0694


Profile mapping and construction (MAPROF)
*****************************************


- WARNING(PROFALC) : Te derivative on axis is large

- WARNING(PROFALC) : Ti derivative on axis is large

Modelling packages (MODEL)
**************************


- WARNING(IONDEN) :  ====> Ti-profile assumption:
                     Tio from PPFs --> NXTI =  3
                     replaced by FALCONs neutron temp with AMMAG =   1.000

Neutral recycling
-----------------

Balance computations (BALANC)
*****************************


- WARNING(MOMBAL) : No NBI heating at this time :
                    ==> no momentum balance !
```

Areas and volumes

	radius (m)	rho	flux tube area (m2)	x-section area (m2)	dif. vol. (m3)	tot. volume (m3)	<eps>	vprime	<grd rho>2	djacdt
1	0.3090E+01	0.1000E-01	0.1333E+01	0.3690E-03	0.7141E-02	0.7141E-02	0.3561E-02	0.1428E+01	0.8772E+00	0.0000E+00
3	0.3119E+01	0.4082E-01	0.5447E+01	0.5392E-02	0.7487E-01	0.1043E+00	0.1456E-01	0.5849E+01	0.8745E+00	0.0000E+00
5	0.3158E+01	0.8163E-01	0.1091E+02	0.2395E-01	0.2096E+00	0.4634E+00	0.2916E-01	0.1175E+02	0.8697E+00	0.0000E+00
7	0.3197E+01	0.1224E+00	0.1640E+02	0.5504E-01	0.3312E+00	0.1065E+01	0.4383E-01	0.1773E+02	0.8631E+00	0.0000E+00
9	0.3235E+01	0.1633E+00	0.2191E+02	0.9888E-01	0.4549E+00	0.1912E+01	0.5858E-01	0.2382E+02	0.8544E+00	0.0000E+00
11	0.3274E+01	0.2041E+00	0.2746E+02	0.1557E+00	0.5810E+00	0.3011E+01	0.7342E-01	0.3003E+02	0.8440E+00	0.0000E+00
13	0.3312E+01	0.2449E+00	0.3304E+02	0.2259E+00	0.7104E+00	0.4367E+01	0.8835E-01	0.3642E+02	0.8313E+00	0.0000E+00
15	0.3351E+01	0.2857E+00	0.3866E+02	0.3099E+00	0.8437E+00	0.5987E+01	0.1034E+00	0.4300E+02	0.8163E+00	0.0000E+00
17	0.3390E+01	0.3265E+00	0.4433E+02	0.4082E+00	0.9818E+00	0.7881E+01	0.1186E+00	0.4983E+02	0.7994E+00	0.0000E+00
19	0.3429E+01	0.3673E+00	0.5006E+02	0.5213E+00	0.1126E+01	0.1006E+02	0.1340E+00	0.5701E+02	0.7792E+00	0.0000E+00
21	0.3469E+01	0.4082E+00	0.5587E+02	0.6504E+00	0.1280E+01	0.1254E+02	0.1496E+00	0.6463E+02	0.7557E+00	0.0000E+00
23	0.3508E+01	0.4490E+00	0.6177E+02	0.7964E+00	0.1443E+01	0.1534E+02	0.1655E+00	0.7277E+02	0.7294E+00	0.0000E+00
25	0.3548E+01	0.4898E+00	0.6778E+02	0.9606E+00	0.1618E+01	0.1849E+02	0.1818E+00	0.8153E+02	0.7008E+00	0.0000E+00
27	0.3589E+01	0.5306E+00	0.7392E+02	0.1145E+01	0.1808E+01	0.2201E+02	0.1985E+00	0.9102E+02	0.6699E+00	0.0000E+00
29	0.3630E+01	0.5714E+00	0.8021E+02	0.1350E+01	0.2015E+01	0.2593E+02	0.2156E+00	0.1014E+03	0.6370E+00	0.0000E+00
31	0.3672E+01	0.6122E+00	0.8667E+02	0.1580E+01	0.2242E+01	0.3030E+02	0.2334E+00	0.1128E+03	0.6021E+00	0.0000E+00
33	0.3715E+01	0.6531E+00	0.9332E+02	0.1836E+01	0.2494E+01	0.3516E+02	0.2517E+00	0.1254E+03	0.5656E+00	0.0000E+00
35	0.3758E+01	0.6939E+00	0.1002E+03	0.2122E+01	0.2776E+01	0.4057E+02	0.2709E+00	0.1397E+03	0.5274E+00	0.0000E+00
37	0.3802E+01	0.7347E+00	0.1073E+03	0.2442E+01	0.3097E+01	0.4659E+02	0.2910E+00	0.1559E+03	0.4874E+00	0.0000E+00
39	0.3848E+01	0.7755E+00	0.1148E+03	0.2802E+01	0.3467E+01	0.5334E+02	0.3123E+00	0.1748E+03	0.4455E+00	0.0000E+00
41	0.3894E+01	0.8163E+00	0.1226E+03	0.3209E+01	0.3903E+01	0.6092E+02	0.3350E+00	0.1971E+03	0.4019E+00	0.0000E+00
43	0.3943E+01	0.8571E+00	0.1308E+03	0.3672E+01	0.4429E+01	0.6950E+02	0.3596E+00	0.2241E+03	0.3569E+00	0.0000E+00
45	0.3993E+01	0.8980E+00	0.1397E+03	0.4207E+01	0.5080E+01	0.7931E+02	0.3867E+00	0.2579E+03	0.3104E+00	0.0000E+00
47	0.4046E+01	0.9388E+00	0.1493E+03	0.4832E+01	0.5919E+01	0.9070E+02	0.4176E+00	0.3018E+03	0.2627E+00	0.0000E+00
49	0.4101E+01	0.9796E+00	0.1599E+03	0.5584E+01	0.7067E+01	0.1042E+03	0.4544E+00	0.3630E+03	0.2139E+00	0.0000E+00

Total area = 0.6023E+01 m2

Total volume = 0.1120E+03 m3

Shafranov shift = 0.1138E+00 m

IDENTC DATA at t= 46.500

	radius (m)	f-IDC	q-IDC	q-psi	B-IDC	Bpol	p-IDC	pth-exp	<(R0/R)**2>	<R0/R>	<(B0/B)**2>
1	3.090D+00	9.546D+00	1.276D+00	1.292D+00	3.090D+00	8.559D-03	4.353D+04	3.128D+04	1.000D+00	1.000D+00	9.937D-01
3	3.119D+00	9.545D+00	1.285D+00	1.294D+00	3.061D+00	3.487D-02	4.343D+04	3.029D+04	1.000D+00	1.000D+00	9.939D-01
5	3.158D+00	9.542D+00	1.296D+00	1.300D+00	3.023D+00	6.955D-02	4.307D+04	2.888D+04	1.001D+00	1.000D+00	9.945D-01
7	3.197D+00	9.537D+00	1.307D+00	1.308D+00	2.986D+00	1.039D-01	4.247D+04	2.740D+04	1.002D+00	1.001D+00	9.954D-01
9	3.235D+00	9.530D+00	1.319D+00	1.319D+00	2.949D+00	1.379D-01	4.149D+04	2.585D+04	1.003D+00	1.001D+00	9.969D-01
11	3.274D+00	9.520D+00	1.333D+00	1.332D+00	2.914D+00	1.713D-01	4.032D+04	2.425D+04	1.005D+00	1.002D+00	9.986D-01
13	3.312D+00	9.510D+00	1.348D+00	1.347D+00	2.879D+00	2.041D-01	3.895D+04	2.248D+04	1.008D+00	1.003D+00	1.001D+00
15	3.351D+00	9.497D+00	1.367D+00	1.366D+00	2.845D+00	2.360D-01	3.728D+04	2.070D+04	1.011D+00	1.003D+00	1.003D+00
17	3.390D+00	9.482D+00	1.390D+00	1.388D+00	2.812D+00	2.671D-01	3.541D+04	1.893D+04	1.014D+00	1.004D+00	1.006D+00
19	3.429D+00	9.467D+00	1.416D+00	1.415D+00	2.779D+00	2.968D-01	3.338D+04	1.718D+04	1.018D+00	1.006D+00	1.010D+00
21	3.469D+00	9.450D+00	1.449D+00	1.447D+00	2.746D+00	3.248D-01	3.114D+04	1.548D+04	1.023D+00	1.007D+00	1.014D+00
23	3.508D+00	9.433D+00	1.489D+00	1.487D+00	2.714D+00	3.511D-01	2.872D+04	1.395D+04	1.028D+00	1.009D+00	1.018D+00
25	3.548D+00	9.414D+00	1.535D+00	1.533D+00	2.682D+00	3.755D-01	2.620D+04	1.254D+04	1.035D+00	1.011D+00	1.022D+00
27	3.589D+00	9.396D+00	1.589D+00	1.588D+00	2.651D+00	3.979D-01	2.357D+04	1.117D+04	1.042D+00	1.013D+00	1.026D+00
29	3.630D+00	9.377D+00	1.653D+00	1.652D+00	2.620D+00	4.179D-01	2.086D+04	9.869D+03	1.050D+00	1.016D+00	1.031D+00
31	3.672D+00	9.358D+00	1.730D+00	1.727D+00	2.589D+00	4.355D-01	1.811D+04	8.756D+03	1.059D+00	1.019D+00	1.036D+00
33	3.715D+00	9.340D+00	1.819D+00	1.815D+00	2.558D+00	4.503D-01	1.537D+04	7.767D+03	1.070D+00	1.022D+00	1.041D+00
35	3.758D+00	9.323D+00	1.924D+00	1.921D+00	2.528D+00	4.622D-01	1.268D+04	6.757D+03	1.082D+00	1.026D+00	1.047D+00
37	3.802D+00	9.307D+00	2.050D+00	2.048D+00	2.498D+00	4.705D-01	1.008D+04	5.713D+03	1.096D+00	1.030D+00	1.052D+00
39	3.848D+00	9.292D+00	2.204D+00	2.205D+00	2.467D+00	4.749D-01	7.625D+03	4.701D+03	1.112D+00	1.036D+00	1.057D+00
41	3.894D+00	9.279D+00	2.398D+00	2.400D+00	2.436D+00	4.748D-01	5.394D+03	3.712D+03	1.132D+00	1.042D+00	1.063D+00
43	3.943D+00	9.268D+00	2.646D+00	2.649D+00	2.405D+00	4.694D-01	3.449D+03	2.783D+03	1.154D+00	1.049D+00	1.067D+00
45	3.993D+00	9.259D+00	2.972D+00	2.979D+00	2.373D+00	4.580D-01	1.856D+03	1.997D+03	1.182D+00	1.058D+00	1.071D+00
47	4.046D+00	9.253D+00	3.431D+00	3.434D+00	2.340D+00	4.391D-01	7.271D+02	1.172D+03	1.216D+00	1.069D+00	1.073D+00
49	4.101D+00	9.250D+00	4.108D+00	4.103D+00	2.308D+00	4.105D-01	1.268D+02	3.889D+02	1.259D+00	1.083D+00	1.071D+00

Ohmic output at t= 46.500 (nohmic = 2)

	radius (m)	rho	xLH(FAST)	xLH(IDC2)	Oh pow den (W/m3)	Oh power (W)	neoc.res. (ohm m)	Ez (V/m)	EdotB (V T/m)	Vloop (V)
1	0.3090E+01	0.1000E-01	0.3304E-01	0.8367E-02	0.2309E+06	0.1649E+04	0.7272E-08	0.4098E-01	0.1588E+00	0.7930E+00
3	0.3119E+01	0.4082E-01	0.5849E-01	0.3360E-01	0.2032E+06	0.2268E+05	0.8359E-08	0.4098E-01	0.1589E+00	0.7930E+00
5	0.3158E+01	0.8163E-01	0.9239E-01	0.6717E-01	0.1708E+06	0.8910E+05	0.9967E-08	0.4098E-01	0.1589E+00	0.7931E+00
7	0.3197E+01	0.1224E+00	0.1263E+00	0.1007E+00	0.1466E+06	0.1840E+06	0.1164E-07	0.4098E-01	0.1590E+00	0.7931E+00
9	0.3235E+01	0.1633E+00	0.1603E+00	0.1346E+00	0.1272E+06	0.2995E+06	0.1344E-07	0.4098E-01	0.1591E+00	0.7932E+00
