Physics Modeling of FIRE Edge Plasma

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Outline

- UEDGE modeling of the edge plasma, T. Rognlien
- Neutral particle modeling, D. Ruzic
- Erosion/redeposition modeling, J. Brooks
- Disruption specification, J. Wesley
- Particle fueling and pumping requirements
- Summary

Operating Scenarios

Case	P_{fusion}	P_{heat}	$P_{divertor}$	Duration
Baseline	200 MW	60 MW	29 MW	18 s
D-D	5	16	8	214
AT Mode	150	45	22	31
High B_T	250	75	37	12

UEDGE Modeling

- **Input parameters**
  - **Power to the divertor 28 MW**
  - **Separatrix density 1.5 x 10^{20} /m^3**
  - **Wall recycling coefficient 1.0**
  - **Three edge transport cases**
    - **High conductivity** c **= 1.5 m^2/s** **D = 1.0 m^2/s**
    - **ITER Baseline** c **= 0.5 m^2/s** **D = 1.0 m^2/s**
    - **Bohm like** c **= 0.5 m^2/s** **D = D_{bohm} +0.1**
      - **D_{bohm} = T_e/16 eB**
  - **A case with tilted plates and wall pumping of 10^{21}/s and Bohm like transport**

UEDGE Modeling Results

Case	Te_m (eV)	l_m (cm)	Te_p (eV)	Ne_p ($10^{21}/m^3$)	Q_p (MW/m^2)	l_p (cm)
A	106	0.8	1.5	61	5.7	6.5
B	152	0.6	15	44	25	1.8
C	138	0.7	14	43	23	2.3
D	138	0.7	13	52	19	2.5

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UEDGE Modeling Results

- The inner divertor is easily detached.
  - Particle flux ~ 1 MW/m^2
  - Radiated power flux 1.8 MW/m^2
- Addition of Be to the outer divertor cases increases the radiated power to about 5 MW/m^2 and decreases the particle power to 20 MW/m^2
- Addition of 30-35 Torr l/s of Ne to the outer divertor causes detachment (not a steady solution yet).
- Radiated power 80 MW/m^3 when detached.

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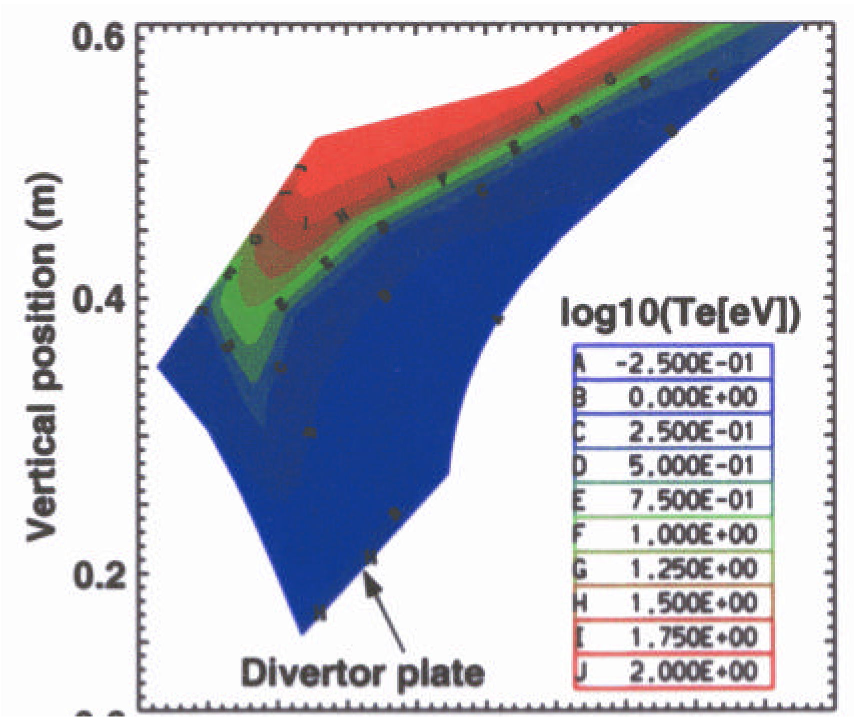
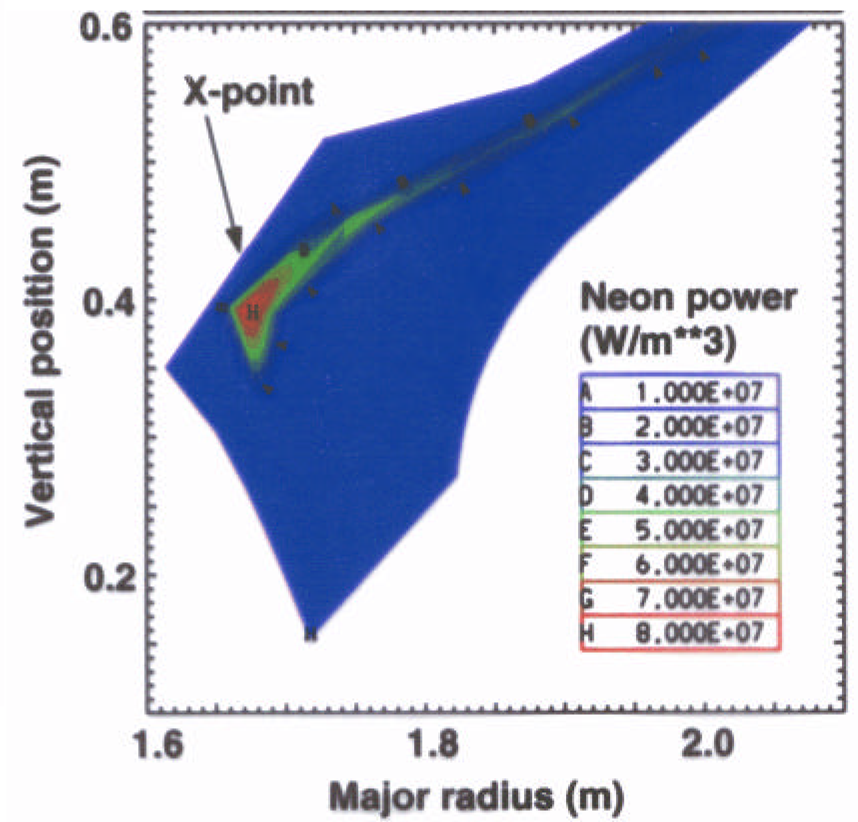
UEDGE Modeling Results





