SÉMINAIRE

À

L'INRS-ÉNERGIE ET MATÉRIAUX

ZOUHIER ABOU-ASSALEH

AEA-Fusion, Culham

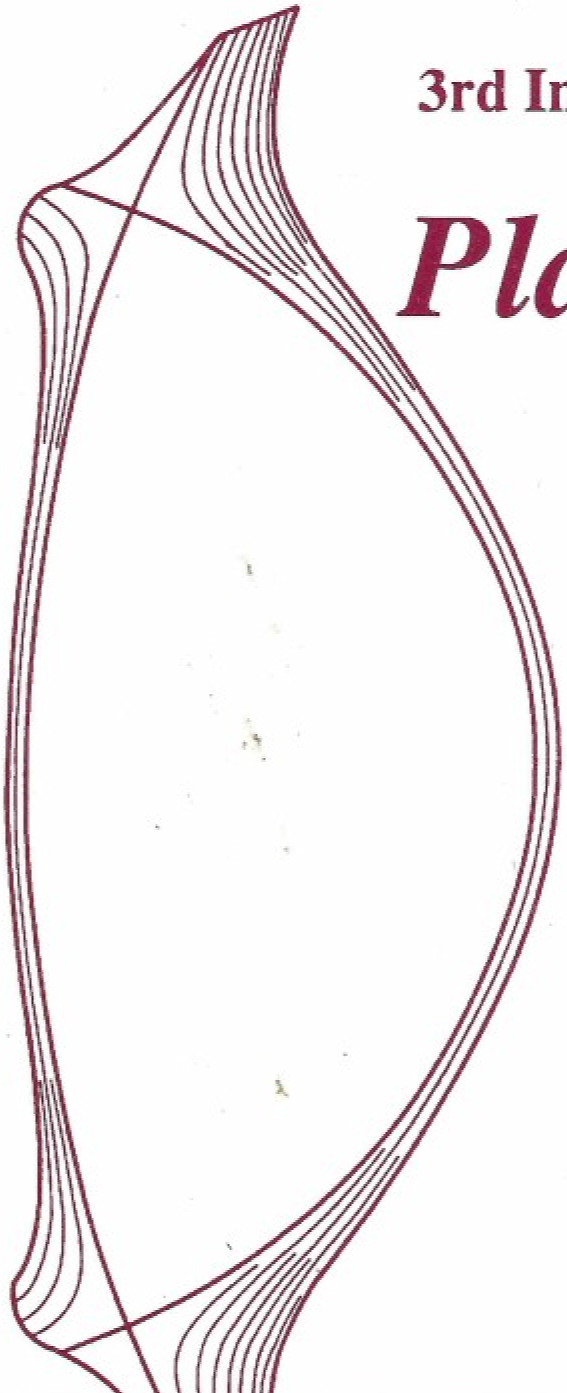
Vendredi le 7 août 1992 à 10h30

"Modélisation du plasma de bord dans le déflecteur d'un tokamak"

Z. ABOU-ASSALEH

FORSCHUNGSZENTRUM JÜLICH GmbH

KFA



3rd International Workshop on

Plasma Edge Theory in Fusion Devices

Bad Honnef
Physikzentrum
22 - 24 June 1992

Abstracts

Review of Papers at the 3rd International Workshop on Plasma Edge Theory
Bad Honnef, Federal Republic of Germany. 92
Zouhier Abou-Assaleh, Ph.D., Culham Laboratory, Abingdon, Oxfordshire, UK. AEA Fusion

INRS

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Zouhier ABOU-ASSALEH
INRS - énergie et Matériaux
AEA-Fusion, Culham

- 3rd International workshop on plasma Edge Theory Bad Honnef. 1992.
- Edge activities at LLNL and UCLA
- Review of Paper on "New Boundary conditions By Yu. L. Igitkhanov et al Presented at Bad Honnef 1992
- Fokker-Planck Modelling of edge Plasma Near the Neutralizer plate in a Tokamak By: Z. ABOU-ASSALEH et al. presented at Bad Honnef 1992.

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Forschungszentrum Jülich GmbH
Institute for Plasma Physics

3rd International Workshop on

Plasma Edge Theory in Fusion Devices

Abstracts of the Papers Presented

Physikzentrum Bad Honnef, Germany
22 - 24 June 1992

The Workshop was jointly organized by the Forschungszentrum Jülich and the Arbeitsgemeinschaft Plasmaphysik of the Universities of Bochum, Düsseldorf, Essen and KFA Jülich.

June 1992

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2D

- R. Zanino : Finite element modelling of the scrape-off layer
  Garching-Torino
- A. Taroni : The multifluid codes EDGE1D and EDGE2D : Models and results
  JET
- K. Parbhakar & J. Lewendowski : properties of a biased divertor scrape-off layer plasma (1D)
  INRS
- T. D. Rognlien, et al : A fully implicit, 2-D fluid transport code for simulating tokamak edge plasma.
  LLNL

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B2

- W. D. D'haeseler, H.D. Pacher, G.W. Pacher
  NET
  B2 with an analytical recycling model for ITER/NE
- M.W. Wuttke et al.: Validation of the B2-EIRENE
  Julich code by comparison with TEXTOR experiments
- H. Kastelewicz et al.,: Parameter study of the diverto
  Garching conditions in ASDEX-up-grade

  B2, Analytical recycling, EIRENE (neutra
- R. Schneider et al. : extensions of B2 for the
  Garching simulation of ASDEX-upgrade scrape-off Layer plasma

  - Deuterium plasma & Helium ions as impurity
  - Neutral atoms and molecules:
    Monte-carlo code EIRENE
  - B2 plasma profiles → calculates the source terms
  - B2-EIRENE more realistic recycling model than the stand-alone B2-code.

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Kinetic

- Krasheninnikov et al.
  - Kinetic modeling of the transport processes in the tokamak edge plasma. (Preliminary results).
  - Electron Heat conduction and suprathermal particles

- R. Chodura (Garching)
  - Kinetic Effects in the scrape-off layer

    Non-Maxwellian : 1- sources: from the bulk plasma
    Reionized recycled neutral

    2- Parallel transport

    3- sheath

- Z. ABOU-ASSALEH et al,

  Fokker-Planck Modelling of Edge plasma Near the Neutralizer plate in a tokamak..

  * electron kinetic / ion fluid

UCLA

R.W. Conn
F. Najmabadi } PISCES ($D_\perp$, $D_\parallel$) 1D & 2D Modelling
Y. HIROOKA
B. Merriman → UCLA next-generation code

LLNL

T. D. Rognlien
M. E. Rensink
G. D. Porter
⋮

2D code : LEDGE — Fully implicit 2D fluid

Applications: DIII-D

Boundary Conditions

- K. Günther : Boundary conditions for the momentu
  Berlin and energy flux of ions at the plasma - sheath interface.

- Yu. L. Igitkhanov et al.
  Kurchatov Institute, Moscow

  - Effective Boundary conditions at the plasma - surface ~~interaction~~ interface.

  - The influence of Different Boundary conditions on the Divertor plasma parameters.

Effective Boundary conditions at the Plasma-surface interface.

Yu. L. Igitkhanov, A.M. Runov

Presented at the 3rd International workshop on plasma Edge Theory in Fusion Devices, Bad Honnef, Germany 1992.

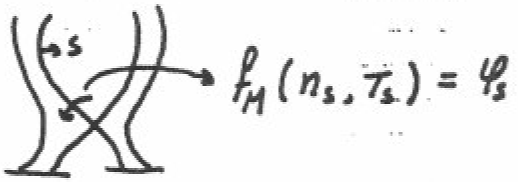
- Fluid can be used if the nonlocal effects are included into the transport coefficients and the appropriate boundary conditions are present.
- The existing boundary conditions do not permit to include the contribution of suprathermal particles due to their local nature.
- New Boundary conditions for fluid models of SOL and divertor plasma:

New Boundary conditions

- starting from BGK Kinetic equation
- This boundary conditions permit to extent the applicability of fluid equations to the moderate collisionality regimes typical for the divertor plasma.
- The BGK approximation gives an apportunity to express the boundary fluxes as functions of fluid profiles instead of local values
- Used $T_i = 0$:
  The Boundary conditions effects By
  - whole ion distribution function
  - Hot tail of the electron distribution function.

Kinetic Model

1D along $\overrightarrow{B}$
e-e collisions presented by the BKG approximation
e-n collisions



$$v_x \frac{\partial F}{\partial x} = \nu_m (n \varphi_m - F) + 0.5\, n\, \nu_n\, \delta(|v_x| - v_0)\, \delta(v_y)\, \delta(v_z) - \nu_n F + \nu_s n_s \varphi_s\, \vartheta(-|x| + a) - F \nu_s$$

$1/\nu_m$ is the Maxwellization time

F is the electron distribution function
φ_s is the Maxwellian
φ_m is the local shifted Maxwellian
ν_n is the frequency of ionisation
$\nu_s = N < \sigma v >$, $N(x) = N_w \exp(-|x|/\lambda - L/\lambda)$

Boundary conditions at the entrance of the Debye sheath:

- Mirror reflection for the particles with energy below a potential barrier
- φ_d the sheath drop is found from the local parameters of φ_m, n, T, and V

New variables

$$\xi = \frac{x}{L} \quad , \quad u = \frac{v_x}{v_s} \quad , \quad \tilde{T} = \frac{T}{T_s} \quad , \quad \tilde{V} = \frac{V}{V_s}$$

The solution of the kinetic equation:

$$f^{+}(u, \xi) = \exp\left[- \int_{-1}^{\xi} \frac{d\xi'}{u} \right] \int_{-1}^{\xi} \frac{R(\xi')}{u} \exp\left[+ \int_{-1}^{\xi'} \frac{d\xi''}{u\tau} \right] d\xi'$$

$$+ C(u) \exp\left[- \int_{-1}^{\xi} \frac{d\xi'}{u\tau} \right]$$

where

$$1/\tau = \nu_m + \nu_n + \nu_s$$

$$R(\xi') = \frac{n}{\sqrt{\pi T}} \nu_m \exp\left[-(u - V^2)/T \right] + \nu_s \frac{\vartheta(-|\xi| + a_-)}{\sqrt{\pi}} \exp(-u^2$$

$$+ 0.5\, n \nu_n \delta(|u| - u_0)$$

[redacted] + : half space of positive velocities

$C(u)$: mirror reflection from the wall.

Fluid Model

Set of fluid equations: particles, energy, and momentum with sink and source terms

Boundary conditions:

at $\xi = 0$ (symmetry plane): $j\big|_0 = 0$, $\frac{\partial T}{\partial \xi}\Big|_0 = 0$

at $\xi = 1$ (plate): The particle, momentum and heat flux values are obtained by integration of $f^+(u,\xi)$

Profiles obtained by iteration

Boundary conditions at the plate with the profiles of hydrodynamic quantities T, v, n and to include kinetic effects into the fluid approach.

Improvement of the transport coefficients by including the nonlocal effects

Heat flux

$$\left(\nu + \frac{8}{3}\frac{\partial u}{\partial x}\right) q = \alpha\, \nu_m\, q_{SH} + \frac{5}{3}\, u P \frac{\partial u}{\partial x} - (R u - Q)$$

where: $\nu = \nu_m + \nu_s + \nu_n$

u is the fluid velocity

$P = nT$

R and Q are the integrals over f_e with the weight of v^2 and $v^2 v_x$

q_{SH} is the classical expression

Viscosity

$$\pi = -\frac{4}{3\nu_m}\, nT\, 0.73 \left[\frac{\partial v}{\partial x} + \frac{2}{5}\frac{1}{nT}\frac{\partial q}{\partial x}\right]$$

q is the thermal conduction flux.