11	0.3274E+01	0.2041E+00	0.1944E+00	0.1685E+00	0.1110E+06	0.4299E+06	0.1546E-07	0.4098E-01	0.1593E+00	0.7933E+00
13	0.3312E+01	0.2449E+00	0.2286E+00	0.2026E+00	0.9612E+05	0.5699E+06	0.1789E-07	0.4098E-01	0.1595E+00	0.7933E+00
15	0.3351E+01	0.2857E+00	0.2631E+00	0.2371E+00	0.8309E+05	0.7147E+06	0.2075E-07	0.4098E-01	0.1598E+00	0.7935E+00
17	0.3390E+01	0.3265E+00	0.2979E+00	0.2719E+00	0.7152E+05	0.8607E+06	0.2416E-07	0.4098E-01	0.1601E+00	0.7937E+00
19	0.3429E+01	0.3673E+00	0.3332E+00	0.3072E+00	0.6121E+05	0.1005E+07	0.2830E-07	0.4098E-01	0.1604E+00	0.7939E+00
21	0.3469E+01	0.4082E+00	0.3688E+00	0.3429E+00	0.5198E+05	0.1145E+07	0.3339E-07	0.4098E-01	0.1609E+00	0.7941E+00
23	0.3508E+01	0.4490E+00	0.4050E+00	0.3792E+00	0.4412E+05	0.1279E+07	0.3934E-07	0.4098E-01	0.1614E+00	0.7943E+00
25	0.3548E+01	0.4898E+00	0.4417E+00	0.4161E+00	0.3741E+05	0.1407E+07	0.4650E-07	0.4098E-01	0.1621E+00	0.7944E+00
27	0.3589E+01	0.5306E+00	0.4790E+00	0.4537E+00	0.3136E+05	0.1528E+07	0.5565E-07	0.4098E-01	0.1629E+00	0.7945E+00
29	0.3630E+01	0.5714E+00	0.5170E+00	0.4922E+00	0.2595E+05	0.1640E+07	0.6741E-07	0.4098E-01	0.1638E+00	0.7946E+00
31	0.3672E+01	0.6122E+00	0.5560E+00	0.5316E+00	0.2147E+05	0.1743E+07	0.8133E-07	0.4098E-01	0.1649E+00	0.7946E+00
33	0.3715E+01	0.6531E+00	0.5958E+00	0.5721E+00	0.1786E+05	0.1838E+07	0.9816E-07	0.4098E-01	0.1663E+00	0.7946E+00
35	0.3758E+01	0.6939E+00	0.6368E+00	0.6138E+00	0.1469E+05	0.1926E+07	0.1208E-06	0.4098E-01	0.1678E+00	0.7944E+00
37	0.3802E+01	0.7347E+00	0.6790E+00	0.6570E+00	0.1185E+05	0.2006E+07	0.1517E-06	0.4098E-01	0.1697E+00	0.7941E+00
39	0.3848E+01	0.7755E+00	0.7228E+00	0.7018E+00	0.9498E+04	0.2078E+07	0.1918E-06	0.4098E-01	0.1720E+00	0.7937E+00
41	0.3894E+01	0.8163E+00	0.7684E+00	0.7488E+00	0.7666E+04	0.2142E+07	0.2437E-06	0.4098E-01	0.1747E+00	0.7930E+00
43	0.3943E+01	0.8571E+00	0.8162E+00	0.7982E+00	0.6063E+04	0.2201E+07	0.3107E-06	0.4098E-01	0.1780E+00	0.7919E+00
45	0.3993E+01	0.8980E+00	0.8668E+00	0.8506E+00	0.4958E+04	0.2255E+07	0.3936E-06	0.4098E-01	0.1821E+00	0.7903E+00
47	0.4046E+01	0.9388E+00	0.9208E+00	0.9069E+00	0.3802E+04	0.2305E+07	0.5464E-06	0.4098E-01	0.1872E+00	0.7877E+00
49	0.4101E+01	0.9796E+00	0.9792E+00	0.9677E+00	0.2352E+04	0.2346E+07	0.9834E-06	0.4098E-01	0.1938E+00	0.7835E+00

Vloop at surface (FAST) = -0.9918E+00 Volts
Ohmic power (FAST) = 0.2163E+07 Watts

Particle balance and neutral calculation at t= 46.500

	radius (m)	n-dens (m-3)	n-temp (eV)	e,i-source (m-3)	NB-source (m-3)	e-flux (s-1)	ion-flux (s-1)	main ion flux	impu ion flux	taup-e (sec)	inw el (s-1)	Dp(el) (m2/s)
1	0.309E+01	0.950E+11	0.217E+04	0.158E+17	0.000E+00	-.765E+15	0.000E+00	0.483E+16	0.000E+00	0.000E+00	0.000E+00	-.437E-03
3	0.312E+01	0.970E+11	0.214E+04	0.150E+17	0.000E+00	-.725E+16	0.340E+17	0.422E+17	-.825E+16	-.515E+03	0.211E+16	-.566E-03
5	0.316E+01	0.100E+12	0.208E+04	0.139E+17	0.000E+00	-.325E+17	0.126E+18	0.158E+18	-.317E+17	-.508E+03	0.957E+16	-.646E-03
7	0.320E+01	0.104E+12	0.201E+04	0.138E+17	0.000E+00	-.890E+17	0.266E+18	0.337E+18	-.709E+17	-.425E+03	0.267E+17	-.809E-03
9	0.324E+01	0.110E+12	0.193E+04	0.145E+17	0.000E+00	-.196E+18	0.436E+18	0.562E+18	-.126E+18	-.344E+03	0.605E+17	-.105E-02
11	0.327E+01	0.117E+12	0.184E+04	0.165E+17	0.000E+00	-.378E+18	0.612E+18	0.810E+18	-.198E+18	-.279E+03	0.120E+18	-.136E-02
13	0.331E+01	0.126E+12	0.174E+04	0.195E+17	0.000E+00	-.664E+18	0.769E+18	0.106E+19	-.287E+18	-.228E+03	0.222E+18	-.178E-02
15	0.335E+01	0.137E+12	0.164E+04	0.233E+17	0.000E+00	-.108E+19	0.879E+18	0.127E+19	-.392E+18	-.190E+03	0.384E+18	-.233E-02
17	0.339E+01	0.152E+12	0.153E+04	0.295E+17	0.000E+00	-.166E+19	0.919E+18	0.143E+19	-.515E+18	-.161E+03	0.637E+18	-.305E-02
19	0.343E+01	0.171E+12	0.142E+04	0.379E+17	0.000E+00	-.241E+19	0.872E+18	0.153E+19	-.656E+18	-.140E+03	0.103E+19	-.402E-02
21	0.347E+01	0.194E+12	0.131E+04	0.488E+17	0.000E+00	-.334E+19	0.738E+18	0.155E+19	-.815E+18	-.124E+03	0.164E+19	-.539E-02
23	0.351E+01	0.227E+12	0.120E+04	0.663E+17	0.000E+00	-.442E+19	0.538E+18	0.153E+19	-.992E+18	-.112E+03	0.264E+19	-.742E-02
25	0.355E+01	0.273E+12	0.109E+04	0.923E+17	0.000E+00	-.561E+19	0.331E+18	0.152E+19	-.119E+19	-.105E+03	0.436E+19	-.107E-01
27	0.359E+01	0.336E+12	0.982E+03	0.129E+18	0.000E+00	-.678E+19	0.227E+18	0.163E+19	-.140E+19	-.102E+03	0.788E+19	-.171E-01
29	0.363E+01	0.424E+12	0.875E+03	0.184E+18	0.000E+00	-.775E+19	0.417E+18	0.205E+19	-.163E+19	-.104E+03	0.183E+20	-.355E-01
31	0.367E+01	0.576E+12	0.774E+03	0.286E+18	0.000E+00	-.816E+19	0.124E+19	0.312E+19	-.188E+19	-.113E+03	0.178E+22	-.310E+01
33	0.371E+01	0.826E+12	0.675E+03	0.466E+18	0.000E+00	-.744E+19	0.326E+19	0.540E+19	-.214E+19	-.142E+03	-.214E+20	0.339E-01
35	0.376E+01	0.127E+13	0.577E+03	0.799E+18	0.000E+00	-.454E+19	0.751E+19	0.992E+19	-.241E+19	-.265E+03	-.796E+19	0.115E-01
37	0.380E+01	0.210E+13	0.480E+03	0.146E+19	0.000E+00	0.274E+19	0.162E+20	0.188E+20	-.269E+19	0.499E+03	0.479E+19	-.637E-02
39	0.385E+01	0.382E+13	0.390E+03	0.287E+19	0.000E+00	0.193E+20	0.341E+20	0.370E+20	-.296E+19	0.804E+02	0.920E+20	-.114E+00
41	0.389E+01	0.784E+13	0.310E+03	0.621E+19	0.000E+00	0.575E+20	0.736E+20	0.769E+20	-.322E+19	0.304E+02	-.766E+20	0.904E-01
43	0.394E+01	0.187E+14	0.242E+03	0.150E+20	0.000E+00	0.154E+21	0.171E+21	0.175E+21	-.347E+19	0.128E+02	-.553E+20	0.643E-01
45	0.399E+01	0.560E+14	0.185E+03	0.413E+20	0.000E+00	0.428E+21	0.446E+21	0.450E+21	-.368E+19	0.515E+01	-.607E+20	0.744E-01
47	0.405E+01	0.269E+15	0.112E+03	0.150E+21	0.000E+00	0.141E+22	0.143E+22	0.143E+22	-.384E+19	0.173E+01	-.803E+20	0.119E+00
49	0.410E+01	0.172E+16	0.397E+02	0.456E+21	0.000E+00	0.537E+22	0.539E+22	0.539E+22	-.395E+19	0.489E+00	-.852E+20	0.242E+00

Exp. data from PPFs - measured Ha fluxes :

haltau	halfll	halflw	halrec
1.728522E-01	1.109355E+22	1.227879E+21	9.510786E-01

Current/momentum balance at t= 46.500

	radius (m)	j-res (A/m2)	jboot B	j-beam -	j-IDC -	jdotB	mom source (PENCIL)	mom source (FALCON)	msflux	mflux	mom diff
1	0.3090E+01	0.5635E+07	0.0000E+00	0.0000E+00	0.1297E+07	0.5266E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	0.3119E+01	0.4902E+07	0.5702E+05	0.0000E+00	0.1295E+07	0.3955E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	0.3158E+01	0.4111E+07	0.5694E+05	0.0000E+00	0.1287E+07	0.3934E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7	0.3197E+01	0.3521E+07	0.5692E+05	0.0000E+00	0.1275E+07	0.3898E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	0.3235E+01	0.3048E+07	0.5608E+05	0.0000E+00	0.1257E+07	0.3851E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	0.3274E+01	0.2651E+07	0.5637E+05	0.0000E+00	0.1235E+07	0.3795E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	0.3312E+01	0.2290E+07	0.5531E+05	0.0000E+00	0.1208E+07	0.3722E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	0.3351E+01	0.1975E+07	0.5271E+05	0.0000E+00	0.1176E+07	0.3639E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	0.3390E+01	0.1696E+07	0.4921E+05	0.0000E+00	0.1139E+07	0.3543E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	0.3429E+01	0.1448E+07	0.4590E+05	0.0000E+00	0.1098E+07	0.3419E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
21	0.3469E+01	0.1227E+07	0.4126E+05	0.0000E+00	0.1052E+07	0.3280E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
23	0.3508E+01	0.1042E+07	0.3513E+05	0.0000E+00	0.1002E+07	0.3132E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