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UEDGE Modeling Summary

- Inner divertor detaches easily
- Outer divertor heat flux 20-25 MW/m^2 attached
- Outer divertor can be detached with Ne addition
- Peak radiated power flux on divertor PFC ~6 MW/m^2

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Neutral Particle Modeling with DEGAS2

- **UEDGE plasma solution used as input**
- **DEGAS2 gives:**
  - **Neutral flux to walls**
  - **Neutral energy spectrum to walls**
- **These outputs are passed on to J. Brooks to do erosion/redeposition modeling**

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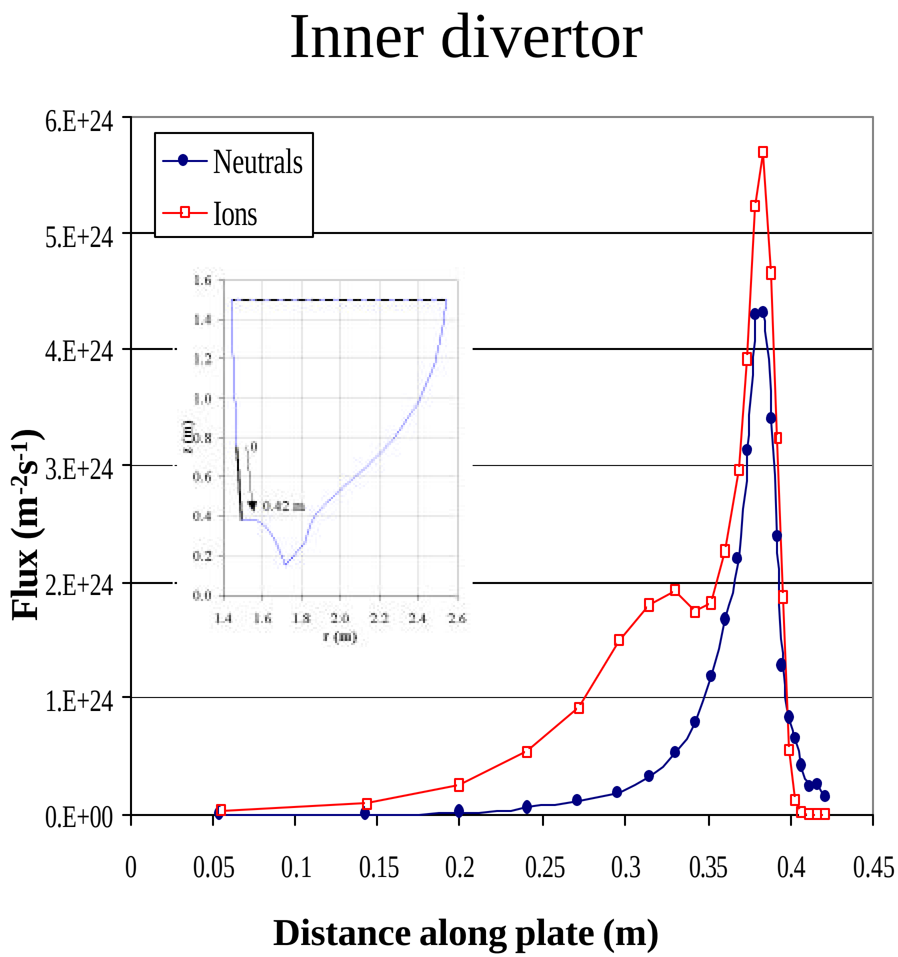
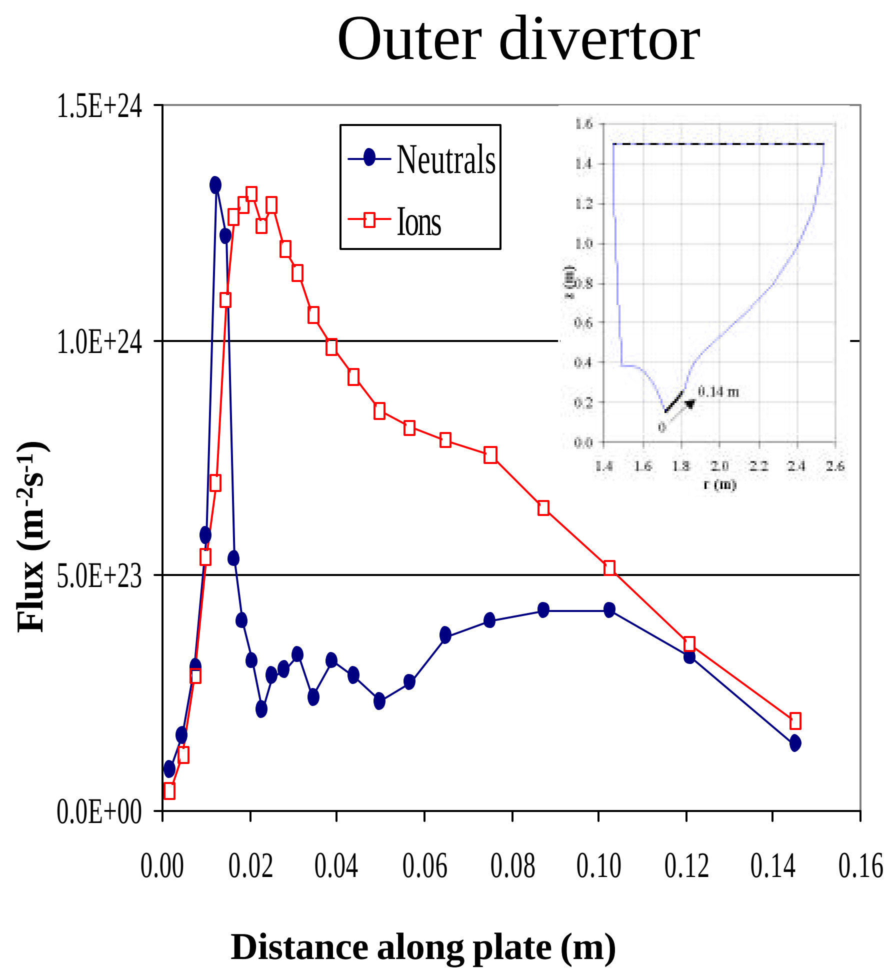
DEGAS2 Results





Erosion/Redeposition Modeling

- **Objective: Compute 1st wall and divertor net erosion rates, plasma contamination, and tritium codeposition, from sputtering.**
- **Method: Use REDEP/WBC impurity transport code package using FIRE plasma/geometry with DEGAS2 code neutrals calculation and VFTRIM-3D and other sputtering coefficients.**
- **Completed analysis: Tungsten erosion for divertor outer plate, "pure tungsten" surface, preliminary plasma model.**