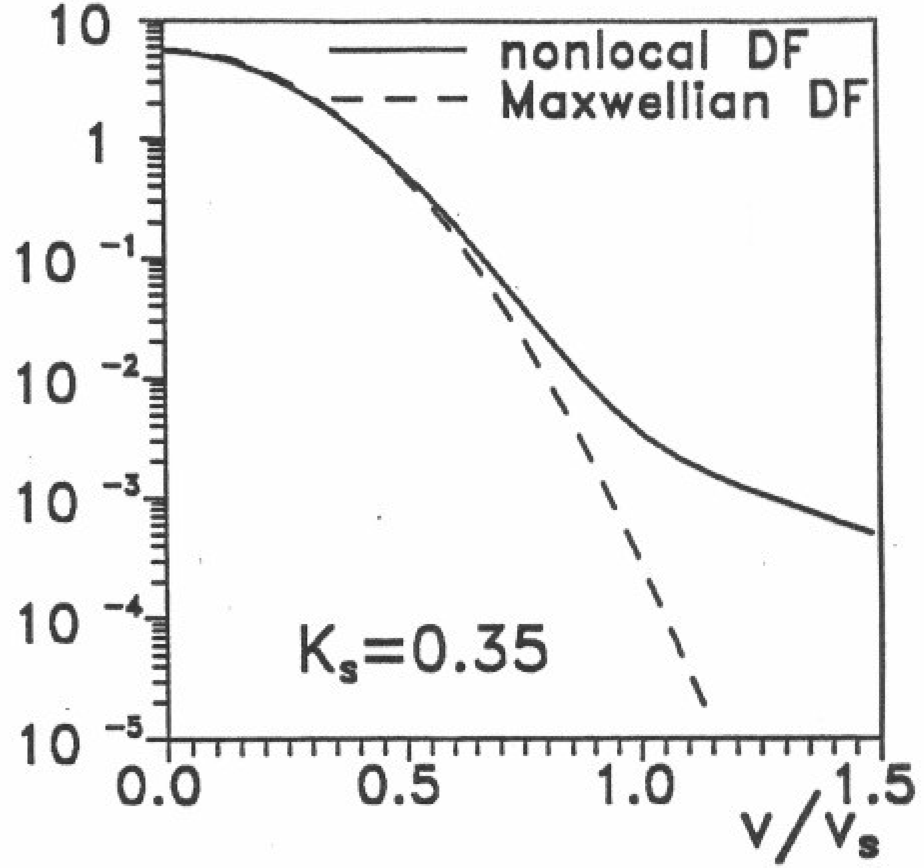


Fig.1 The comparison of the boundary distribution functions, corresponding to the nonlocal boundary conditions with the Maxwellian one

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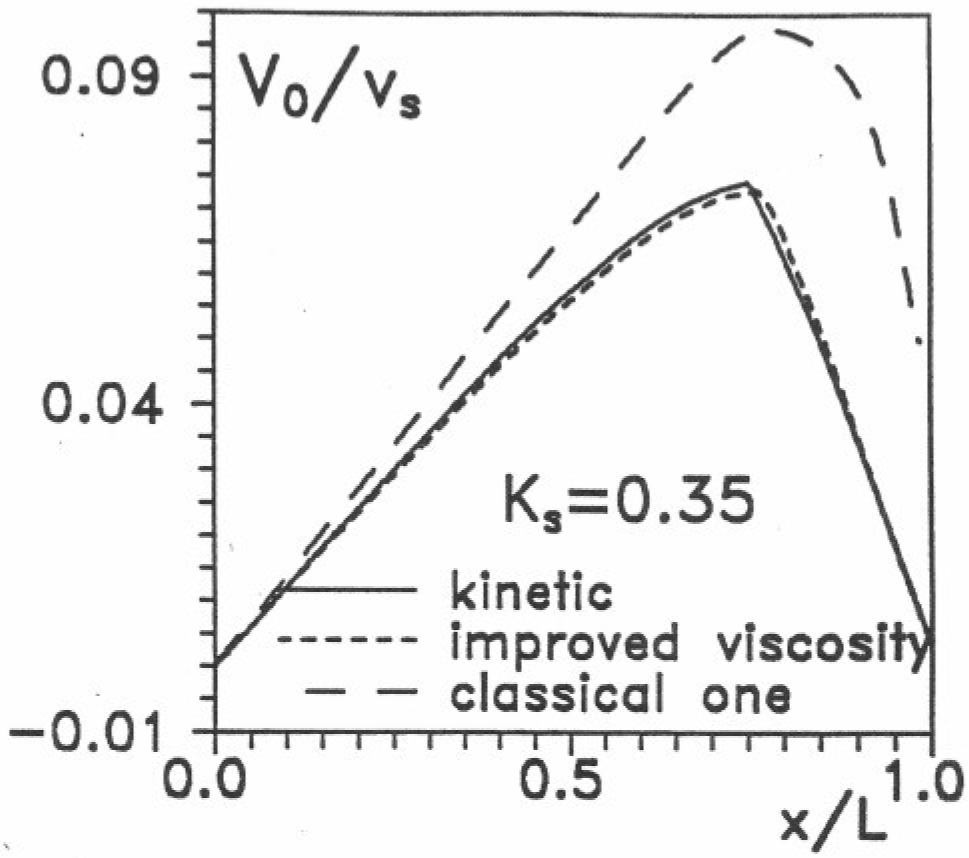

Fig.2 The velocity profiles corresponding to the classical viscosity, the improved one and the result of kinetic treatment

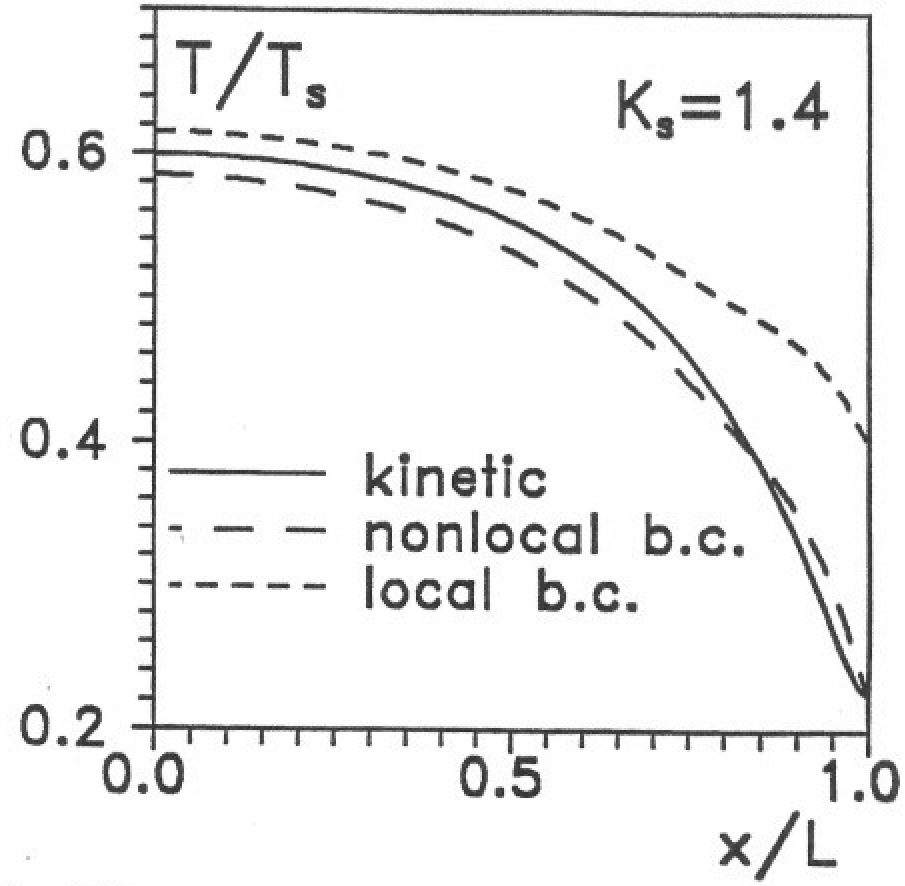

Fig.3 The temperature profiles for three cases: kinetic, local and nonlocal boundary conditions

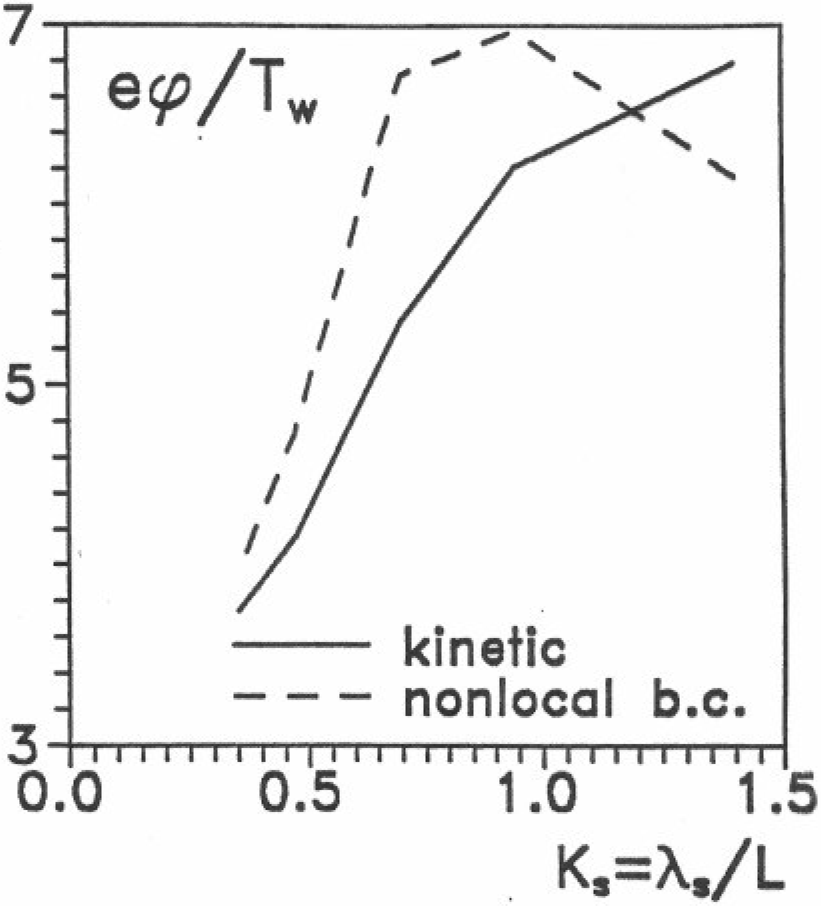

Fig.4 The sheath potential drop vs $K_s=\lambda_s/L$, where λ is electron mean free path and L is the length of magnetic field line

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Conclusions.

1.The effective boundary conditions for the fluid set of equation at the plasma surfase interfase, which include the kinetic effects, are suggested.

2.The BGK approximation gives an opportunity to express the boundary fluxes as functionals of fluide profiles insted of local values.

3.The comparison with the kinetic solution shows that the propoused boundary conditions give such an accuracy of plasma parameters at the plate which is provided by the proximity of fluide profiles to the kinetic ones, i.e. the contribution of suprathermal particles in the transport coefficients is taken into account.

4.The conventional viscosity therm does not allow one to obtain the velocity profiles close to the kinetic ones. It has been shown that the usage of a viscous therm from the 13 - moment Grad approximation, taking account of a heat flux contribution, is more adequate to represent the regimes of moderate collisionality.

5.The flux - limited classical electron heat conduction does not bring to satisfactory resultes. The expression for a thermal heat flux in terms of higher moments of distribution function, could be recommeded for the fluid codes.

$$\begin{Bmatrix} j \\ \Pi \\ q \end{Bmatrix} = \int G(\nabla n, T, v)\, dv$$

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Fokker-Planck Modelling Of Edge Plasma Near The Neutralizer Plate In A Tokamak

Z. Abou-Assaleh*, J.P. Matte, T.W. Johnston and R. Marchand
INRS-Energie, C.P. 1020, Varennes, Quebec, Canada J3X 1S2

An electron kinetic code (FPI)+ is modified and used to simulate longitudinal transport and recycling near the neutralizer plate in a divertor plasma. In addition to the previous features, such as Fokker-Planck e-e and e-i Coulomb collisions, transport, ion motion, and a self-consistent electric filed, the code now accounts for ionization, excitation, and recycling of hydrogen near the plate. Ions and neutrals are treated as fluids. As one might expect, this full FPI code is very expensive to run, having fast (electron) and slow (ion motion) timescales. We therefore use this FPI code in conjunction with a two-fluid ambipolar code, whose electron heat flow is obtained from usual flux limited coefficients on thermal transport. We alternate the codes, using the FPI code to correct the fluid code's temperature and local heat transport, while using the fluid code for ion dynamics. We thus arrive at an equilibrium consistent with electron kinetics but at a tiny fraction of the cost of doing so with the FPI code alone. Results and applications will be discussed.

* Present address: Culham Laboratory, D2, Abingdon, Oxfordshire, UK

\+ J.P. Matte and J. Virmont, Phys. Rev. Lett. 49,1936 (1982); J.P. Matte, T.W. Johnston, J. Delettrez and R.L. McCrory, Phys. Rev. Lett. 53, 1461 (1984); J.H. Rogers, J.S. De Groot, Z. Abou-Assaleh, J.P. Matte, T.W. Johnston and M.D. Rosen, Phys. Fluids B1, 1989.

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INTRODUCTION

Aim:

Modelling of the divertor plasma in a tokamak (Particles and energy transport along the magnetic field line)

Methods:

Electron kinetic / ion fluid code (FPI)

1D and 2-fluid code

Iteration FPI code ↔ modified fluid code

FOKKER-PLANCK INTERNATIONAL CODE FPI

* Electrons are treated kinetically
* Ions and neutrals are treated as fluids.
* 1-D in space (x) and 2-D in velocity space $(v_x\ ,\ v_\perp)$.
* The electron distribution function is:

$$f(X,V,t)=f(x,v_x,v_\perp,t)=f(x,v,\mu,t)=\sum_{l=0}^{N} f_l(x,v,t)P_l(\mu)$$

where $v=(v_x^2+v_\perp^2)^{1/2}$, $\mu=v_x/v$ and $P_l(\mu)$ is the l th Legendre polynomial. We have used N=3 in the simulations.

* The kinetic equation for the electron is given by :

$$\frac{\partial f}{\partial t}+v_x\frac{\partial f}{\partial x}+\frac{eE}{m_e}\frac{\partial f}{\partial v_x}=\left(\frac{\partial f}{\partial t}\right)_{(e-i,e-e)}+\left(\frac{\partial f}{\partial t}\right)_{(E_{ei})}+\left(\frac{\partial f}{\partial t}\right)_{(e-n)}$$

- The second and third terms in the left hand side are the advection and the acceleration due to the electric field, respectively.
- The right-hand side terms represent respectively electron-ion, electron-electron, Coulomb scattering, electron-ion energy exchange and electron-neutral collisions.

* f_l's are advanced in time.