25	0.3548E+01	0.8812E+06	0.3159E+05	0.0000E+00	0.9479E+06	0.2971E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
27	0.3589E+01	0.7363E+06	0.2895E+05	0.0000E+00	0.8899E+06	0.2798E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
29	0.3630E+01	0.6079E+06	0.2537E+05	0.0000E+00	0.8280E+06	0.2615E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
31	0.3672E+01	0.5039E+06	0.2010E+05	0.0000E+00	0.7625E+06	0.2421E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
33	0.3715E+01	0.4174E+06	0.1837E+05	0.0000E+00	0.6936E+06	0.2216E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
35	0.3758E+01	0.3392E+06	0.1934E+05	0.0000E+00	0.6214E+06	0.1997E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
37	0.3802E+01	0.2701E+06	0.1898E+05	0.0000E+00	0.5464E+06	0.1762E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
39	0.3848E+01	0.2137E+06	0.1808E+05	0.0000E+00	0.4685E+06	0.1517E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
41	0.3894E+01	0.1681E+06	0.1894E+05	0.0000E+00	0.3881E+06	0.1261E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
43	0.3943E+01	0.1319E+06	0.1606E+05	0.0000E+00	0.3054E+06	0.9968E+06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
45	0.3993E+01	0.1041E+06	0.1688E+05	0.0000E+00	0.2205E+06	0.7195E+06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
47	0.4046E+01	0.7499E+05	0.1778E+05	0.0000E+00	0.1338E+06	0.4435E+06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
49	0.4101E+01	0.4167E+05	0.1573E+05	0.0000E+00	0.4506E+05	0.1841E+06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Current: total, boot, beam = 0.3018E+07 0.1352E+06 0.0000E+00 Ampere
Internal inductance = 0.1186E-05 Henry
momentum conf time = 0.0000E+00 sec (angmom = 0.0000E+00 , ratmom = 0.0000E+00)

Electron power balance at t= 46.500

	radius (m)	e-chi (m2/s)	oh-pow (W)	rf-pow. (W)	ni-pow. (W)	ei-pow. (W)	rad-pow (W)	We-dot. (W)	heat flux (W)	cd-pow. (W)	cv-pow. (W)
1	0.3090E+01	0.1142E+00	0.1649E+04	0.0000E+00	0.0000E+00	0.3019E+03	0.7123E+01	0.1517E+01	0.1338E+04	0.1339E+04	-.1005E+01
3	0.3119E+01	0.1933E+00	0.2268E+05	0.0000E+00	0.0000E+00	0.4434E+04	0.1041E+03	0.4284E+02	0.1809E+05	0.1810E+05	-.9235E+01
5	0.3158E+01	0.3678E+00	0.8910E+05	0.0000E+00	0.0000E+00	0.1983E+05	0.4622E+03	0.3563E+03	0.6842E+05	0.6846E+05	-.3975E+02
7	0.3197E+01	0.4925E+00	0.1840E+06	0.0000E+00	0.0000E+00	0.4574E+05	0.1062E+04	0.1182E+04	0.1359E+06	0.1360E+06	-.1041E+03
9	0.3235E+01	0.5867E+00	0.2995E+06	0.0000E+00	0.0000E+00	0.8219E+05	0.1908E+04	0.2766E+04	0.2126E+06	0.2128E+06	-.2189E+03
11	0.3274E+01	0.6142E+00	0.4299E+06	0.0000E+00	0.0000E+00	0.1291E+06	0.3004E+04	0.5347E+04	0.2923E+06	0.2927E+06	-.4025E+03
13	0.3312E+01	0.6280E+00	0.5699E+06	0.0000E+00	0.0000E+00	0.1863E+06	0.4360E+04	0.8983E+04	0.3699E+06	0.3706E+06	-.6674E+03
15	0.3351E+01	0.6448E+00	0.7147E+06	0.0000E+00	0.0000E+00	0.2539E+06	0.5990E+04	0.1363E+05	0.4408E+06	0.4418E+06	-.1023E+04
17	0.3390E+01	0.6586E+00	0.8607E+06	0.0000E+00	0.0000E+00	0.3316E+06	0.7925E+04	0.1914E+05	0.5016E+06	0.5030E+06	-.1467E+04
19	0.3429E+01	0.6456E+00	0.1005E+07	0.0000E+00	0.0000E+00	0.4196E+06	0.1023E+05	0.2526E+05	0.5494E+06	0.5514E+06	-.1983E+04
21	0.3469E+01	0.6510E+00	0.1145E+07	0.0000E+00	0.0000E+00	0.5182E+06	0.1308E+05	0.3105E+05	0.5821E+06	0.5847E+06	-.2539E+04
23	0.3508E+01	0.6939E+00	0.1279E+07	0.0000E+00	0.0000E+00	0.6279E+06	0.1680E+05	0.3640E+05	0.5974E+06	0.6005E+06	-.3109E+04
25	0.3548E+01	0.6489E+00	0.1407E+07	0.0000E+00	0.0000E+00	0.7496E+06	0.2203E+05	0.4178E+05	0.5929E+06	0.5965E+06	-.3631E+04
27	0.3589E+01	0.5665E+00	0.1528E+07	0.0000E+00	0.0000E+00	0.8849E+06	0.2993E+05	0.4724E+05	0.5649E+06	0.5689E+06	-.3997E+04
29	0.3630E+01	0.5009E+00	0.1640E+07	0.0000E+00	0.0000E+00	0.1036E+07	0.4227E+05	0.5281E+05	0.5074E+06	0.5115E+06	-.4109E+04
31	0.3672E+01	0.4610E+00	0.1743E+07	0.0000E+00	0.0000E+00	0.1207E+07	0.6151E+05	0.5864E+05	0.4141E+06	0.4180E+06	-.3896E+04
33	0.3715E+01	0.2995E+00	0.1838E+07	0.0000E+00	0.0000E+00	0.1402E+07	0.9052E+05	0.6526E+05	0.2791E+06	0.2823E+06	-.3184E+04
35	0.3758E+01	0.8692E-01	0.1926E+07	0.0000E+00	0.0000E+00	0.1626E+07	0.1321E+06	0.7262E+05	0.9373E+05	0.9543E+05	-.1703E+04
37	0.3802E+01	-.1368E+00	0.2006E+07	0.0000E+00	0.0000E+00	0.1889E+07	0.1880E+06	0.7954E+05	-.1532E+06	-.1541E+06	0.8734E+03
39	0.3848E+01	-.4505E+00	0.2078E+07	0.0000E+00	0.0000E+00	0.2203E+07	0.2584E+06	0.8559E+05	-.4725E+06	-.4776E+06	0.5097E+04
41	0.3894E+01	-.8402E+00	0.2142E+07	0.0000E+00	0.0000E+00	0.2578E+07	0.3412E+06	0.8999E+05	-.8707E+06	-.8830E+06	0.1225E+05
43	0.3943E+01	-.1863E+01	0.2201E+07	0.0000E+00	0.0000E+00	0.3022E+07	0.4320E+06	0.9237E+05	-.1350E+07	-.1376E+07	0.2568E+05
45	0.3993E+01	-.3144E+01	0.2255E+07	0.0000E+00	0.0000E+00	0.3511E+07	0.5256E+06	0.9360E+05	-.1882E+07	-.1939E+07	0.5658E+05
47	0.4046E+01	-.5225E+01	0.2305E+07	0.0000E+00	0.0000E+00	0.3981E+07	0.6167E+06	0.9447E+05	-.2400E+07	-.2538E+07	0.1374E+06
49	0.4101E+01	-.1275E+02	0.2346E+07	0.0000E+00	0.0000E+00	0.4291E+07	0.7015E+06	0.9530E+05	-.2778E+07	-.3116E+07	0.3383E+06

	radius (m)	rho	oh-dens (W/m3)	rf-dens (W/m3)	nb-dens (W/m3)	ei-dens (W/m3)	rad-dens (W/m3)	ez-dens (W/m3)
1	0.3090E+01	0.1000E-01	0.2309E+06	0.0000E+00	0.0000E+00	0.4228E+05	0.9974E+03	0.5771E+02
3	0.3119E+01	0.4082E-01	0.2032E+06	0.0000E+00	0.0000E+00	0.4269E+05	0.9974E+03	0.5790E+02
5	0.3158E+01	0.8163E-01	0.1708E+06	0.0000E+00	0.0000E+00	0.4302E+05	0.9974E+03	0.5819E+02
7	0.3197E+01	0.1224E+00	0.1466E+06	0.0000E+00	0.0000E+00	0.4308E+05	0.9975E+03	0.5812E+02
9	0.3235E+01	0.1633E+00	0.1272E+06	0.0000E+00	0.0000E+00	0.4289E+05	0.9978E+03	0.5780E+02
11	0.3274E+01	0.2041E+00	0.1110E+06	0.0000E+00	0.0000E+00	0.4248E+05	0.9988E+03	0.5710E+02
13	0.3312E+01	0.2449E+00	0.9612E+05	0.0000E+00	0.0000E+00	0.4200E+05	0.1002E+04	0.5626E+02
15	0.3351E+01	0.2857E+00	0.8309E+05	0.0000E+00	0.0000E+00	0.4138E+05	0.1011E+04	0.5531E+02
17	0.3390E+01	0.3265E+00	0.7152E+05	0.0000E+00	0.0000E+00	0.4071E+05	0.1034E+04	0.5424E+02
19	0.3429E+01	0.3673E+00	0.6121E+05	0.0000E+00	0.0000E+00	0.4004E+05	0.1090E+04	0.5322E+02
21	0.3469E+01	0.4082E+00	0.5198E+05	0.0000E+00	0.0000E+00	0.3945E+05	0.1212E+04	0.5224E+02
23	0.3508E+01	0.4490E+00	0.4412E+05	0.0000E+00	0.0000E+00	0.3888E+05	0.1456E+04	0.5140E+02
25	0.3548E+01	0.4898E+00	0.3741E+05	0.0000E+00	0.0000E+00	0.3848E+05	0.1897E+04	0.5088E+02
27	0.3589E+01	0.5306E+00	0.3136E+05	0.0000E+00	0.0000E+00	0.3843E+05	0.2623E+04	0.5074E+02
29	0.3630E+01	0.5714E+00	0.2595E+05	0.0000E+00	0.0000E+00	0.3882E+05	0.3699E+04	0.5120E+02
31	0.3672E+01	0.6122E+00	0.2147E+05	0.0000E+00	0.0000E+00	0.3950E+05	0.5129E+04	0.5243E+02
33	0.3715E+01	0.6531E+00	0.1786E+05	0.0000E+00	0.0000E+00	0.4059E+05	0.6811E+04	0.5458E+02
35	0.3758E+01	0.6939E+00	0.1469E+05	0.0000E+00	0.0000E+00	0.4241E+05	0.8524E+04	0.5832E+02
37	0.3802E+01	0.7347E+00	0.1185E+05	0.0000E+00	0.0000E+00	0.4503E+05	0.9963E+04	0.6463E+02
39	0.3848E+01	0.7755E+00	0.9498E+04	0.0000E+00	0.0000E+00	0.4804E+05	0.1082E+05	0.7538E+02
41	0.3894E+01	0.8163E+00	0.7666E+04	0.0000E+00	0.0000E+00	0.5088E+05	0.1091E+05	0.9610E+02
43	0.3943E+01	0.8571E+00	0.6063E+04	0.0000E+00	0.0000E+00	0.5186E+05	0.1019E+05	0.1441E+03
45	0.3993E+01	0.8980E+00	0.4958E+04	0.0000E+00	0.0000E+00	0.4720E+05	0.8844E+04	0.2833E+03
47	0.4046E+01	0.9388E+00	0.3802E+04	0.0000E+00	0.0000E+00	0.3428E+05	0.7160E+04	0.9013E+03
49	0.4101E+01	0.9796E+00	0.2352E+04	0.0000E+00	0.0000E+00	0.1121E+05	0.5451E+04	0.2855E+04

```
Final output (OUTPUT)
**********************

                CONTROL SWITCHES
                ----------------

                 output              input
NIBBAL             1                   1
NEBBAL             1                   1
NCURBA             1                   1
NMOMBA             1                   1
NOUTP              2                   2
NEQUIL             2                   2
NDVLDT             0                   0
NCONSI             0                   0
NXTE               3                   3
NTEMAP             0                   0
NXNE               5                   5
NXTI               5                   0
NXZEFF             1                   1
NXPRAD             2                   0
NXANGV             1                   0
NOHMIC             2                   2
NRESIS             1                   1
NNBI               1                   1
NICRF              1                   1
NNEUTR             1                   1


                PARAMETERS
                ----------

AMAIN , ZMAIN , AMINO , CONMIN, ZIMPU                =     2.00     1.00     1.00     0.05     6.00

RXTRAP, AMMAG , CZEFF1, CZEFF2, RHORAD, WRAD , ALFINW =     4.00     1.00     0.00     0.75     0.80     0.20     0.50

dt- Te , Ti , ne , Zeff , Prad , angv , scal , icrf , nbi =      0.500     0.500     0.500     0.500     0.500
                                                                 0.500     0.500     0.500     0.500

                                                        pulse # 19739   nts =  2   time slice = 50.000

Main discharge parameters :
---------------------------

 major radius   =    3.155  m              minor radius   =    1.365  m

 toroidal field =    2.997 Tesla           plasma current =  3.05E+06  A

 NBI  auxiliary heating power :  2.59E+06  W

 ICRF auxiliary heating power :  8.83E+06  W

 mass # (main, impu, RF min, NB fast ions)    2.000  12.000   1.000   2.000  amu

 charge (main, impu, RF min, NB fast ions)    1.000   6.000   1.000   1.000  amu

 q-psi (axis  edge)  =    0.934   4.421


Stored energy , dW/dt  and  neutron yield
-----------------------------------------

We,Wi (kin-FALCON)              =   2.19E+06  1.10E+06

Wfast (PENCIL / ICRDEP)         =   1.70E+05  6.75E+05

W(rotational)                   =   2.23E+03

W-tot (FALCON, FAST, IDC, dia)  =   4.14E+06  4.44E+06  5.68E+06  5.01E+06

<dTe/dt> (FALCON), d<Te>/dt (EC2 PPF) =  -1.79E+01  1.52E+02

<dne/dt> (FALCON), d<ne>/dt (NEX PPF) =   6.02E+18  5.76E+18

dWe/dt , dWi/dt  (kin-FALCON)   =   3.94E+05  1.80E+05

d Wfast /dt (PENCIL / ICRDEP)   =  -1.51E+04 -2.33E+04

d Wrot /dt                      =  -3.10E+02

dW/dt (FALC,FAST,IDC,dia)  =   5.35E+05  4.47E+05  5.96E+05  2.79E+05


D-D neutron production rate ( s-1 ) :