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FLUID CODE

The code solves for a single density, single velocity and two temperatures as a function of time. The following equations are advanced in time:

Continuity:

$$\frac{\partial}{\partial t}n+\frac{\partial}{\partial x}(nv)=S_n$$

Momentum balance:

$$\frac{\partial}{\partial t}(m_i nv)+\frac{\partial}{\partial x}\left(m_i nv^2+P_e+P_i-\frac{4}{3}\eta\frac{\partial V}{\partial x}\right)=S_p$$

Electron energy balance:

$$\frac{\partial}{\partial t}\left(\frac{3}{2}nT_e\right)+\frac{\partial}{\partial x}Q_e=v\frac{\partial}{\partial x}P_e+E_{ei}+S_e$$

Ion energy balance:

$$\frac{\partial}{\partial t}\left(\frac{3}{2}nT_i+\frac{1}{2}m_i nv^2\right)+\frac{\partial}{\partial x}\left(Q_i-\frac{4}{3}\eta v\frac{\partial v}{\partial x}\right)=-v\frac{\partial}{\partial x}P_e-E_{ei}+S_i.$$

With:

$$q_e=q_{SH}\left[1+\frac{|q_{SH}|}{fn_e v_e T_e}\right]^{-1}$$

f = 0.2 (Electron heat flux limit factor)

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BOUNDARY CONDITIONS

FPI CODE

PLASMA SOURCE (x = 0):

Ions:	n_i , V_i and T_i are fixed.
Electrons:	T_e fixed. Zero current ($\Gamma_e=\Gamma_i$) is imposed as follows: incoming particles are absorbed and an appropriate current with half-Maxwellian distribution at this temperature is emitted.

PLATE SHEATH EDGE (x = L):

Ions:	Outgoing ions are absorbed by the plate.
Electrons:	Zero current ($\Gamma_e=\Gamma_i$) is imposed as follows: low energy electrons ($< m_e V_r^2/2$) are reflected so that the flux of higher energy electrons is equal to the ionic current.

FLUID CODE

PLASMA SOURCE (x = 0):

$n = n_{e,i}$, $V = V_{e,i}$, T_e and T_i are fixed.

PLATE SHEATH EDGE (X = L):

- The outgoing plasma is absorbed.
- Ion drift velocity : $V \geq C_S = \sqrt{(T_e+T_i)/m_i}$
- Heat flux: $Q_i=3.5nVT_i$, $Q_e=2\delta nVT_e$, ($\delta=3$)

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FLUID AND FOKKER-PLANCK HYBRID ITERATION

FLUID CODE

Moves ions ect. quickly, but electron heat flow is approximate.

FOKKER-PLANCK (FPI) CODE

Some ion dynamics but with electron kinetics, too slow on ion timescale.

SOLUTION

Iterate fluid modified by FPI
Use T_e(FPI) and force q_e to agree with FPI by correcting each grid point with correction factors:

$$CFQ = q_{e\text{-}FPI} / q_{e\text{-}fluid}(T_{e\text{-}FPI})$$

ITERATE UNTIL NO FURTHER SIGNIFICANT CHANGE

FINAL RESULT

Profile consistent with electron kinetic but at affordable cost.

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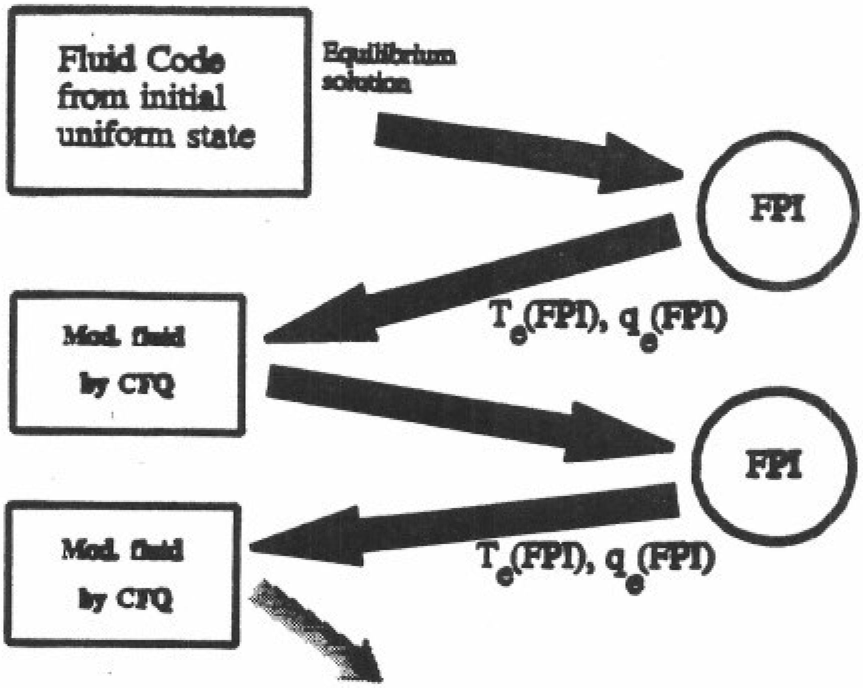
FLUID AND FOKKER-PLANCK HYBRID ITERATION



$$CFQ = \frac{q_{e\text{-}FPI}}{q_{e\text{-}fluide}\left(T_{e\text{-}FPI}\right)}$$

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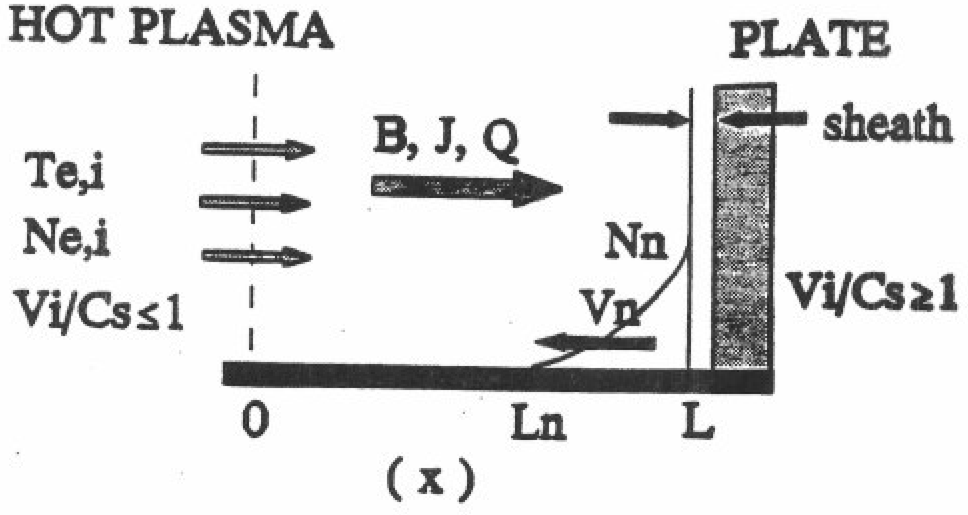
DIVERTOR PLASMA SIMULATIONS WITH HIGH RECYCLING



$L = 300$ cm
$T_{e0} = T_{i0} = 30$ eV
$n_{e0} = n_{i0} = 3\times10^{13}$ cm^{-3}
$m_n V_n^2/2 = 3$ eV
$n_n V_n = 0.8\, n_i V_i$ at $x=L$
$m_i/m_e = 1836$

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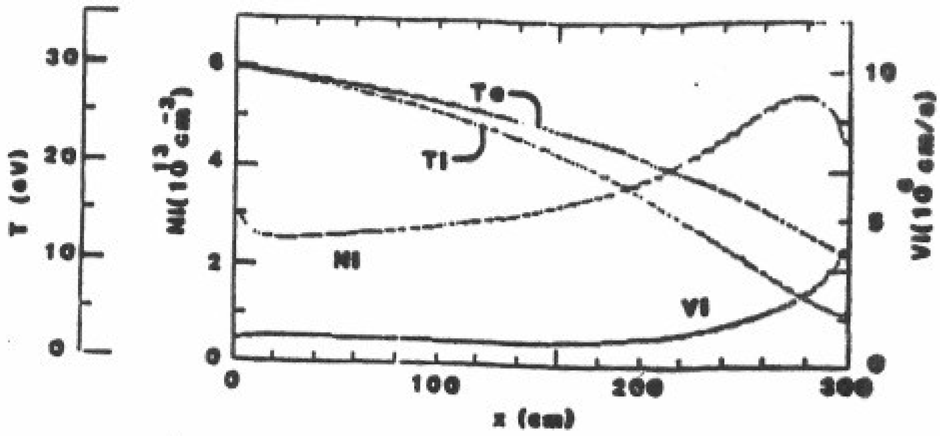
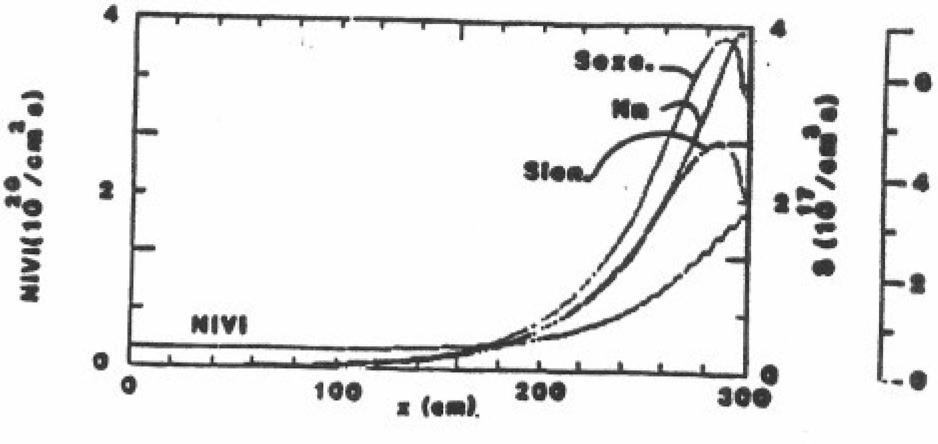
FLUID CODE SIMULATION

T_e , T_i , V_i and n_i vs x



n_iV_i , n_n , S_{exc} and S_{ion} vs x



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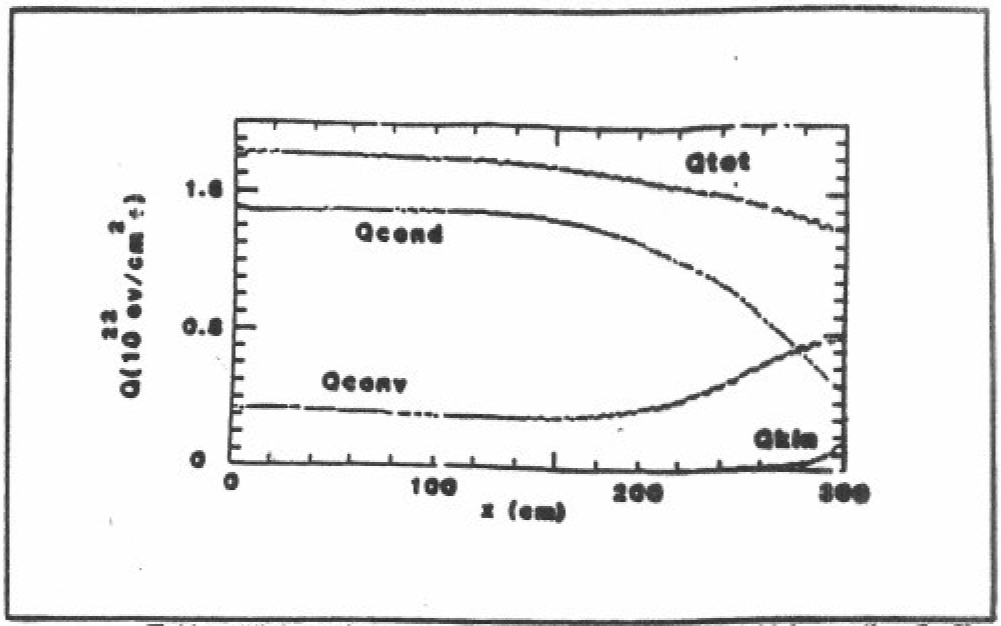
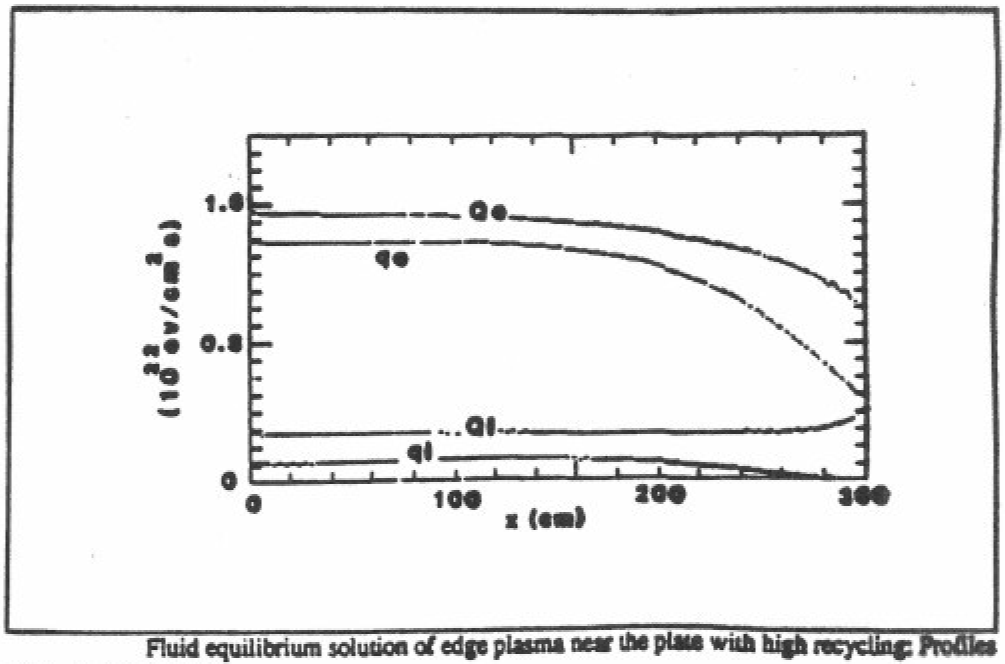
FLUID CODE SIMULATION

Energy flux



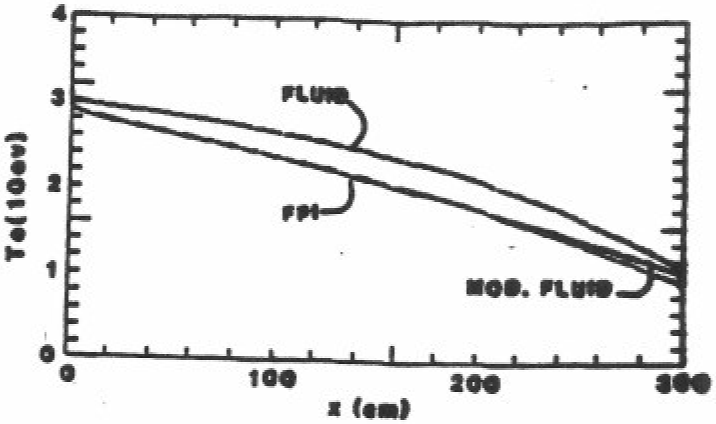
Fluid equilibrium solution of edge plasma near the plate with high recycling: Profiles of Q_{tot}, Q_{cond}, Q_{conv}, and Q_{kin}.