FALCON (thermal) , measured (TIN.RDD/2)=   3.17E+14  1.76E+15

PENCIL (thermal  , beam-thermal)        =   3.97E+14  6.81E+14

Tio from neutrons (TIN.TIX , FALCON)    =   0.00E+00  0.00E+00


FALCONs    W-fast   =  20.3875 %  of W-tot

while   d/dt(Wfast) =  -0.3047 %  of P-tot
```

MAIN INPUT EXPERIMENTAL DATA at t= 50.000 (impurity charge = 6.00)

	radius (m)	e-dens (m-3)	e-temp (eV)	i-temp (eV)	p-rad (W m-3)	Zeff	ang fr (rad/s)	ni-tot (m-3)	ni-main (m-3)	n-imp (m-3)	n-min (m-3)	n-fast (m-3)
1	3.164D+00	4.819D+19	9.547D+03	6.651D+03	3.12D+02	2.739D+00	1.592D+04	3.422D+19	2.866D+19	2.793D+18	2.409D+18	3.524D+17
3	3.191D+00	4.812D+19	9.190D+03	6.148D+03	4.13D+02	2.739D+00	1.411D+04	3.417D+19	2.844D+19	2.790D+18	2.406D+18	5.391D+17
5	3.228D+00	4.793D+19	8.718D+03	5.565D+03	5.94D+02	2.739D+00	1.194D+04	3.404D+19	2.807D+19	2.778D+18	2.396D+18	7.871D+17
7	3.264D+00	4.761D+19	8.246D+03	5.253D+03	8.68D+02	2.739D+00	1.048D+04	3.381D+19	2.768D+19	2.760D+18	2.381D+18	9.909D+17
9	3.299D+00	4.718D+19	7.774D+03	5.040D+03	1.31D+03	2.739D+00	9.945D+03	3.350D+19	2.733D+19	2.735D+18	2.359D+18	1.076D+18
11	3.335D+00	4.663D+19	7.304D+03	5.000D+03	2.18D+03	2.739D+00	1.103D+04	3.312D+19	2.703D+19	2.703D+18	2.332D+18	1.057D+18
13	3.371D+00	4.598D+19	6.898D+03	4.961D+03	3.78D+03	2.739D+00	1.212D+04	3.265D+19	2.677D+19	2.666D+18	2.299D+18	9.229D+17
15	3.406D+00	4.524D+19	6.488D+03	4.646D+03	6.16D+03	2.739D+00	1.237D+04	3.212D+19	2.648D+19	2.622D+18	2.262D+18	7.633D+17
17	3.442D+00	4.441D+19	6.027D+03	4.213D+03	9.20D+03	2.739D+00	1.226D+04	3.154D+19	2.614D+19	2.574D+18	2.220D+18	5.992D+17
19	3.479D+00	4.351D+19	5.567D+03	3.780D+03	1.25D+04	2.739D+00	1.216D+04	3.090D+19	2.568D+19	2.522D+18	2.176D+18	5.187D+17
21	3.515D+00	4.256D+19	5.113D+03	3.431D+03	1.54D+04	2.739D+00	1.146D+04	3.022D+19	2.518D+19	2.467D+18	2.128D+18	4.532D+17
23	3.552D+00	4.158D+19	4.660D+03	3.142D+03	1.74D+04	2.739D+00	1.035D+04	2.952D+19	2.463D+19	2.410D+18	2.079D+18	4.068D+17
25	3.589D+00	4.057D+19	4.210D+03	2.853D+03	1.84D+04	2.739D+00	9.237D+03	2.881D+19	2.406D+19	2.352D+18	2.029D+18	3.695D+17
27	3.626D+00	3.957D+19	3.766D+03	2.634D+03	1.92D+04	2.739D+00	8.213D+03	2.810D+19	2.348D+19	2.294D+18	1.978D+18	3.409D+17
29	3.664D+00	3.857D+19	3.321D+03	2.471D+03	1.98D+04	2.739D+00	7.259D+03	2.739D+19	2.291D+19	2.236D+18	1.929D+18	3.223D+17
31	3.703D+00	3.760D+19	3.000D+03	2.309D+03	1.97D+04	2.739D+00	6.306D+03	2.670D+19	2.235D+19	2.180D+18	1.880D+18	2.924D+17
33	3.743D+00	3.665D+19	2.680D+03	2.145D+03	1.80D+04	2.739D+00	5.317D+03	2.603D+19	2.181D+19	2.125D+18	1.833D+18	2.665D+17
35	3.784D+00	3.571D+19	2.349D+03	1.980D+03	1.51D+04	2.739D+00	4.284D+03	2.536D+19	2.126D+19	2.070D+18	1.785D+18	2.424D+17
37	3.826D+00	3.472D+19	2.007D+03	1.815D+03	1.41D+04	2.739D+00	3.251D+03	2.465D+19	2.069D+19	2.012D+18	1.736D+18	2.184D+17
39	3.869D+00	3.358D+19	1.675D+03	1.634D+03	1.69D+04	2.739D+00	2.481D+03	2.385D+19	2.003D+19	1.947D+18	1.679D+18	1.922D+17
41	3.913D+00	3.211D+19	1.393D+03	1.429D+03	2.30D+04	2.739D+00	2.078D+03	2.280D+19	1.917D+19	1.861D+18	1.605D+18	1.609D+17
43	3.960D+00	2.996D+19	1.111D+03	1.225D+03	2.95D+04	2.739D+00	1.674D+03	2.127D+19	1.791D+19	1.736D+18	1.498D+18	1.282D+17
45	4.009D+00	2.651D+19	9.878D+02	1.021D+03	3.66D+04	2.739D+00	1.271D+03	1.883D+19	1.586D+19	1.537D+18	1.326D+18	1.047D+17
47	4.060D+00	2.068D+19	8.645D+02	8.162D+02	4.46D+04	2.739D+00	8.676D+02	1.469D+19	1.236D+19	1.199D+18	1.034D+18	9.355D+16
49	4.114D+00	1.037D+19	7.413D+02	6.119D+02	-1.00D-05	2.739D+00	4.643D+02	7.367D+18	6.159D+18	6.013D+17	5.187D+17	8.761D+16

	radius	dne/dt	dTe/dt	dTi/dt	dZf/dt	dav/dt	dni/dt	dnf/dt
1	0.316E+01	0.691E+19	0.125E+04	-.116E+04	0.837E+00	-.172E+05	-.181E+19	-.807E+17
3	0.319E+01	0.691E+19	0.105E+04	0.559E+02	0.837E+00	-.989E+04	-.180E+19	-.124E+18
5	0.323E+01	0.690E+19	0.788E+03	0.131E+04	0.837E+00	-.284E+04	-.178E+19	-.182E+18
7	0.326E+01	0.690E+19	0.523E+03	0.144E+04	0.837E+00	-.411E+04	-.174E+19	-.231E+18
9	0.330E+01	0.688E+19	0.259E+03	0.161E+04	0.837E+00	-.461E+04	-.169E+19	-.256E+18
11	0.333E+01	0.687E+19	0.275E+01	0.187E+04	0.837E+00	-.377E+04	-.162E+19	-.259E+18
13	0.337E+01	0.686E+19	-.127E+02	0.213E+04	0.837E+00	-.292E+04	-.154E+19	-.239E+18
15	0.341E+01	0.685E+19	-.246E+02	0.174E+04	0.837E+00	-.339E+04	-.144E+19	-.194E+18
17	0.344E+01	0.685E+19	0.828E+00	0.108E+04	0.837E+00	-.443E+04	-.133E+19	-.141E+18
19	0.348E+01	0.685E+19	0.262E+02	0.416E+03	0.837E+00	-.547E+04	-.120E+19	-.113E+18
21	0.351E+01	0.686E+19	0.504E+02	0.198E+03	0.837E+00	-.472E+04	-.106E+19	-.889E+17
23	0.355E+01	0.689E+19	0.744E+02	0.299E+03	0.837E+00	-.269E+04	-.907E+18	-.691E+17
25	0.359E+01	0.693E+19	0.761E+02	0.401E+03	0.837E+00	-.658E+03	-.740E+18	-.843E+17
27	0.363E+01	0.698E+19	0.519E+02	0.424E+03	0.837E+00	0.454E+03	-.561E+18	-.748E+17
29	0.366E+01	0.705E+19	0.277E+02	0.384E+03	0.837E+00	0.824E+03	-.372E+18	-.302E+17
31	0.370E+01	0.713E+19	0.187E+02	0.343E+03	0.837E+00	0.119E+04	-.177E+18	-.187E+17
33	0.374E+01	0.723E+19	0.987E+01	0.316E+03	0.837E+00	0.156E+04	0.219E+17	-.994E+16
35	0.378E+01	0.732E+19	-.108E+02	0.305E+03	0.837E+00	0.193E+04	0.219E+18	-.366E+16
37	0.383E+01	0.739E+19	-.422E+02	0.294E+03	0.837E+00	0.229E+04	0.406E+18	0.806E+15
39	0.387E+01	0.740E+19	-.689E+02	0.265E+03	0.837E+00	0.240E+04	0.571E+18	0.485E+16
41	0.391E+01	0.729E+19	-.736E+02	0.210E+03	0.837E+00	0.214E+04	0.697E+18	0.843E+16
43	0.396E+01	0.695E+19	-.784E+02	0.155E+03	0.837E+00	0.188E+04	0.760E+18	0.839E+16
45	0.401E+01	0.622E+19	-.523E+02	0.100E+03	0.837E+00	0.162E+04	0.719E+18	0.680E+16
47	0.406E+01	0.478E+19	-.523E+02	0.452E+02	0.837E+00	0.136E+04	0.512E+18	0.701E+16
49	0.411E+01	0.208E+19	-.523E+02	-.967E+01	0.837E+00	0.110E+04	0.334E+17	0.122E+17

Total (e+i) power balance at t= 50.000

	radius (m)	P-oh (W)	P-nbi (W)	P-icrf (W)	Prad+cx (W)	W-dot (W)	Q-tot (W)	Q-cd (W)	Q-cv (W)	CHI-eff cd only	Therm exch e -> i
1	0.3164E+01	0.5797E+03	0.2106E+03	0.2136E+05	0.2763E+01	0.1129E+03	0.2203E+05	0.2218E+05	-.1592E+03	0.3929E+00	0.3149E+03
3	0.3191E+01	0.7992E+04	0.3922E+04	0.3324E+06	0.4417E+02	0.1964E+04	0.3423E+06	0.3414E+06	0.7972E+03	0.7398E+00	0.4851E+04
5	0.3228E+01	0.3160E+05	0.2423E+05	0.1485E+07	0.2347E+03	0.1096E+05	0.1530E+07	0.1523E+07	0.6418E+04	0.1660E+01	0.2349E+05
7	0.3264E+01	0.6578E+05	0.7015E+05	0.3169E+07	0.6610E+03	0.2630E+05	0.3278E+07	0.3256E+07	0.2136E+05	0.2386E+01	0.5622E+05
9	0.3299E+01	0.1076E+06	0.1445E+06	0.4931E+07	0.1522E+04	0.4589E+05	0.5136E+07	0.5088E+07	0.4591E+05	0.2833E+01	0.1026E+06
11	0.3335E+01	0.1547E+06	0.2469E+06	0.6435E+07	0.3276E+04	0.6931E+05	0.6763E+07	0.6679E+07	0.8018E+05	0.3273E+01	0.1586E+06
13	0.3371E+01	0.2054E+06	0.3620E+06	0.7530E+07	0.6941E+04	0.9791E+05	0.7993E+07	0.7871E+07	0.1158E+06	0.3532E+01	0.2210E+06
15	0.3406E+01	0.2588E+06	0.4804E+06	0.8228E+07	0.1423E+05	0.1311E+06	0.8821E+07	0.8671E+07	0.1419E+06	0.3164E+01	0.2908E+06
17	0.3442E+01	0.3133E+06	0.5925E+06	0.8623E+07	0.2743E+05	0.1621E+06	0.9338E+07	0.9173E+07	0.1544E+06	0.2862E+01	0.3770E+06
19	0.3479E+01	0.3673E+06	0.6994E+06	0.8833E+07	0.4901E+05	0.1884E+06	0.9661E+07	0.9491E+07	0.1574E+06	0.2728E+01	0.4829E+06
21	0.3515E+01	0.4196E+06	0.8050E+06	0.8949E+07	0.8079E+05	0.2100E+06	0.9882E+07	0.9711E+07	0.1568E+06	0.2624E+01	0.6099E+06
23	0.3552E+01	0.4696E+06	0.9123E+06	0.9022E+07	0.1230E+06	0.2340E+06	0.1005E+08	0.9877E+07	0.1545E+06	0.2517E+01	0.7532E+06
25	0.3589E+01	0.5167E+06	0.1022E+07	0.9072E+07	0.1750E+06	0.2621E+06	0.1017E+08	0.1001E+08	0.1495E+06	0.2477E+01	0.9127E+06
27	0.3626E+01	0.5602E+06	0.1134E+07	0.9106E+07	0.2362E+06	0.2927E+06	0.1027E+08	0.1011E+08	0.1466E+06	0.2413E+01	0.1087E+07
29	0.3664E+01	0.5998E+06	0.1250E+07	0.9130E+07	0.3078E+06	0.3235E+06	0.1034E+08	0.1018E+08	0.1481E+06	0.2738E+01	0.1260E+07