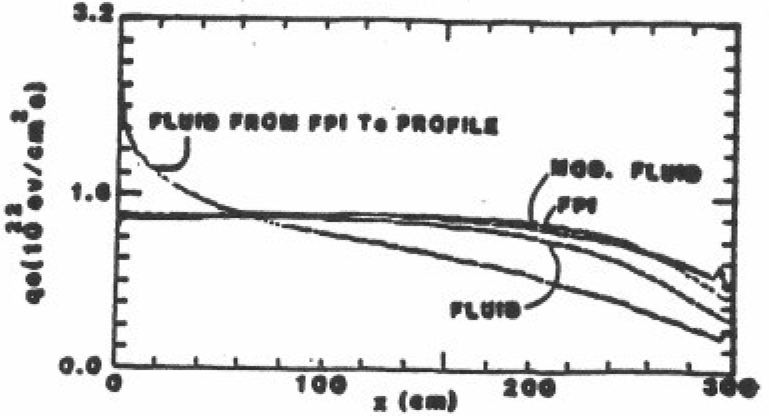
Fluid equilibrium solution of edge plasma near the plate with high recycling: Profiles of Q_e, q_e, Q_i, and q_i.

FLUID AND FOKKER-PLANCK HYBRID SIMULATION

Profile of T_e
Fluid (f=0.2), FPI and Mod. Fluid



Profile of q_e
Fluid (f=0.2), FPI and Mod. Fluid



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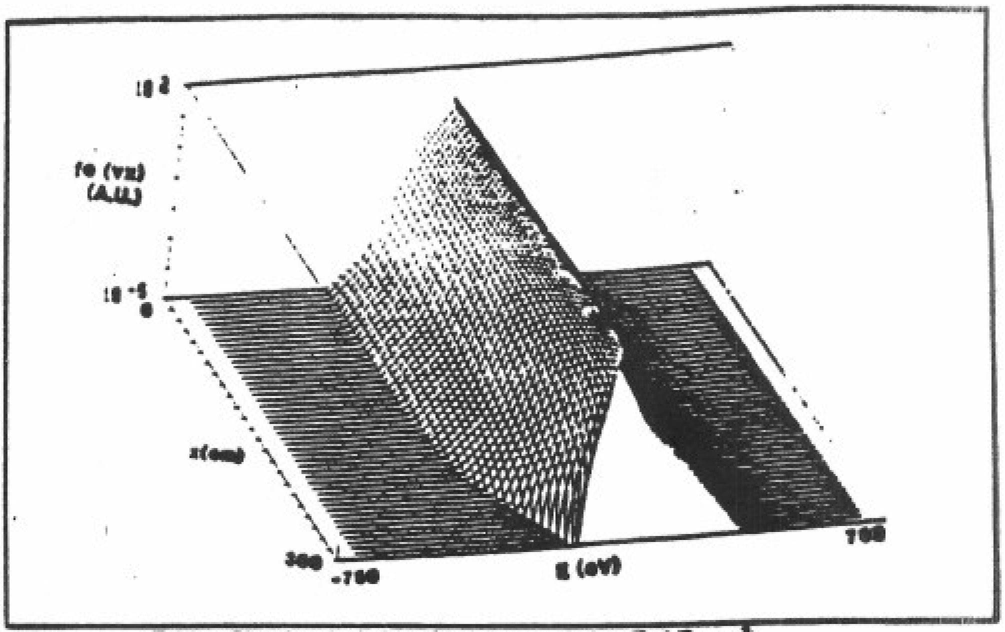
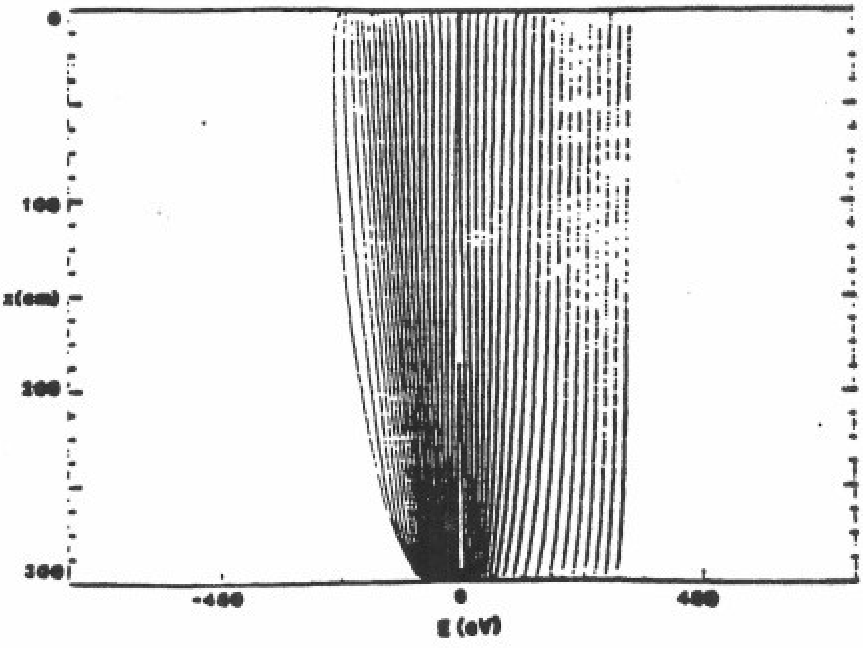
ELECTRON DISTRIBUTION FUNCTION CALCULATED BY FOKKER-PLANCK CODE



Fokker-Planck calculation: $f_e(v_x)$ vs x and sign $E=1/2m_ev_x^2$



Fokker-Planck calculation: the contour lines of $f_e(v_x)$ vs x and sign $E=1/2m_ev_x^2$. The truncation of fe(vx) at the plate is clearly seen from this figure.

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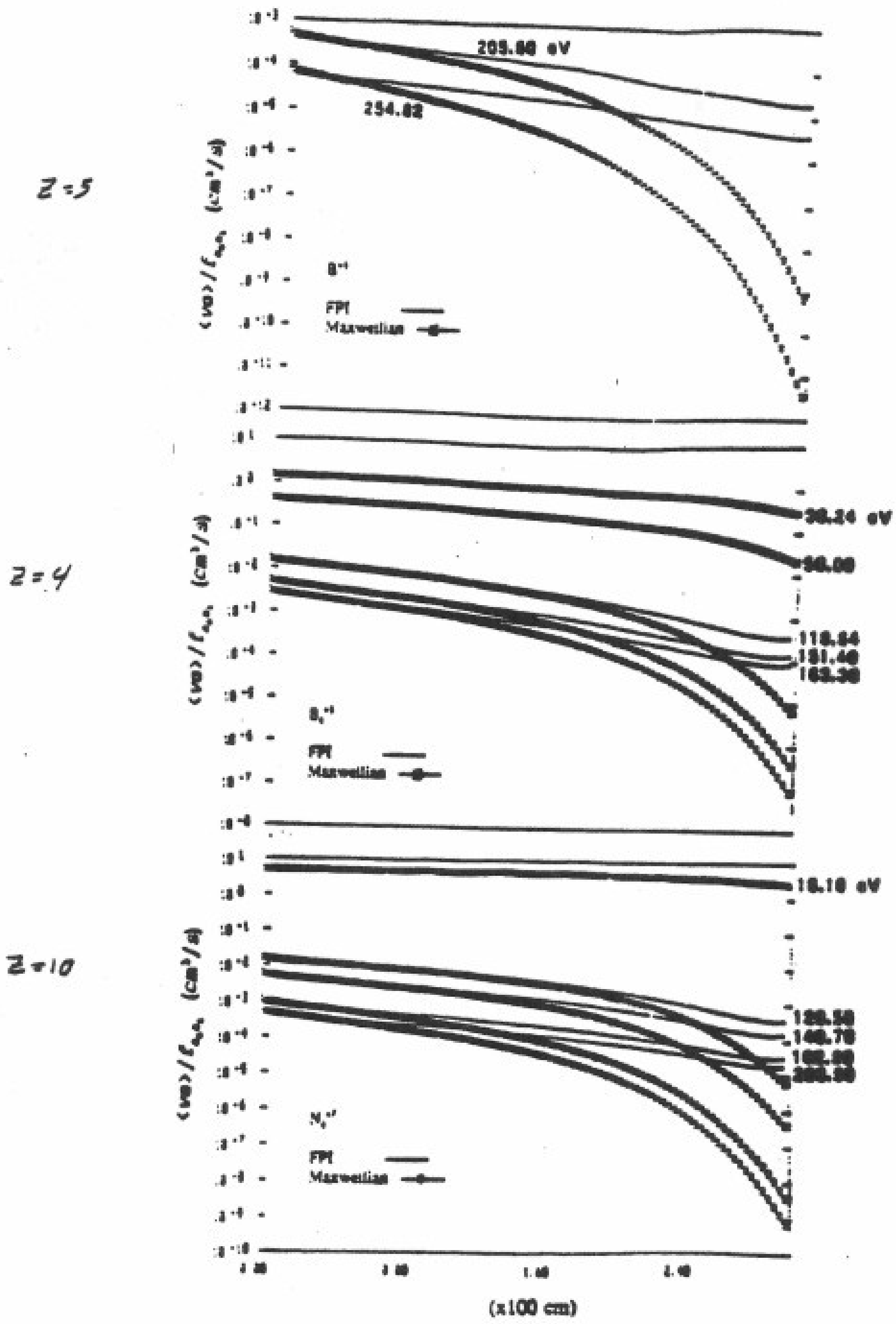
NON-MAXWELLIAN ELECTRON DISTRIBUTION EFFECT ON THE IMPURITIES RADIATIONS



CONCLUSION

We model the plasma transport along the magnetic field line in a tokamak divertor:

- Fluid and kinetic simulations.
- Including: ionization, excitation, boundary condition at the sheath edge.
- Hybrid technique was developed which produced an equilibrium solution with the electron kinetic model but with much reduced computer cost.
- Steep temperature gradients.
- The fluid code with electron heat flux limiter f=0.2 gave closer results to the Fokker-Planck calculation.
- The electron distribution function calculated from the FPI code is not locally Maxwellian, especially near the plate. The deviation from Maxwellian is due to the absorption of the most energetic electrons by the plate and to the non-local transport of high energy electrons.
- Effect of non-Maxwellian electron distribution function on the ionization and excitation of the impurities.

Present and Future work

Electron Kinetic / ion fluid

* change the recycling factor R

* Epithermal electron: The plasma to be injected to the system at $x = 0$ with bi-Maxwellian

see the effects on:

- plasma sheath and pre-sheath
  $e\Phi, q_e, T_e, N_e, \ldots$
- CFQ as a function of $\nu_{e.e}, \nu_{e.i}, \nu_{e-n}$
  n_0(neutral)....
- The heat flux limiter $f = ?$ in the fluid mode
- Q_e at the plate ~~to~~
- The effects of f_e (Non-Maxwellian) on the impurities radiations

* New Boundary conditions for the fluid model with the improvement of the transport coefficient by including the nonlocal effects "Model By Yu. L. Igitkhanov"

SÉMINAIRE
À
L'INRS-ÉNERGIE ET MATÉRIAUX

ZOUHIER ABOU-ASSALEH

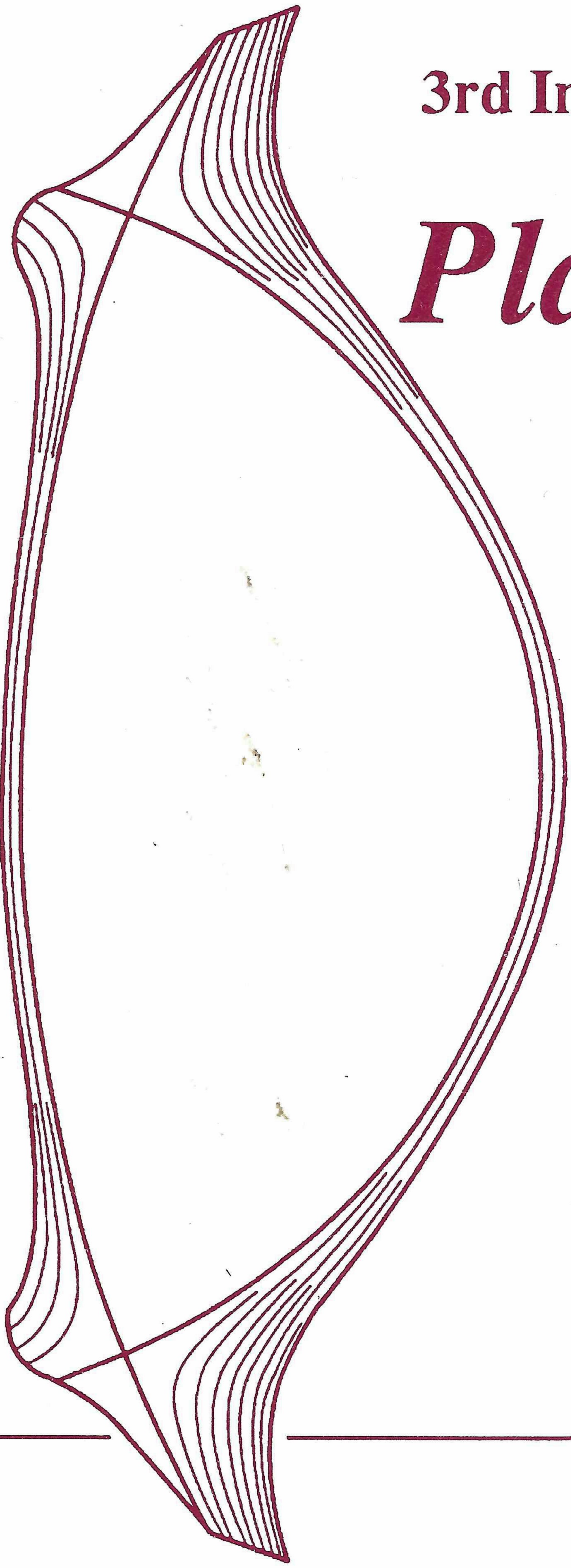
AEA-Fusion, Culham

Vendredi le 7 août 1992 à 10h30

*"Modélisation du plasma de bord
dans le déflecteur d'un tokamak"*

Z. ABOU-ASSALEH

FORSCHUNGSZENTRUM JÜLICH GmbH KFA



3rd International Workshop on

Plasma Edge Theory in Fusion Devices

Bad Honnef
Physikzentrum
22 - 24 June 1992

Abstracts

Review of Papers at the 3rd International Workshop on Plasma Edge Theory
Bad Honnef, Federal Republic of Germany. 92
Zouhier Abou-Assaleh, Ph.D., Culham Laboratory, Abingdon, Oxfordshire, UK. AEA Fusion

INRS

ÉNERGIE ÉNERGIE

ÉNERGIE ÉNERGIE

Zouhier ABOU-ASSALEH
INRS - énergie et Matériaux
AEA-Fusion, Culham

- 3rd International workshop on plasma edge Theory
  Bad Honnef. 1992.
- Edge activities at LLNL and UCLA
- Review of Paper on "New Boundary conditions
  By Yu. L. Igitkhanov et al
  Presented at Bad Honnef 1992
- Fokker-Planck Modelling of edge Plasma
  Near the Neutralizer Plate in a Tokamak
  By: Z. ABOU-ASSALEH et al.
  presented at Bad Honnef 1992.

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Forschungszentrum Jülich GmbH
Institute for Plasma Physics

3rd International Workshop on
Plasma Edge Theory in Fusion Devices
Abstracts of the Papers Presented
Physikzentrum Bad Honnef, Germany
22 - 24 June 1992

The Workshop was jointly organized by the Forschungszentrum Jülich and the Arbeitsgemeinschaft Plasmaphysik of the Universities of Bochum, Düsseldorf, Essen and KFA Jülich.

June 1992

2D

- R. Zanino Garching-Torino : Finite element modelling of the scrape-off layer
- A. Taroni JET : The multifluid codes EDGE1D and EDGE2D : Models and results
- K. Parbhakar & J. Lewendowski : INRS properties of a biased divertor scrape-off layer plasma (1D)
- T. D. Ragnlien, et al : LLNL A fully implicit, 2-D fluid transport code for simulating tokamak edge plasma.

B2

- W. D. D'haeseler, H. D. Pacher, G. W. Pacher
  NET
  B2 with an analytical recycling model for ITER/NE
- M. W. Wuttke et al.: Validation of the B2-EIRENE
  Julich code by comparison with TEXTOR experiments
- H. Kastelewicz et al.,: Parameter study of the diverto
  Garching conditions in ASDEX-up-grade

  B2, Analytical recycling, EIRENE (neutral
- R. Schneider et al. : extensions of B2 for the
  Garching simulation of ASDEX-upgrade scrape-off layer plasma

  - Deuterium plasma & Helium ions as impurity
  - Neutral atoms and molecules:
    Monte-carlo code EIRENE
  - B2 plasma profiles ⟶ calculates the source terms
  - B2-EIRENE more realistic recycling model than the stand-alone B2-code.

Kinetic

- Krasheninnikov et al.
  - Kinetic modeling of the transport processes in the tokamak edge plasma. (Preliminary results).
  - Electron Heat conduction and suprathermal particles

- R. Chodura (Garching)
  - Kinetic effects in the scrape-off layer

    Non-Maxwellian: 1- sources: from the bulk plasma
    Reionized recycled neutral
    2- Parallel transport
    3- Sheath

- Z. ABOU-ASSALEH et al.

  FoKKer-Planck Modelling of Edge plasma Near the Neutralizer plate in a tokamak..
  * electron kinetic / ion fluid

UCLA

R.W. Conn
F. Najmabadi
Y. HIROOKA
B. Merriman → UCLA next-generation code

PISCES ($D_\perp$, $D_\parallel$)
1D & 2D Modelling

LLNL

T. D. Rognlien
M. E. Rensink
G. D. Porter
⋮

2D code : LEDGE

Fully implicit
2D fluid

Applications : DIII-D

Boundary Conditions

- K. Günther : Boundary conditions for the momentu
  Berlin and energy flux of ions at the plasma - sheath interface.

- Yu. L. Igitkhanov et al.
  Kurchatov Institute, Moscow

  - Effective Boundary conditions at the plasma - surface ~~interaction~~ interface.
  - The influence of Different Boundary conditions on the Divertor plasma parameters.

Effective Boundary Conditions at the Plasma-surface interface.

Yu. L. Igitkhanov, A.M. Runov

Presented at the 3rd International workshop on plasma Edge Theory in Fusion Devices, Bad Honnef, Germany 1992.

- Fluid can be used if the nonlocal effects are included into the transport coefficients and the appropriate boundary conditions are present.
- The existing boundary conditions do not permit to include the contribution of suprathermal particles due to their local nature.
- New Boundary conditions for fluid models of SOL and divertor plasma:

New Boundary conditions

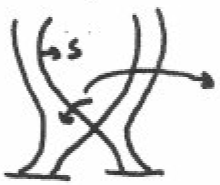
- starting from BGK Kinetic equation
- This boundary conditions permit to extent the applicability of fluid equations to the moderate collisionality regimes typical for the divertor plasma.
- The BGK approximation gives an apportunity to express the boundary fluxes as functions of fluid profiles instead of local values
- Used $T_i = 0$:
  The Boundary conditions effects By
  - whole ion distribution function
  - Hot tail of the electron distribution function.

Kinetic Model

1D along $\overrightarrow{B}$

e-e collisions presented by the BKG approximation

e-n collisions



$f_M(n_s, T_s) = \varphi_s$

$$v_x \frac{\partial F}{\partial x} = \nu_m (n \varphi_m - F) + 0.5 n \nu_n \delta(|v_x| - v_0) \delta(v_y) \delta(v_z)$$

$$- \nu_n F + \nu_s n_s \varphi_s \vartheta(-|x| + a) - F \nu_s$$

$1/\nu_m$ is the Maxwellization time

F is the electron distribution function

φ_s is the Maxwellian

φ_m is the local shifted Maxwellian

ν_n is the frequency of ionisation

$\nu_s = N < \sigma v >$, $N(x) = N_w \exp(|x|/\lambda - L/\lambda)$

Boundary conditions at the entrance of the Debye sheath:

- Mirror reflection for the particles with energy below a potential barrier
- φ_d the sheath drop is found from the local parameters of φ_m, n, T, and V

New variables

$$\xi = \frac{x}{L} \quad , \quad u = \frac{v_x}{v_s} \quad , \quad \tilde{T} = \frac{T}{T_s} \quad , \quad \tilde{V} = \frac{V}{V_s}$$

The solution of the kinetic equation:

$$f^{+}(u, \xi) = \exp\left[- \int_{-1}^{\xi} \frac{d\xi'}{u} \right] \int_{-1}^{\xi} \frac{R(\xi')}{u} \exp\left[+ \int_{-1}^{\xi'} \frac{d\xi''}{u\tau} \right] d\xi'$$

$$+ C(u) \exp\left[- \int_{-1}^{\xi} \frac{d\xi'}{u\tau} \right]$$

where

$$1/\tau = \nu_m + \nu_n + \nu_s$$

$$R(\xi') = \frac{n}{\sqrt{\pi T}} \nu_m \exp\left[-(u - V^2)/T \right] + \nu_s \frac{\vartheta(-|\xi| + a_-)}{\sqrt{\pi}} \exp(-u^2$$

$$+ 0.5\, n \nu_n \delta(|u| - u_0)$$

[redacted] + : half space of positive velocity

$C(u)$: mirror reflection from the wall.

Fluid Model

Set of fluid equations: particles, energy, and momentum with sink and source terms

Boundary conditions:

at $\xi = 0$ (symmetry plane): $j\big|_0 = 0$, $\frac{\partial T}{\partial \xi}\Big|_0 = 0$

at $\xi = 1$ (plate): The particle, momentum and heat flux values are obtained by integration of $f^+(u, \xi)$

Profiles obtained by iteration

Boundary conditions at the plate with the profiles of hydrodynamic quantities T, v, n and to include kinetic effects into the fluid approach.

Improvement of the transport coefficients by including the nonlocal effects

Heat flux

$$\left(\nu + \frac{8}{3} \frac{\partial u}{\partial \xi} \right) q = \alpha \nu_m q_{SH} + \frac{5}{3} u P \frac{\partial u}{\partial \xi} - (R u - Q)$$

where: $\nu = \nu_m + \nu_s + \nu_n$

u is the fluid velocity

$P = nT$

R and Q are the integrals over f_e with the weight of v^2 and $v^2 v_x$

q_{SH} is the classical expression

Viscosity

$$\pi = - \frac{4}{3 \nu_m} n T \, 0.73 \left[\frac{\partial v}{\partial \xi} + \frac{2}{5} \frac{1}{nT} \frac{\partial q}{\partial \xi} \right]$$

q is the thermal conduction flux.