31	0.3703E+01	0.6356E+06	0.1369E+07	0.9146E+07	0.3898E+06	0.3544E+06	0.1040E+08	0.1024E+08	0.1512E+06	0.3241E+01	0.1430E+07
33	0.3743E+01	0.6687E+06	0.1493E+07	0.9158E+07	0.4785E+06	0.3858E+06	0.1045E+08	0.1028E+08	0.1585E+06	0.3204E+01	0.1599E+07
35	0.3784E+01	0.6993E+06	0.1621E+07	0.9166E+07	0.5669E+06	0.4177E+06	0.1049E+08	0.1031E+08	0.1739E+06	0.2985E+01	0.1757E+07
37	0.3826E+01	0.7271E+06	0.1752E+07	0.9172E+07	0.6568E+06	0.4490E+06	0.1053E+08	0.1032E+08	0.2033E+06	0.2994E+01	0.1885E+07
39	0.3869E+01	0.7519E+06	0.1888E+07	0.9177E+07	0.7668E+06	0.4785E+06	0.1055E+08	0.1029E+08	0.2537E+06	0.3434E+01	0.1951E+07
41	0.3913E+01	0.7744E+06	0.2027E+07	0.9179E+07	0.9307E+06	0.5053E+06	0.1052E+08	0.1017E+08	0.3379E+06	0.3754E+01	0.1951E+07
43	0.3960E+01	0.7950E+06	0.2167E+07	0.9181E+07	0.1181E+07	0.5283E+06	0.1039E+08	0.9899E+07	0.4829E+06	0.5425E+01	0.1858E+07
45	0.4009E+01	0.8144E+06	0.2305E+07	0.9182E+07	0.1546E+07	0.5485E+06	0.1013E+08	0.9367E+07	0.7607E+06	0.9570E+01	0.1750E+07
47	0.4060E+01	0.8353E+06	0.2436E+07	0.9182E+07	0.2110E+07	0.5643E+06	0.9640E+07	0.8300E+07	0.1338E+07	0.1102E+02	0.1759E+07
49	0.4114E+01	0.8590E+06	0.2542E+07	0.9182E+07	0.3017E+07	0.5726E+06	0.8438E+07	0.5184E+07	0.3253E+07	0.1405E+02	0.1838E+07

Ion power balance at t= 50.000

	radius (m)	i-chi (m2/s)	ei-pow. (W)	ni-pow. (W)	rf-pow. (W)	cx-pow. (W)	Wi-dot. (W)	heat flux (W)	cd-pow. (W)	cv-pow. (W)	viscous (W)
1	0.3164E+01	0.3091E-01	0.3149E+03	0.1873E+03	0.1220E+04	0.8373E+00	-.7436E+02	0.1795E+04	0.1789E+04	0.0000E+00	0.6221E+01
3	0.3191E+01	0.5533E-01	0.4851E+04	0.3482E+04	0.1844E+05	0.1138E+02	-.6393E+03	0.2740E+05	0.2557E+05	0.1725E+04	0.1013E+03
5	0.3228E+01	0.2185E+00	0.2349E+05	0.2148E+05	0.8591E+05	0.4326E+02	0.4663E+03	0.1303E+06	0.1224E+06	0.7482E+04	0.4450E+03
7	0.3264E+01	0.4835E+00	0.5622E+05	0.6213E+05	0.2166E+06	0.8483E+02	0.4556E+04	0.3303E+06	0.3103E+06	0.1884E+05	0.1074E+04
9	0.3299E+01	0.2653E+01	0.1026E+06	0.1277E+06	0.3654E+06	0.1428E+03	0.1109E+05	0.5843E+06	0.5463E+06	0.3589E+05	0.2082E+04
11	0.3335E+01	0.6169E+01	0.1586E+06	0.2174E+06	0.5185E+06	0.2331E+03	0.2116E+05	0.8730E+06	0.8094E+06	0.5967E+05	0.3921E+04
13	0.3371E+01	0.2356E+01	0.2210E+06	0.3178E+06	0.6754E+06	0.3853E+03	0.3583E+05	0.1178E+07	0.1085E+07	0.8642E+05	0.6287E+04
15	0.3406E+01	0.7139E+00	0.2908E+06	0.4203E+06	0.8338E+06	0.6055E+03	0.5349E+05	0.1490E+07	0.1374E+07	0.1078E+06	0.8508E+04
17	0.3442E+01	0.7835E+00	0.3770E+06	0.5167E+06	0.9848E+06	0.8929E+03	0.6737E+05	0.1810E+07	0.1677E+07	0.1219E+06	0.1046E+05
19	0.3479E+01	0.8734E+00	0.4829E+06	0.6077E+06	0.1115E+07	0.1234E+04	0.7478E+05	0.2129E+07	0.1986E+07	0.1309E+06	0.1235E+05
21	0.3515E+01	0.1367E+01	0.6099E+06	0.6966E+06	0.1216E+07	0.1646E+04	0.7581E+05	0.2444E+07	0.2291E+07	0.1389E+06	0.1354E+05
23	0.3552E+01	0.1454E+01	0.7532E+06	0.7857E+06	0.1287E+07	0.2154E+04	0.7787E+05	0.2745E+07	0.2584E+07	0.1466E+06	0.1395E+05
25	0.3589E+01	0.1579E+01	0.9127E+06	0.8751E+06	0.1336E+07	0.2782E+04	0.8258E+05	0.3037E+07	0.2871E+07	0.1519E+06	0.1397E+05
27	0.3626E+01	0.2902E+01	0.1087E+07	0.9645E+06	0.1370E+07	0.3604E+04	0.8988E+05	0.3326E+07	0.3153E+07	0.1589E+06	0.1376E+05
29	0.3664E+01	0.3061E+01	0.1260E+07	0.1055E+07	0.1394E+07	0.4751E+04	0.9781E+05	0.3604E+07	0.3422E+07	0.1686E+06	0.1339E+05
31	0.3703E+01	0.3223E+01	0.1430E+07	0.1145E+07	0.1411E+07	0.6449E+04	0.1060E+06	0.3869E+07	0.3678E+07	0.1784E+06	0.1273E+05
33	0.3743E+01	0.3343E+01	0.1599E+07	0.1234E+07	0.1423E+07	0.9010E+04	0.1145E+06	0.4126E+07	0.3926E+07	0.1891E+06	0.1168E+05
35	0.3784E+01	0.3511E+01	0.1757E+07	0.1322E+07	0.1431E+07	0.1295E+05	0.1239E+06	0.4366E+07	0.4154E+07	0.2023E+06	0.1021E+05
37	0.3826E+01	0.3673E+01	0.1885E+07	0.1409E+07	0.1437E+07	0.1926E+05	0.1343E+06	0.4566E+07	0.4337E+07	0.2209E+06	0.8360E+04
39	0.3869E+01	0.3128E+01	0.1951E+07	0.1492E+07	0.1441E+07	0.2951E+05	0.1456E+06	0.4693E+07	0.4438E+07	0.2481E+06	0.6860E+04
41	0.3913E+01	0.3182E+01	0.1951E+07	0.1570E+07	0.1444E+07	0.4586E+05	0.1565E+06	0.4737E+07	0.4440E+07	0.2900E+06	0.6157E+04
43	0.3960E+01	0.3285E+01	0.1858E+07	0.1639E+07	0.1446E+07	0.7174E+05	0.1661E+06	0.4663E+07	0.4294E+07	0.3641E+06	0.5296E+04
45	0.4009E+01	0.3509E+01	0.1750E+07	0.1697E+07	0.1447E+07	0.1121E+06	0.1737E+06	0.4541E+07	0.4043E+07	0.4937E+06	0.4268E+04
47	0.4060E+01	0.4163E+01	0.1759E+07	0.1746E+07	0.1447E+07	0.2019E+06	0.1786E+06	0.4444E+07	0.3692E+07	0.7488E+06	0.3070E+04
49	0.4114E+01	0.4745E+01	0.1838E+07	0.1783E+07	0.1447E+07	0.7452E+06	0.1801E+06	0.3619E+07	0.2061E+07	0.1556E+07	0.1697E+04

	radius (m)	i-chi-neo (m2/s)	ei-dens (W/m3)	ni-dens (W/m3)	rf-dens (W/m3)	cx-dens (W/m3)	iz-dens (W/m3)
1	0.3164E+01	0.3936E+01	0.5106E+05	0.3036E+05	0.1978E+06	0.1358E+03	0.9470E+02
3	0.3191E+01	0.2010E+01	0.5631E+05	0.4633E+05	0.2162E+06	0.1174E+03	0.8559E+02
5	0.3228E+01	0.1234E+01	0.6216E+05	0.6754E+05	0.2566E+06	0.8981E+02	0.7191E+02
7	0.3264E+01	0.8995E+00	0.6287E+05	0.8491E+05	0.2290E+06	0.7678E+02	0.6557E+02
9	0.3299E+01	0.7088E+00	0.6128E+05	0.9193E+05	0.1774E+06	0.7970E+02	0.6729E+02
11	0.3335E+01	0.5845E+00	0.5522E+05	0.9003E+05	0.1435E+06	0.1098E+03	0.8215E+02
13	0.3371E+01	0.4954E+00	0.4919E+05	0.7828E+05	0.1205E+06	0.1425E+03	0.9782E+02
15	0.3406E+01	0.4310E+00	0.4962E+05	0.6444E+05	0.1005E+06	0.1637E+03	0.1062E+03
17	0.3442E+01	0.3830E+00	0.5258E+05	0.5025E+05	0.7862E+05	0.1732E+03	0.1090E+03
19	0.3479E+01	0.3469E+00	0.5587E+05	0.4315E+05	0.5550E+05	0.1767E+03	0.1090E+03
21	0.3515E+01	0.3187E+00	0.5699E+05	0.3733E+05	0.3558E+05	0.1921E+03	0.1156E+03
23	0.3552E+01	0.2969E+00	0.5619E+05	0.3311E+05	0.2179E+05	0.2095E+03	0.1237E+03
25	0.3589E+01	0.2802E+00	0.5547E+05	0.2952E+05	0.1334E+05	0.2317E+03	0.1347E+03
27	0.3626E+01	0.2673E+00	0.5171E+05	0.2632E+05	0.8247E+04	0.2787E+03	0.1589E+03
29	0.3664E+01	0.2578E+00	0.4426E+05	0.2360E+05	0.5139E+04	0.3630E+03	0.2020E+03
31	0.3703E+01	0.2519E+00	0.3965E+05	0.2086E+05	0.3232E+04	0.4828E+03	0.2633E+03
33	0.3743E+01	0.2490E+00	0.3437E+05	0.1844E+05	0.2046E+04	0.6464E+03	0.3480E+03
35	0.3784E+01	0.2485E+00	0.2721E+05	0.1615E+05	0.1296E+04	0.8932E+03	0.4811E+03
37	0.3826E+01	0.2502E+00	0.1678E+05	0.1393E+05	0.8136E+03	0.1300E+04	0.7105E+03
39	0.3869E+01	0.2538E+00	0.4378E+04	0.1168E+05	0.4910E+03	0.1857E+04	0.1044E+04
41	0.3913E+01	0.2584E+00	-.4623E+04	0.9300E+04	0.2782E+03	0.2561E+04	0.1499E+04
43	0.3960E+01	0.2617E+00	-.1749E+05	0.6997E+04	0.1340E+03	0.3552E+04	0.2182E+04
45	0.4009E+01	0.2609E+00	-.4687E+04	0.4993E+04	0.4449E+02	0.4600E+04	0.2947E+04
47	0.4060E+01	0.2435E+00	0.5133E+04	0.3528E+04	0.5925E+01	0.1351E+05	0.9373E+04
49	0.4114E+01	0.1760E+00	0.4391E+04	0.1618E+04	0.2416E+01	0.7265E+05	0.5463E+05

9.6 *Test case: "automatic" run*

The following 4 pages contain a reproduction of the listed output in the standard file *JETuid.FALCON.PRINT* resulting from an "automatic" run of FALCON.

The job was submitted by entering the command

falcon auto file(example)

from the TSO environment on the IBM mainframe at JET.

The run is driven by the IBM file *JETuid.FALCSHOT.DATA(EXAMPLE)*, which contains the information on pulse(s) and time slice(s) to be analyzed, in the following format:

number of pulses to be analyzed 1
pulse and number of time slices 19739 2
1st time slice to be analyzed 46.50
2nd time slice to be analyzed 50.00

Pulse and times are thus the same used for the example of "manual" run in Appendix 9.5 . However, since the code is now run in "automatic" mode, switches and input parameters will be set differently (according to their default values, see Section 6.4) - the code will produce different results.

The entire output is stored in a *FALC* PPF also in the case of "automatic" run. On the other hand, the listed output contains only a limited amount of information, as can be seen below. It is to be regarded as an essential log of the run.