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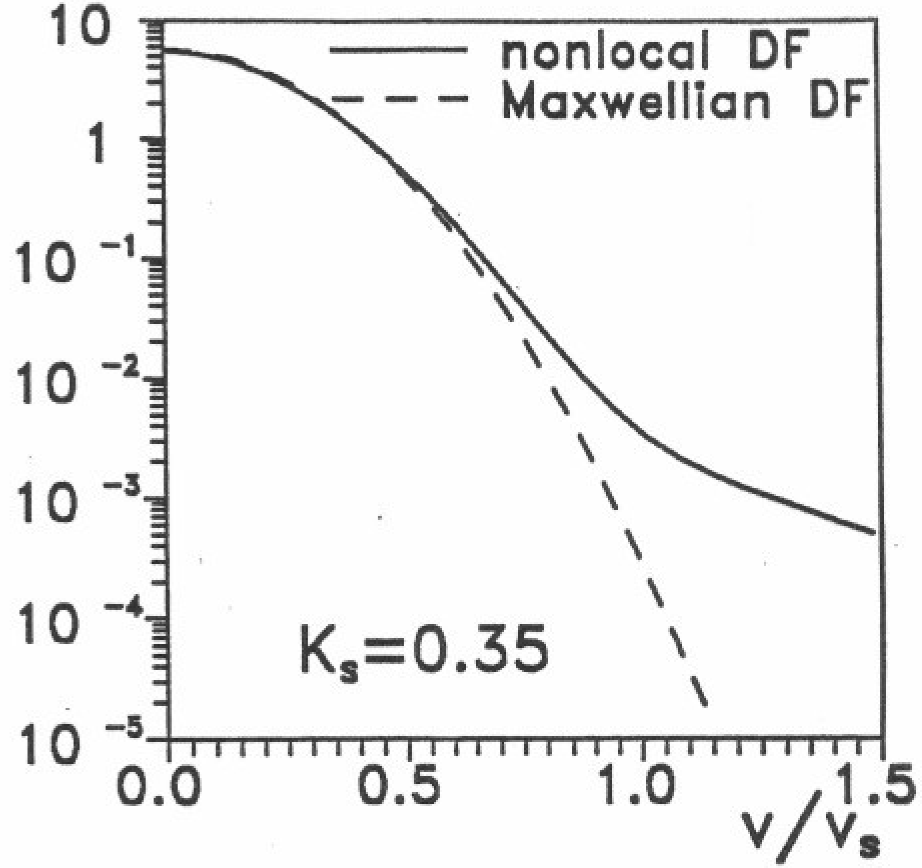

Fig.1 The comparison of the boundary distribution functions, corresponding to the nonlocal boundary conditions with the Maxwellian one

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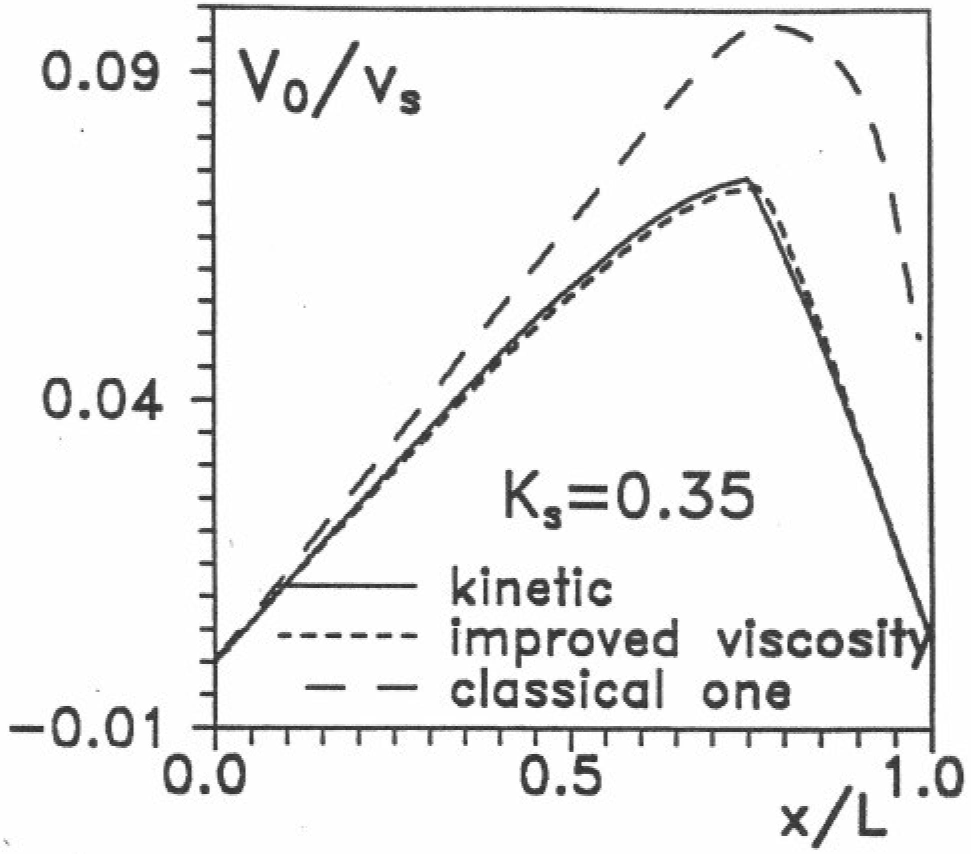

Fig.2 The velocity profiles corresponding to the classical viscosity, the improved one and the result of kinetic treatment

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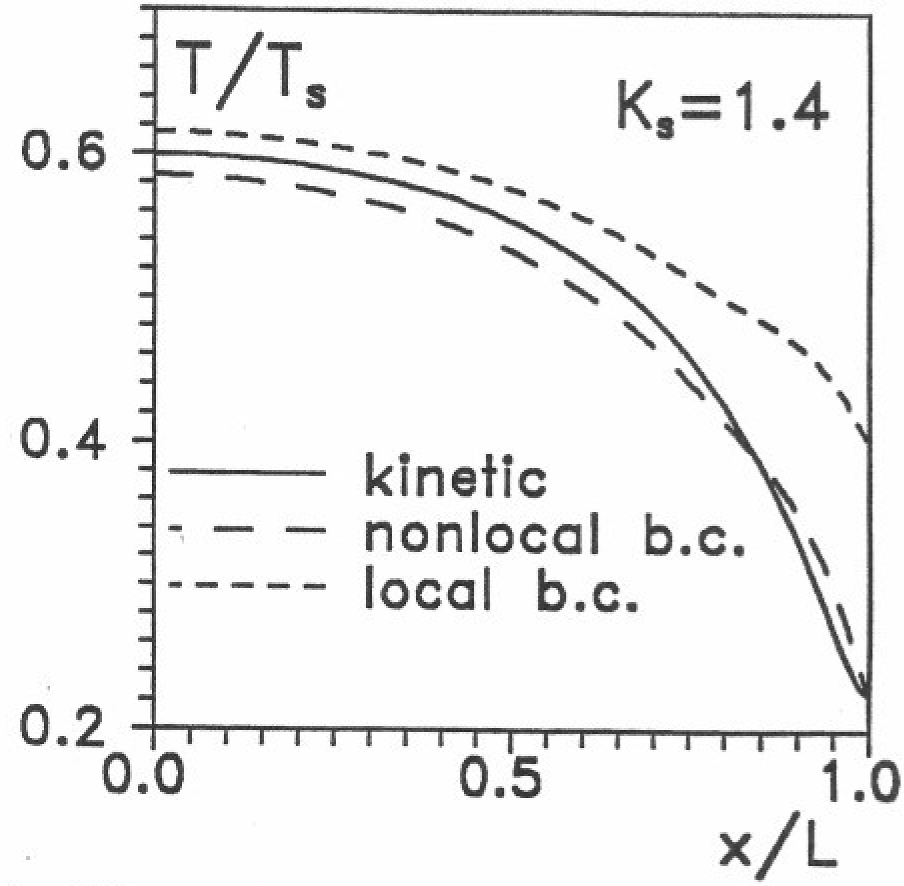

Fig.3 The temperature profiles for three cases: kinetic, local and nonlocal boundary conditions

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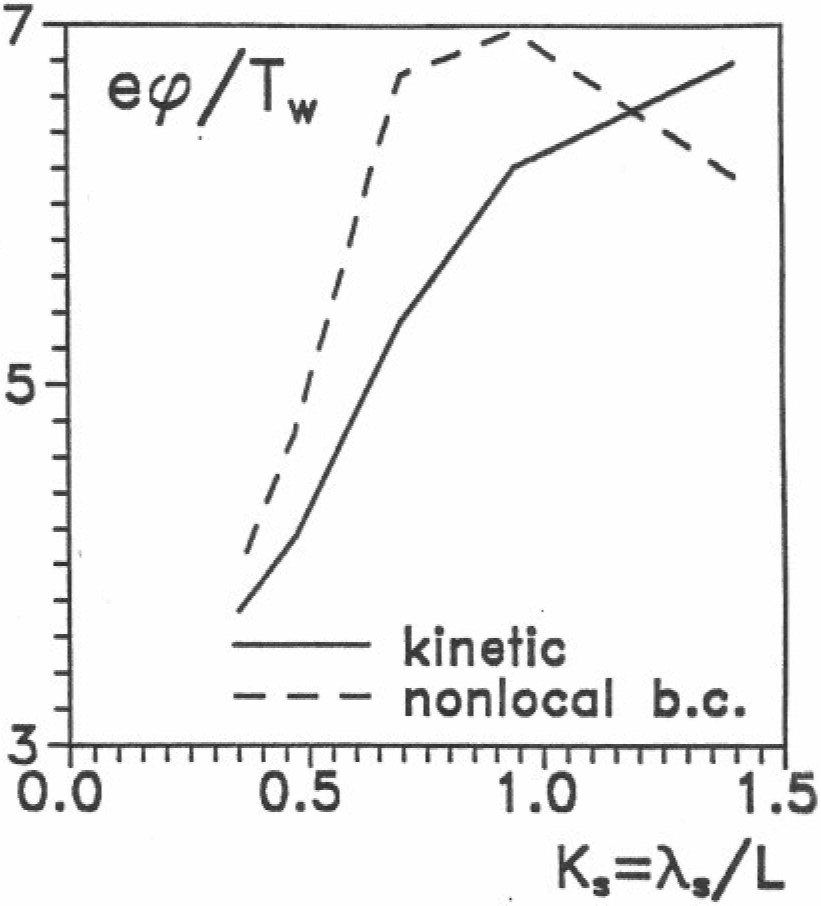

Fig.4 The sheath potential drop vs $K_s=\lambda_s/L$, where λ is electron mean free path and L is the length of magnetic field line

Conclusions.

1.The effective boundary conditions for the fluid set of equation at the plasma surfase interfase, which include the kinetic effects, are suggested.

2.The BGK approximation gives an opportunity to express the boundary fluxes as functionals of fluide profiles insted of local values.

3.The comparison with the kinetic solution shows that the propoused boundary conditions give such an accuracy of plasma parameters at the plate which is provided by the proximity of fluide profiles to the kinetic ones, i.e. the contribution of suprathermal particles in the transport coefficients is taken into account.

4.The conventional viscosity therm does not allow one to obtain the velocity profiles close to the kinetic ones. It has been shown that the usage of a viscous therm from the 13 - moment Grad approximation, taking account of a heat flux contribution, is more adequate to represent the regimes of moderate collisionality.

5.The flux - limited classical electron heat conduction does not bring to satisfactory resultes. The expression for a thermal heat flux in terms of higher moments of distribution function, could be recommeded for the fluid codes.

$$\begin{Bmatrix} j \\ \Pi \\ q \end{Bmatrix} = \int G(\nabla n, T, V)\, dV$$

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Federal Republic of Germany

Fokker-Planck Modelling Of Edge Plasma Near The Neutralizer Plate In A Tokamak

Z. Abou-Assaleh*, J.P. Matte, T.W. Johnston and R. Marchand
INRS-Energie, C.P. 1020, Varennes, Quebec, Canada J3X 1S2

An electron kinetic code (FPI)+ is modified and used to simulate longitudinal transport and recycling near the neutralizer plate in a divertor plasma. In addition to the previous features, such as Fokker-Planck e-e and e-i Coulomb collisions, transport, ion motion, and a self-consistent electric filed, the code now accounts for ionization, excitation, and recycling of hydrogen near the plate. Ions and neutrals are treated as fluids. As one might expect, this full FPI code is very expensive to run, having fast (electron) and slow (ion motion) timescales. We therefore use this FPI code in conjunction with a two-fluid ambipolar code, whose electron heat flow is obtained from usual flux limited coefficients on thermal transport. We alternate the codes, using the FPI code to correct the fluid code's temperature and local heat transport, while using the fluid code for ion dynamics. We thus arrive at an equilibrium consistent with electron kinetics but at a tiny fraction of the cost of doing so with the FPI code alone. Results and applications will be discussed.

* Present address: Culham Laboratory, D2, Abingdon, Oxfordshire, UK

\+ J.P. Matte and J. Virmont, Phys. Rev. Lett. 49,1936 (1982); J.P. Matte, T.W. Johnston, J. Delettrez and R.L. McCrory, Phys. Rev. Lett. 53, 1461 (1984); J.H. Rogers, J.S. De Groot, Z. Abou-Assaleh, J.P. Matte, T.W. Johnston and M.D. Rosen, Phys. Fluids B1, 1989.

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INTRODUCTION

Aim:

Modelling of the divertor plasma in a tokamak (Particles and energy transport along the magnetic field line)

Methods:

Electron kinetic / ion fluid code (FPI)

1D and 2-fluid code

Iteration FPI code ↔ modified fluid code

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FOKKER-PLANCK
INTERNATIONAL CODE
FPI

- * Electrons are treated kinetically
- * Ions and neutrals are treated as fluids.
- * 1-D in space (x) and 2-D in velocity space $(v_x\ ,\ v_\perp)$.
- * The electron distribution function is:

$$f(X,V,t)=f(x,v_x,v_\perp,t)=f(x,v,\mu,t)=\sum_{l=0}^{N} f_l(x,v,t)P_l(\mu)$$

where $v=(v_x^2+v_\perp^2)^{1/2}$, $\mu=v_x/v$ and $P_l(\mu)$ is the l th Legendre polynomial. We have used N=3 in the simulations.

- * The kinetic equation for the electron is given by :

$$\frac{\partial f}{\partial t}+v_x\frac{\partial f}{\partial x}+\frac{eE}{m_e}\frac{\partial f}{\partial v_x}=\left(\frac{\partial f}{\partial t}\right)_{(e-i,e-e)}+\left(\frac{\partial f}{\partial t}\right)_{(E_{ei})}+\left(\frac{\partial f}{\partial t}\right)_{(e-n)}$$

- \- The second and third terms in the left hand side are the advection and the acceleration due to the electric field, respectively.
- \- The right-hand side terms represent respectively electron-ion, electron-electron, Coulomb scattering, electron-ion energy exchange and electron-neutral collisions.
- * f_l's are advanced in time.

FLUID CODE

The code solves for a single density, single velocity and two temperatures as a function of time. The following equations are advanced in time:

Continuity:

$$\frac{\partial}{\partial t}n+\frac{\partial}{\partial x}(nv)=S_n$$

Momentum balance:

$$\frac{\partial}{\partial t}(m_i nv)+\frac{\partial}{\partial x}\left(m_i nv^2+P_e+P_i-\frac{4}{3}\eta\frac{\partial V}{\partial x}\right)=S_p$$

Electron energy balance:

$$\frac{\partial}{\partial t}\left(\frac{3}{2}nT_e\right)+\frac{\partial}{\partial x}Q_e=v\frac{\partial}{\partial x}P_e+E_{ei}+S_e$$

Ion energy balance:

$$\frac{\partial}{\partial t}\left(\frac{3}{2}nT_i+\frac{1}{2}m_i nv^2\right)+\frac{\partial}{\partial x}\left(Q_i-\frac{4}{3}\eta v\frac{\partial v}{\partial x}\right)=-v\frac{\partial}{\partial x}P_e-E_{ei}+S_i.$$

With:

$$q_e=q_{SH}\left[1+\frac{|q_{SH}|}{fn_e v_e T_e}\right]^{-1}$$

f = 0.2 (Electron heat flux limit factor)

BOUNDARY CONDITIONS

FPI CODE

PLASMA SOURCE ($x = 0$):

Ions:	n_i , V_i and T_i are fixed.
Electrons:	T_e fixed. Zero current ($\Gamma_e=\Gamma_i$) is imposed as follows: incoming particles are absorbed and an appropriate current with half-Maxwellian distribution at this temperature is emitted.

PLATE SHEATH EDGE ($x = L$):

Ions:	Outgoing ions are absorbed by the plate.
Electrons:	Zero current ($\Gamma_e=\Gamma_i$) is imposed as follows: low energy electrons ($< m_e V_r^2/2$) are reflected so that the flux of higher energy electrons is equal to the ionic current.

FLUID CODE

PLASMA SOURCE ($x = 0$):

$n = n_{e,i}$, $V = V_{e,i}$, T_e and T_i are fixed.

PLATE SHEATH EDGE ($X = L$):

- The outgoing plasma is absorbed.
- Ion drift velocity : $V \geq C_S = \sqrt{(T_e+T_i)/m_i}$
- Heat flux: $Q_i = 3.5 nVT_i$, $Q_e = 2\delta nVT_e$, ($\delta = 3$)

FLUID AND FOKKER-PLANCK HYBRID ITERATION

FLUID CODE

Moves ions ect. quickly, but electron heat flow is approximate.

FOKKER-PLANCK (FPI) CODE

Some ion dynamics but with electron kinetics, too slow on ion timescale.

SOLUTION

Iterate fluid modified by FPI
Use T_e(FPI) and force q_e to agree with FPI by correcting each grid point with correction factors:

$$CFQ = q_{e\text{-}FPI} / q_{e\text{-}fluid}(T_{e\text{-}FPI})$$

ITERATE UNTIL NO FURTHER SIGNIFICANT CHANGE

FINAL RESULT

Profile consistent with electron kinetic but at affordable cost.

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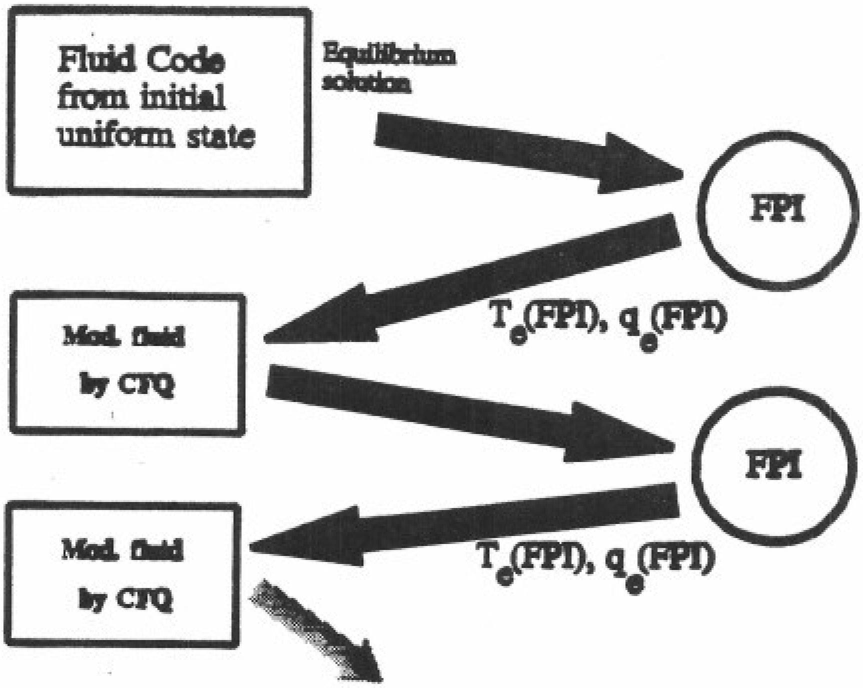
FLUID AND FOKKER-PLANCK HYBRID ITERATION



Fluid Code from initial uniform state

Equilibrium solution

FPI

T_e(FPI), q_e(FPI)

Mod. fluid by CFQ

FPI

T_e(FPI), q_e(FPI)

Mod. fluid by CFQ

$$CFQ = \frac{q_{e\text{-}FPI}}{q_{e\text{-}fluide}\left(T_{e\text{-}FPI}\right)}$$

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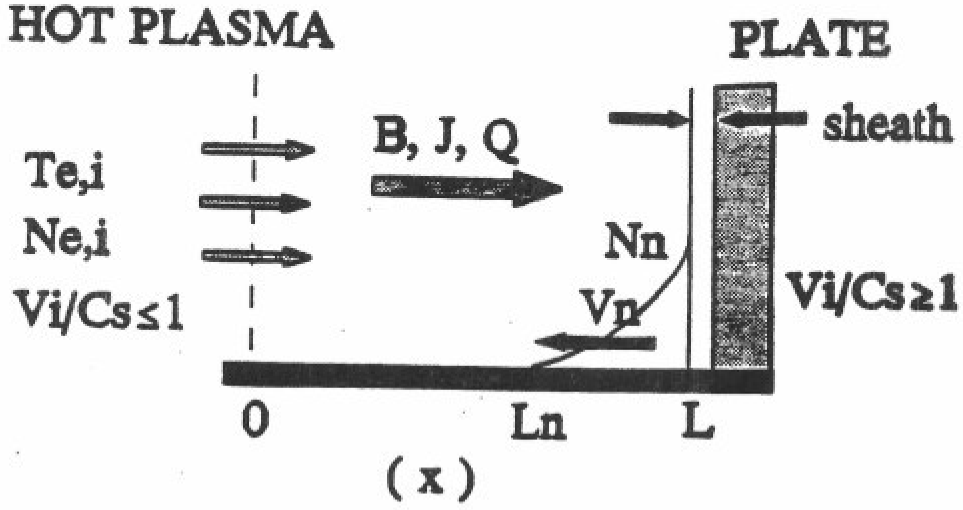
DIVERTOR PLASMA SIMULATIONS WITH HIGH RECYCLING



$L = 300$ cm
$T_{e0} = T_{i0} = 30$ eV
$n_{e0} = n_{i0} = 3\text{x}10^{13}$ cm^{-3}
$m_n V_n^2/2 = 3$ eV
$n_n V_n = 0.8\ n_i\ V_i$ at $x=L$
$m_i/m_e = 1836$

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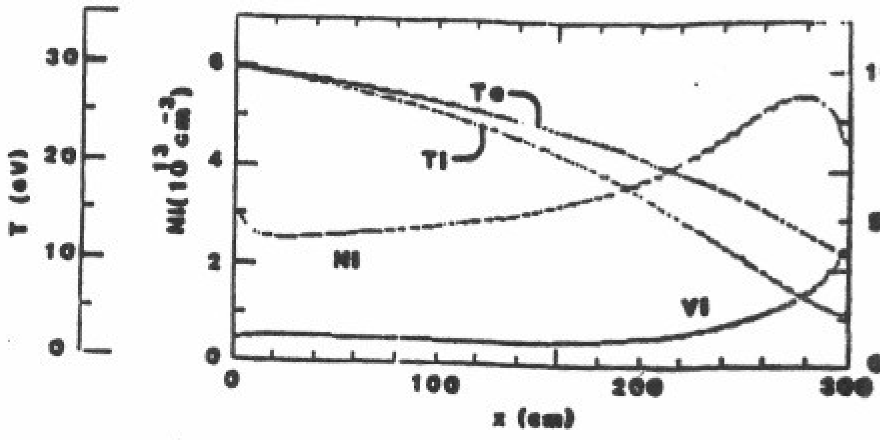
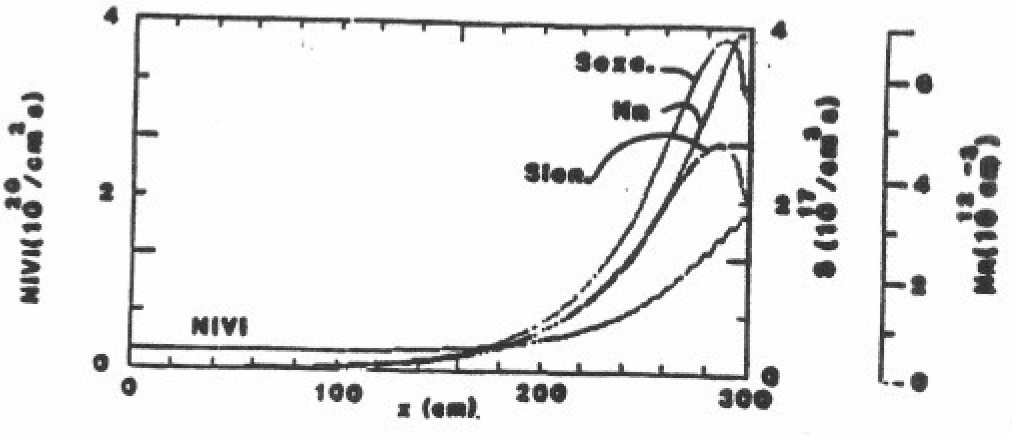
FLUID CODE SIMULATION

T_e , T_i , V_i and n_i vs x



n_iV_i , n_n , S_{exc} and S_{ion} vs x



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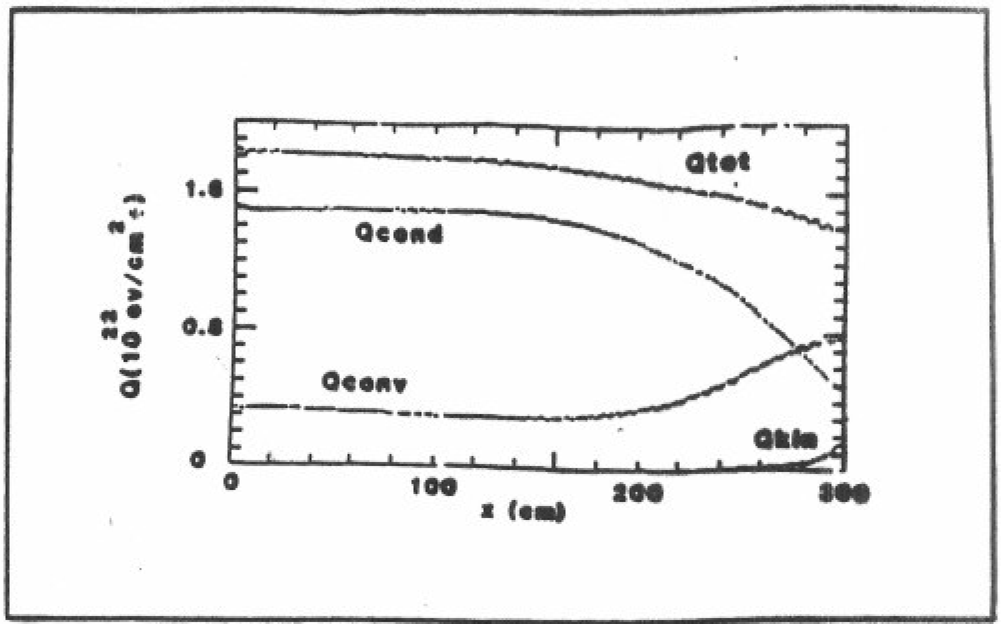
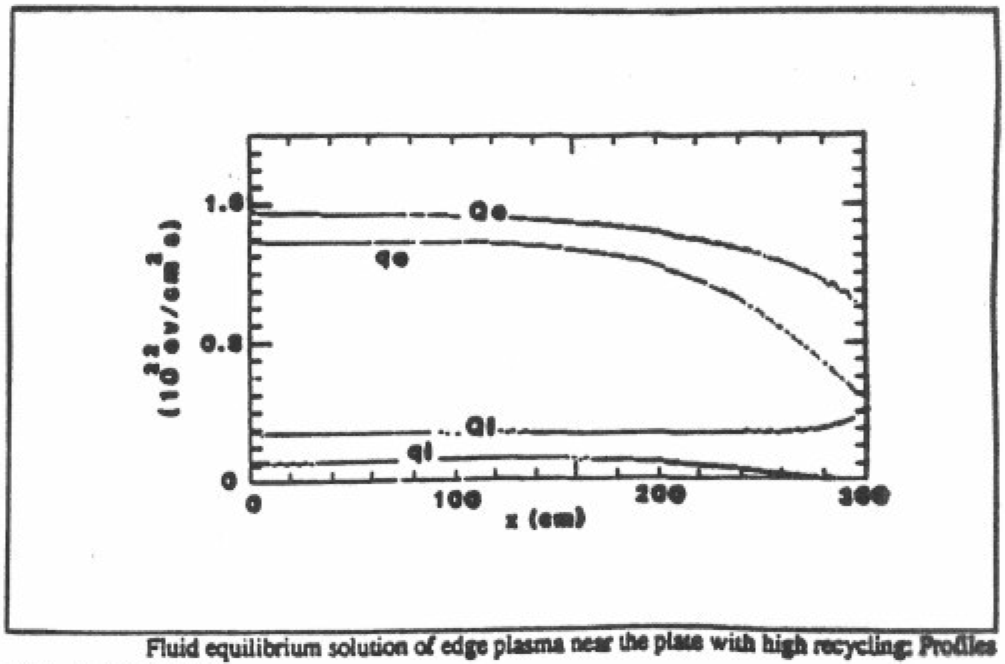
FLUID CODE SIMULATION