```
==================================================
FALCON transport analysis for JET pulse #   19739
==================================================

   DEFAULT SETTINGS USED FOR SWITCHES !

Time slice #     1  is  t =   46.500

Time slice #     2  is  t =   50.000
```

```
**************************************************
*  Time loop:   time slice # =  1   t = 46.500  *
**************************************************


Time slice checking routine
***************************

- WARNING(TSLCHK) : CXSM.PSI  is zero-valued --> CXSM data cannot be used for this time

- WARNING(TSLCHK) :   50 zero-valued data points eliminated for LIDRTE

- WARNING(TSLCHK) :   50 zero-valued data points eliminated for LIDRNE

- WARNING(TSLCHK) :   41 zero-valued data points eliminated for NEPRPRFL

- WARNING(TSLCHK) :    1 zero-valued data points eliminated for CXS1TI

- WARNING(TSLCHK) :   63 zero-valued data points eliminated for BRADPROF


Equilibrium reconstruction (EQUIL)
**********************************

------------------------------------------------------------------------

* FLUSH *  FOR PULSE NUMBER     :   19739
           TIME  REQUESTED :   46.500
           TIME  FOUND     :   46.235

  SPLINE APPROXIMATION USED
       NPX,NPY  =   19  19
       MX,MY    =   11  11  (INTERIOR KNOTS)
       NC       =  225      (NUMBER OF COEFFICIENTS)
       NPP      =  144
  WINDOW
       RW. (CM) =    153.600   448.100
       ZW. (CM) =   -231.450   231.450

  MAGNETIC AXIS
       XP0 (CM) =    308.000
       YP0 (CM) =      0.180
       FP0      =     -0.001
  BT        (G) =  31248.3
  DPSI      (WB) =     8.877
  SIGMA          =     0.00009
  IGO            =     5
  ERROR CODE     =     0

------------------------------------------------------------------------


- WARNING(EQSEL) : Time derivatives of equilibrium quantities set to zero
                   as previous FALCON equilibrium time point is too far

* FLUPX *  NO X-POINT FOUND

  PLASMA BOUNDARY (AXIS VALUES)
       R,Z (CM) =    412.972     0.180
       FBFL     =    1.00000
       ABFL(CM) =    104.972

  CLOSED SURFACE NEAR VESSEL (AXIS VALUES)
       R,Z (CM) =    420.257     0.180
       FMAFL    =    1.10179
       AMAFL    =    1.0694


Profile mapping and construction (MAPROF)
*****************************************

Modelling packages (MODEL)
**************************


- WARNING(IONDEN) :  ====> Ti-profile assumption:
                     Tio from PPFs --> NXTI =  3
                     replaced by FALCONs neutron temp with AMMAG =   1.000
```

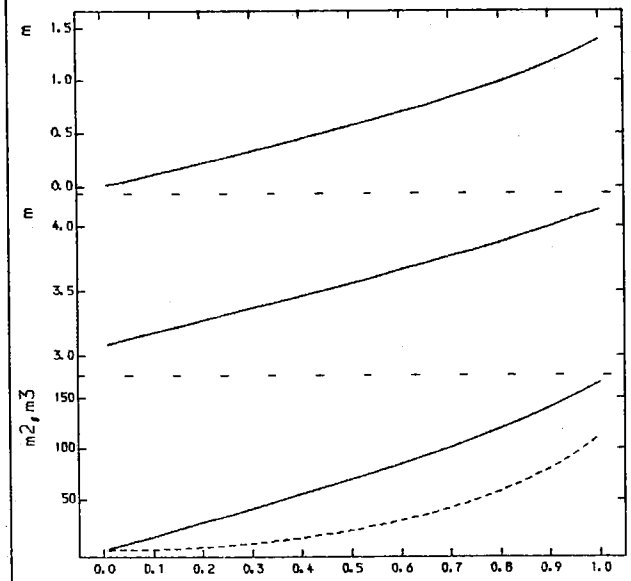
```
*** Data for shot  19739 written to PPF with seq. no.     99

 TOTAL CPU TIME TAKEN THIS SESSION :     22.855
```

The following graphs have been obtained by executing the clist *PFALC* described in Section 6.5. They show a selection of radial profiles stored in the JET PPF system (under the user's id) as a result of the above automatic run.

TTTTTTTT BBBBBBBB HHHHHHHH OOOOOOOO PPPPPPPP LLLLLLLL

FALCON - Geometry SHOT 19739



SYMBOL TABLE

Avg. flux surf. radius (0)
(FALC AVRA T 46.50)
( )

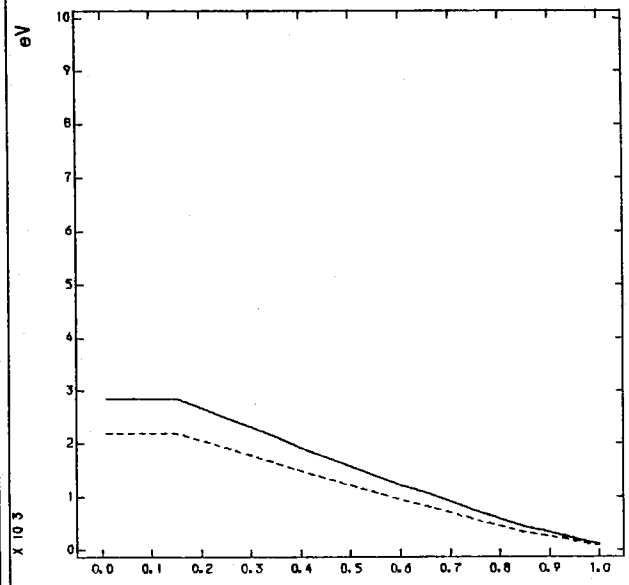
Outer major radius (0)
(FALC RHAJ T 46.50)
( )

Area of flux tube (0)
(FALC SURF T 46.50)
( )

Flux surface volume (0)
(FALC VOLU T 46.50)
( )

BHOPLT 16.47.22 07/12/90

FALCON - Temperature profiles SHOT 19739



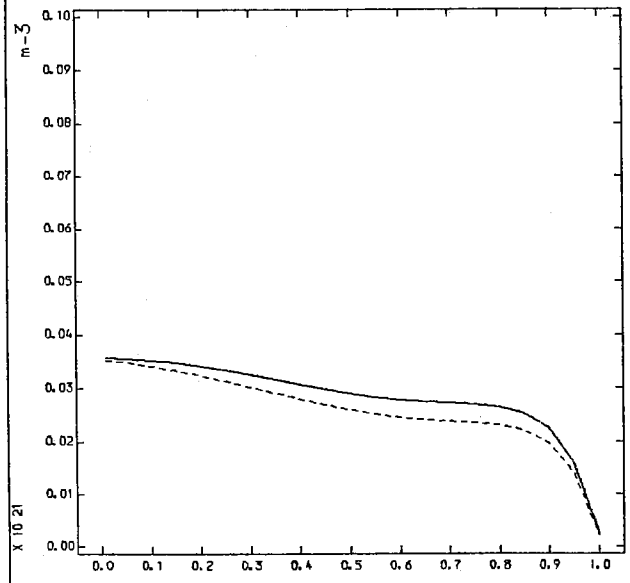
SYMBOL TABLE

Electron temp. profile (0)
(FALC XTE T 46.50)
( )

Ion temp. profile (0)
(FALC XTI T 46.50)
( )

BHOPLT 16.49.25 07/12/90

FALCON - Density profiles SHOT 19739



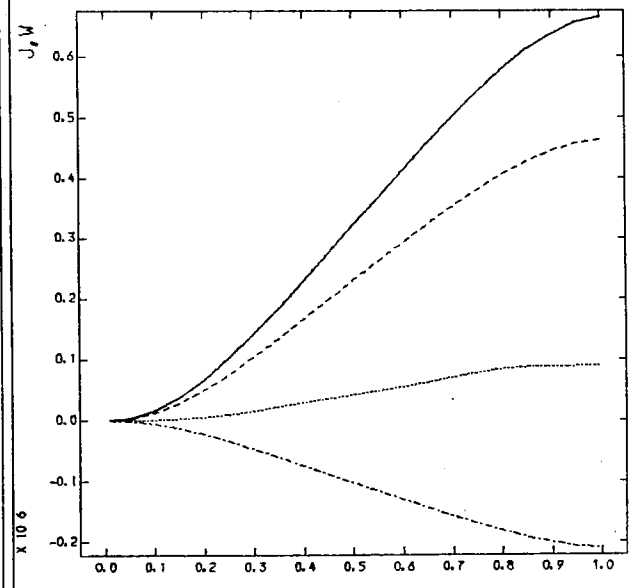
SYMBOL TABLE

Electron density profile (0)
(FALC XNE T 46.50)
( )

Total ion dens. profile (0)
(FALC XNI T 46.50)
( )

BHOPLT 16.49.25 07/12/90

FALCON - Kinetic energy content and dW/dt SHOT 19739



SYMBOL TABLE

Electron kinetic energy (0)
(FALC WETH T 46.50)
( )

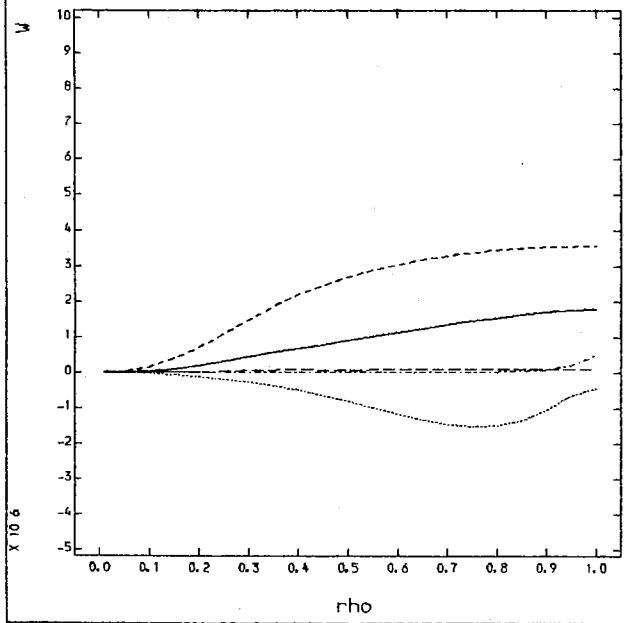
Ion kinetic energy (0)
(FALC WITH T 46.50)
( )

d/dt (elec. kin. energy) (0)
(FALC WEDT T 46.50)
( )

d/dt (ion kin. energy) (0)
(FALC WIDT T 46.50)
( )

BHOPLT 16.49.25 07/12/90

FALCON - Ion energy sources and sinks SHOT 19739

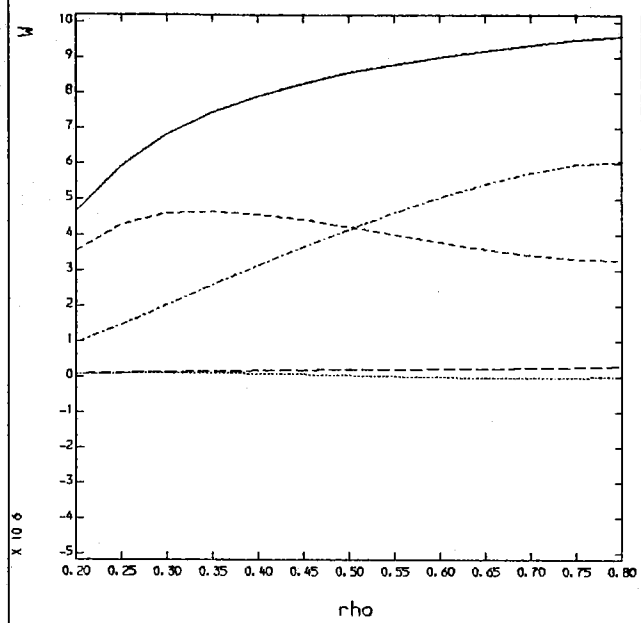


SYMBOL TABLE

- NBI power dep. on ions (0) (FALC PINB T 50.00) ( )
- ICRH power dep. on ions (0) (FALC PIRF T 50.00) ( )
- e-i equipartition power (0) (FALC PEI T 50.00) ( )
- Charge exchange power (0) (FALC PCX T 50.00) ( )
- d/dt (ion kin. energy) (0) (FALC WIDT T 50.00) ( )

BHOPLT 16.49.34 07/12/90

FALCON - Energy fluxes SHOT 19739

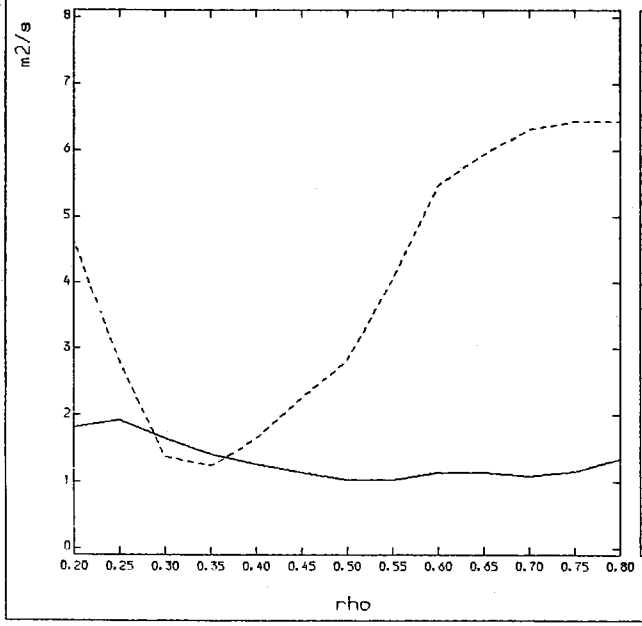


SYMBOL TABLE

- Total integ. heat flux (0) (FALC QTOT T 50.00) ( )
- Electron cond. heat flux (0) (FALC QCDE T 50.00) ( )
- Electron conv. heat flux (0) (FALC QCVE T 50.00) ( )
- Ion conductive heat flux (0) (FALC QCDI T 50.00) ( )
- Ion convective heat flux (0) (FALC QCVI T 50.00) ( )

BHOPLT 16.49.35 07/12/90

FALCON - Thermal conductivities SHOT 19739

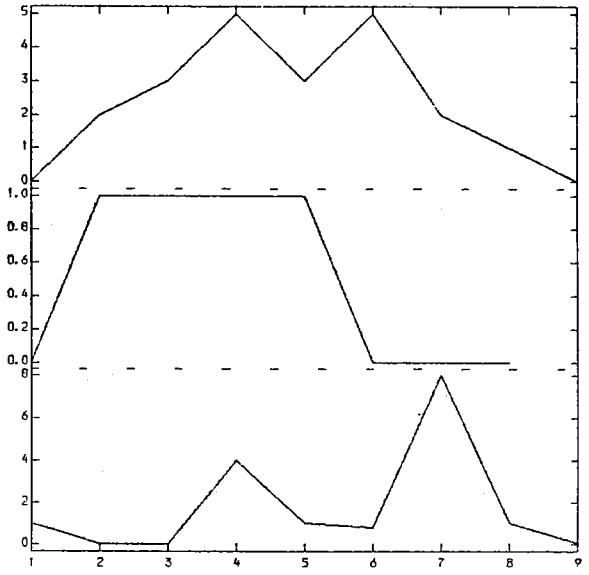


SYMBOL TABLE

- Elec. ther. conductivity (0) (FALC CHIE T 50.00) ( )
- Ion thermal conductivity (0) (FALC CHII T 50.00) ( )

BHOPLT 16.49.35 07/12/90

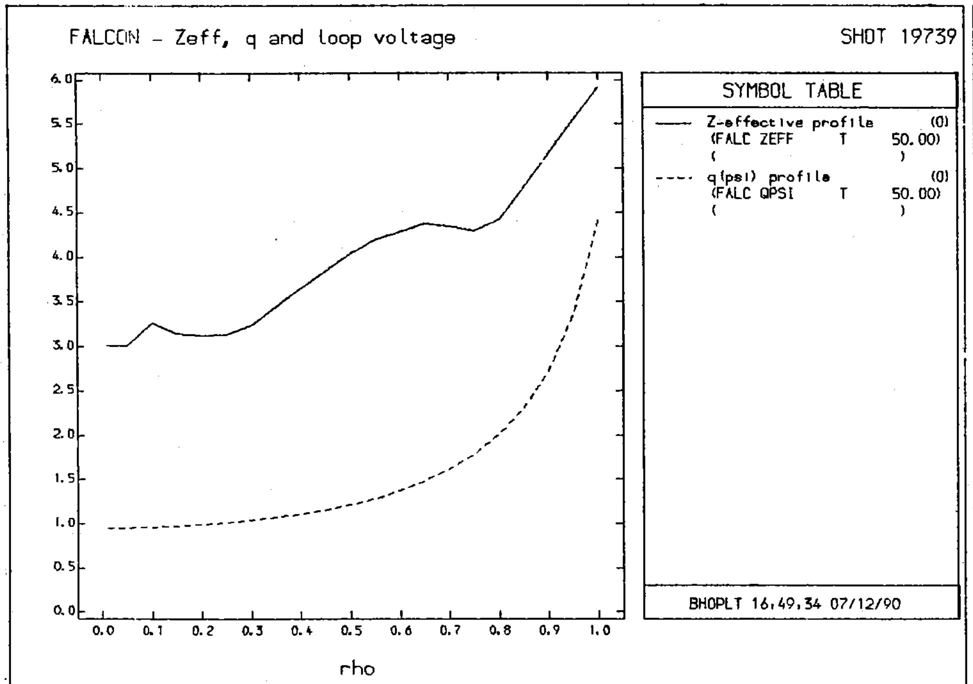
FALCON - Switches and input parameters SHOT 19739

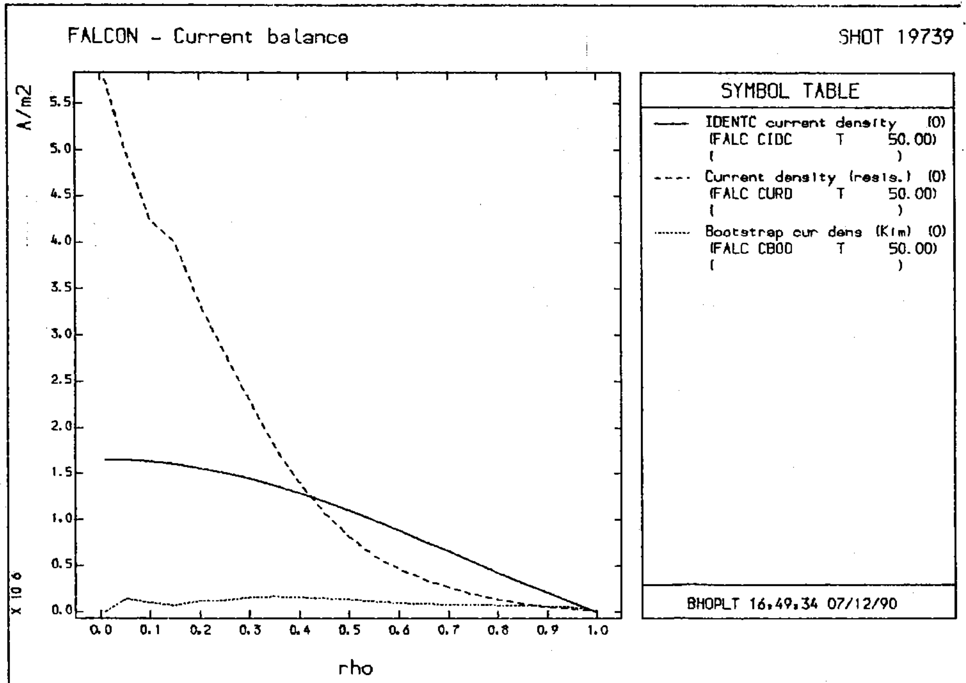


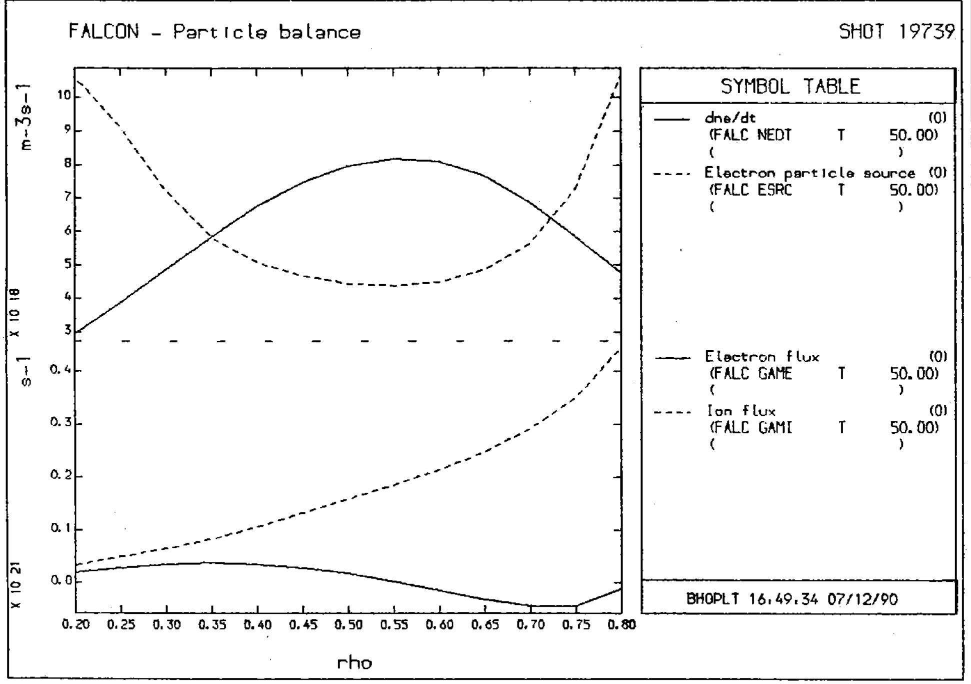
SYMBOL TABLE

- Input control switches (0) (FALC SCON T 50.00) ( )
- Phys. modelling switches (0) (FALC SMOD T 50.00) ( )
- Input parameters (0) (FALC PARM T 50.00) ( )

BHOPLT 16.49.35 07/12/90


FALCON - Zeff, q and loop voltage
SHOT 19739
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
rho
SYMBOL TABLE
Z-effective profile (0) (FALC ZEFF T 50.00) ( )
q(psi) profile (0) (FALC QPSI T 50.00) ( )
BHOPLT 16.49.34 07/12/90


FALCON - Current balance
SHOT 19739
A/m2
X 10 6
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
rho
SYMBOL TABLE
IDENTC current density (0) (FALC CIDC T 50.00) ( )
Current density (resis.) (0) (FALC CURD T 50.00) ( )
Bootstrap cur dens (Kim) (0) (FALC CBOO T 50.00) ( )
BHOPLT 16.49.34 07/12/90


FALCON - Particle balance
SHOT 19739
m-3s-1
X 10 18
s-1
X 10 21
10
9
8
7
6
5
4
3
0.4
0.3
0.2
0.1
0.0
0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
rho
SYMBOL TABLE
dne/dt (0) (FALC NEDT T 50.00) ( )
Electron particle source (0) (FALC ESRC T 50.00) ( )
Electron flux (0) (FALC GAME T 50.00) ( )
Ion flux (0) (FALC GAMI T 50.00) ( )
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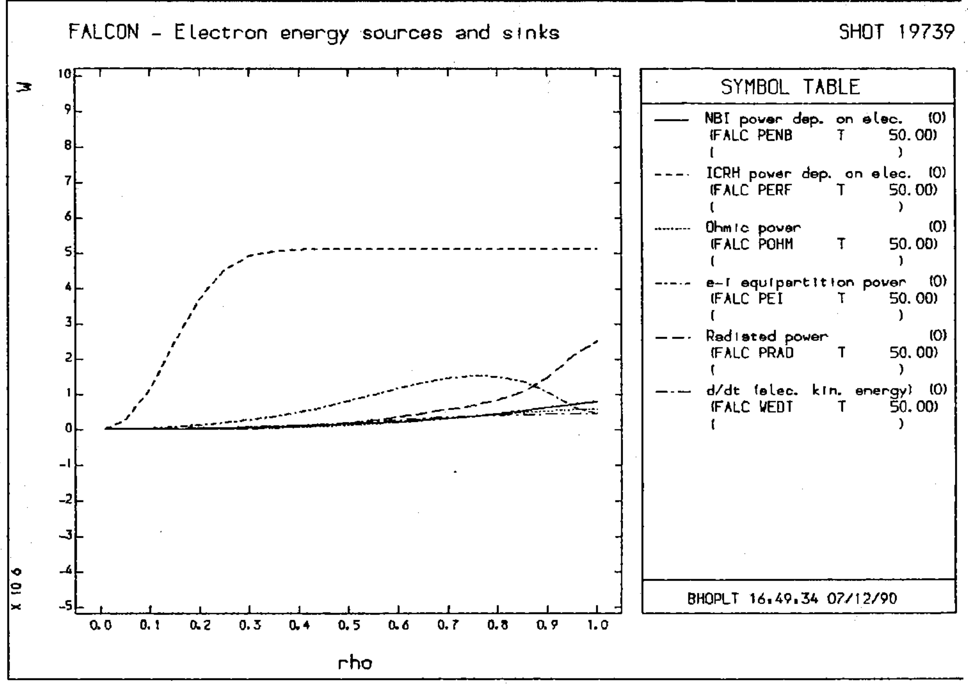
FALCON - Electron energy sources and sinks
SHOT 19739
W
X 10 6
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
rho
SYMBOL TABLE
NBI power dep. on elec. (0) (FALC PENB T 50.00) ( )
ICRH power dep. on elec. (0) (FALC PERF T 50.00) ( )
Ohmic power (0) (FALC POHM T 50.00) ( )
e-i equipartition power (0) (FALC PEI T 50.00) ( )
Radiated power (0) (FALC PRAD T 50.00) ( )
d/dt (elec. kin. energy) (0) (FALC WEDT T 50.00) ( )
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