Energy flux



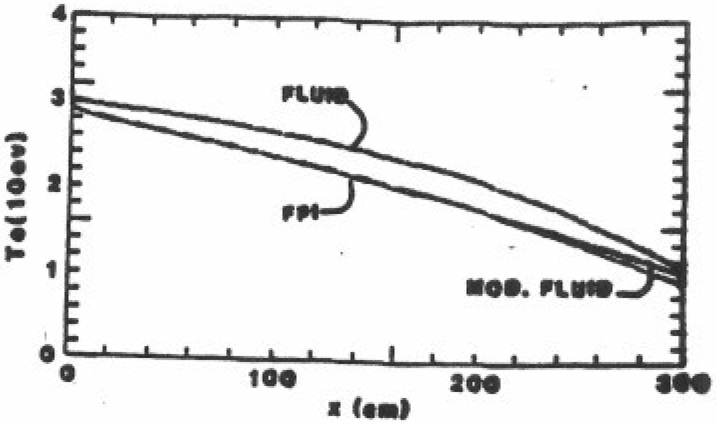
Fluid equilibrium solution of edge plasma near the plate with high recycling: Profiles of Q_{tot}, Q_{cond}, Q_{conv}, and Q_{kin}.



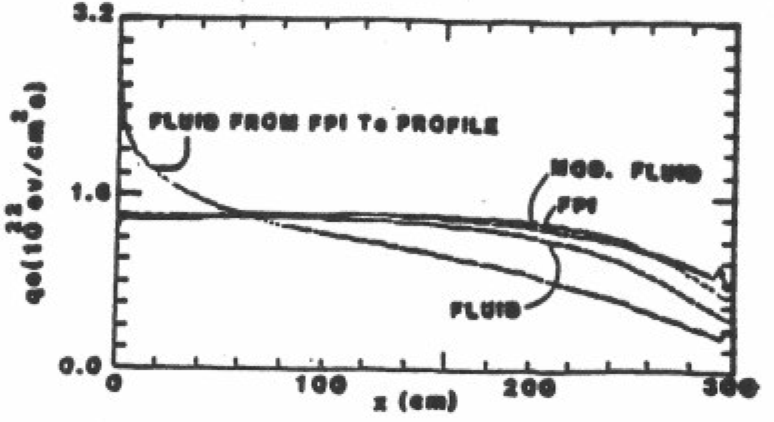
Fluid equilibrium solution of edge plasma near the plate with high recycling: Profiles of Q_e, q_e, Q_i, and q_i.

FLUID AND FOKKER-PLANCK HYBRID SIMULATION

Profile of T_e
Fluid (f=0.2), FPI and Mod. Fluid



Profile of q_e
Fluid (f=0.2), FPI and Mod. Fluid



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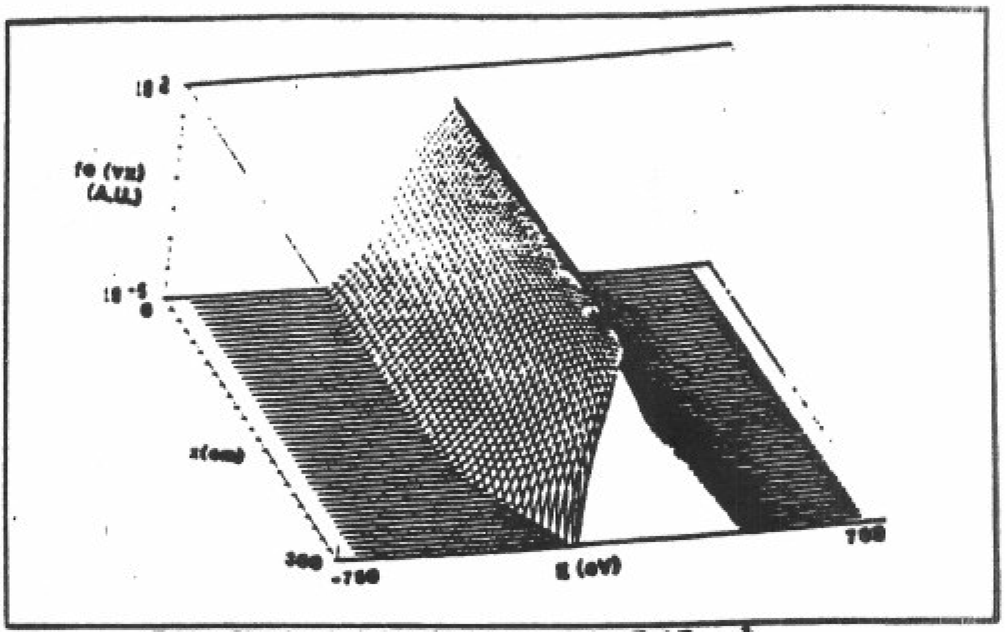
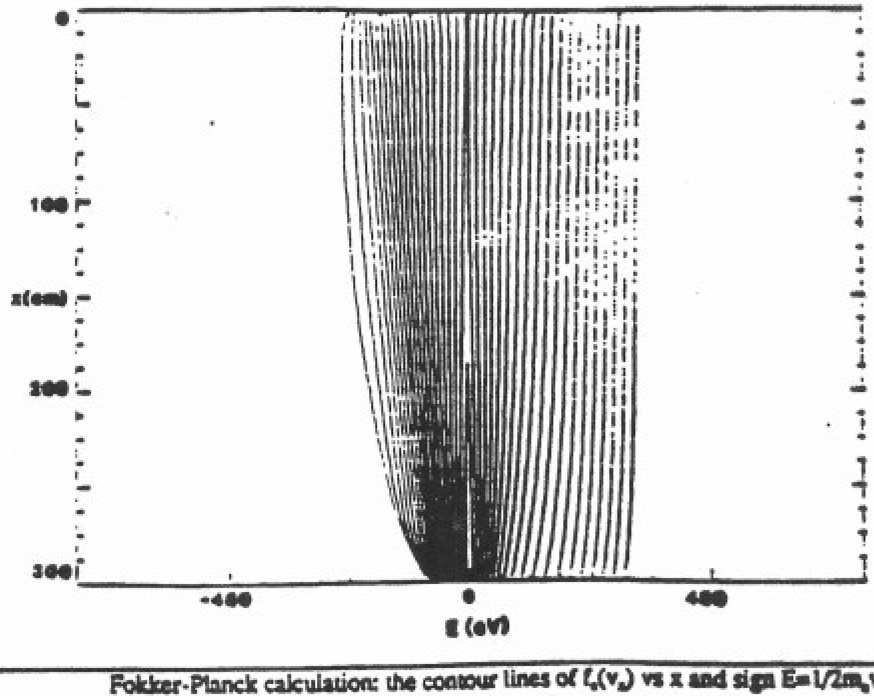
ELECTRON DISTRIBUTION FUNCTION CALCULATED BY FOKKER-PLANCK CODE



Fokker-Planck calculation: $f_e(v_x)$ vs x and sign $E=1/2m_ev_x^2$



Fokker-Planck calculation: the contour lines of $f_e(v_x)$ vs x and sign $E=1/2m_ev_x^2$. The truncation of fe(vx) at the plate is clearly seen from this figure.

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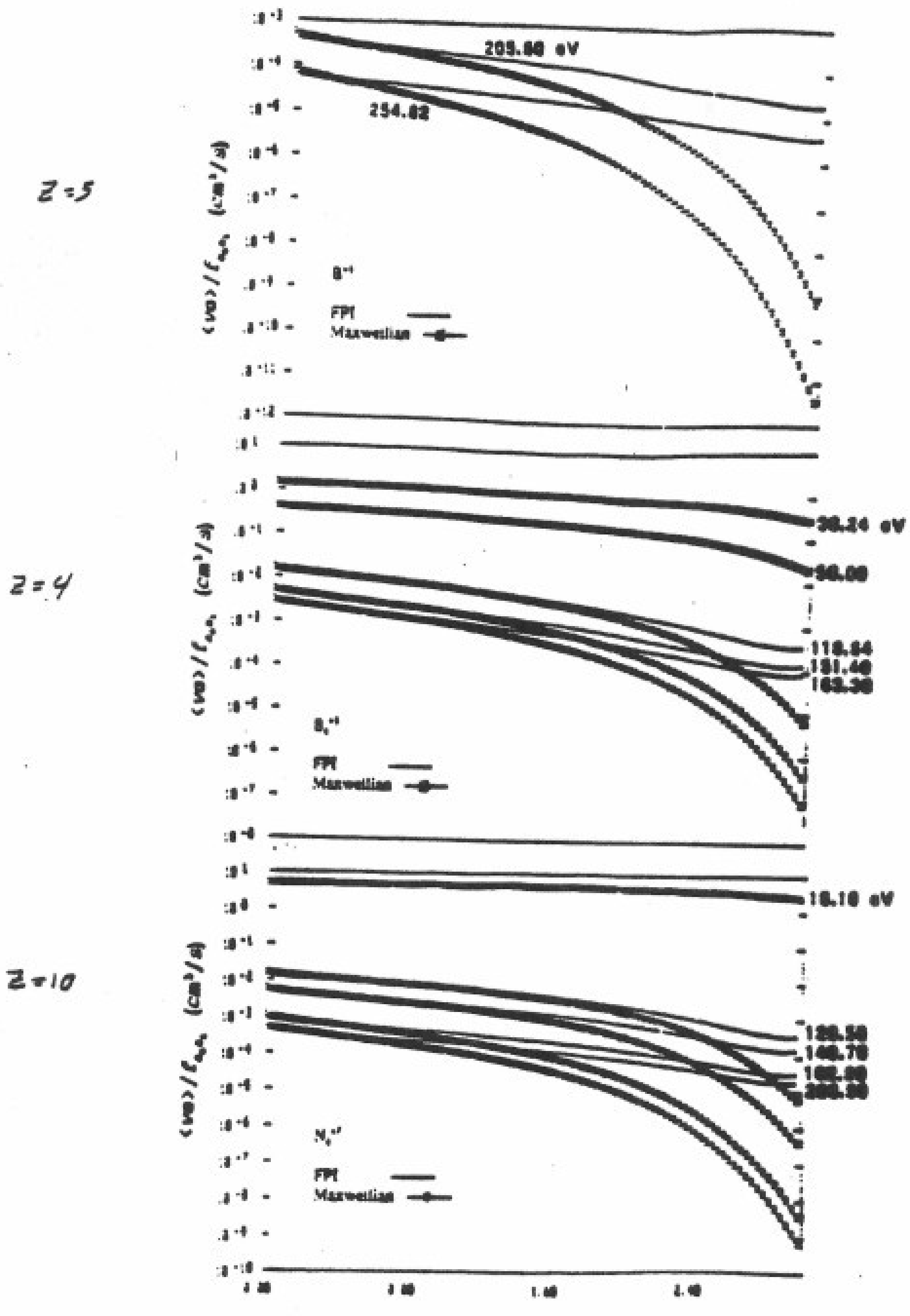
NON-MAXWELLIAN ELECTRON DISTRIBUTION EFFECT ON THE IMPURITIES RADIATIONS



CONCLUSION

We model the plasma transport along the magnetic field line in a tokamak divertor:

* Fluid and kinetic simulations.

* Including: ionization, excitation, boundary condition at the sheath edge.

* Hybrid technique was developed which produced an equilibrium solution with the electron kinetic model but with much reduced computer cost.

* Steep temperature gradients.

* The fluid code with electron heat flux limiter f=0.2 gave closer results to the Fokker-Planck calculation.

* The electron distribution function calculated from the FPI code is not locally Maxwellian, especially near the plate. The deviation from Maxwellian is due to the absorption of the most energetic electrons by the plate and to the non-local transport of high energy electrons.

* Effect of non-Maxwellian electron distribution function on the ionization and excitation of the impurities.

Present and Future work

Electron kinetic / ion fluid

* change the recycling factor R

* Epithermal electron: The plasma to be injected to the system at $x = 0$ with bi-Maxwellian

see the effects on:

- plasma sheath and pre-sheath
  $e\phi$, q_e, T_e, N_e, ...
- CFQ as a function of $\nu_{e.e}$, $\nu_{e.i}$, $\nu_{e\text{-}n}$
  n_0(neutral), ...
- The heat flux limiter $f = ?$ in the fluid mode
- Q_e at the plate ~~to~~
- The effects of f_e (Non-Maxwellian) on the impurities radiations

* New Boundary conditions for the fluid model with the improvement of the transport coefficient by including the nonlocal effects, "Model By Yu. L. Igitkhanov"