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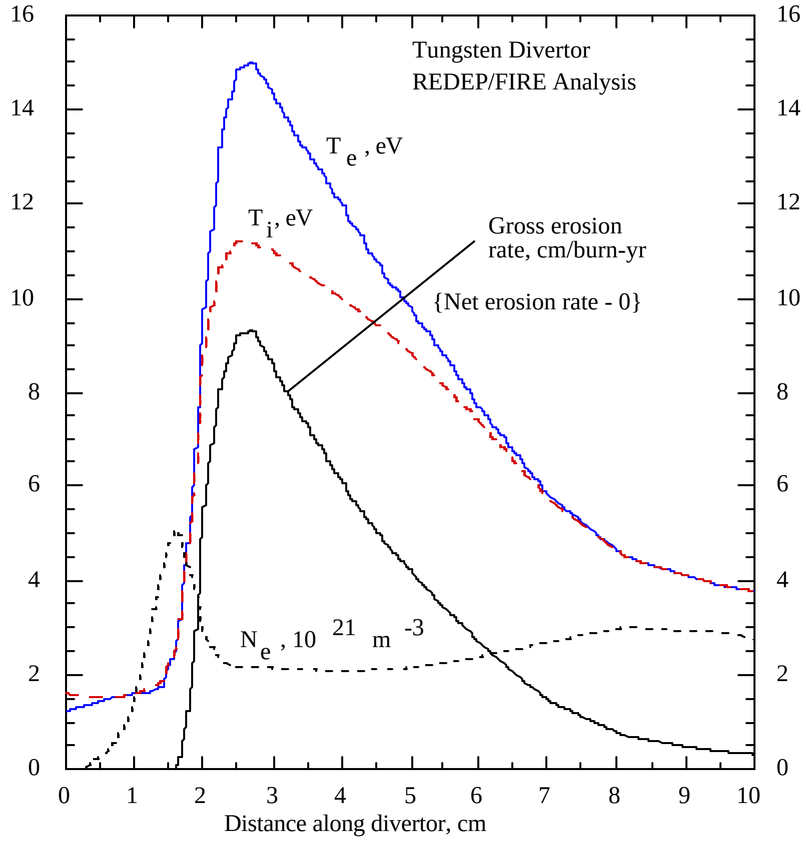
Erosion/Redeposition Modeling

- Inputs: Outer plate and magnetic field geometry, plasma ion and electron profiles, DEGAS2 neutral flux. 0.1 % oxygen ion flux assumed.
- WBC Monte code used to compute detailed (single-particle, kinetic, sub-gyro motion) characteristics of sputtered tungsten transport. Code includes sputtered atom velocity distribution, electron impact ionization, Lorentz force motion, magnetic/Debye dual-structure sheath, impurity-plasma charge changing and velocity changing collisions.

Erosion/Redeposition Modeling

- **WBC redeposition parameters used as input to REDEP (integral equation type) code for computation of self-consistent gross and net erosion rates over entire outer divertor region.**
- **Results are favorable-essentially zero net erosion and plasma contamination predicted.**

Erosion/Redeposition Modeling



- **REDEP Analysis: Sputtering erosion of a tungsten coated FIRE outer divertor plate for high recycle plasma with 0.1 % oxygen content.**
- **Net erosion rate is essentially zero due to very high redeposition of sputtered material.**

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Erosion/Redeposition Summary

- Tungsten is an excellent material choice from the sputtering erosion/redeposition standpoint.
- Most sputtered tungsten is ionized in the (magnetic) sheath. Strong frictional forces and/or sheath electric field then cause very fast ion redeposit.
- There is essentially zero net erosion and plasma contamination.
- Gross tungsten sputtering is due mostly to plasma impurities (oxygen) and self-sputtering, and not plasma fuel ions.

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Disruption Specifications

- Based on the database assembled for ITER
- Thermal quench phase
  - 33 MJ plasma stored energy
  - Variation of values from data
  - Uncertainty in understanding
  - Uncertainty in extrapolation to FIRE
  - Range of values specified for FIRE

Disruption Specifications

	Low End Flux (MJ/m^2)	Reference Flux (MJ/m^2)	Most Likely (MJ/m^2)	High End Flux (MJ/m^2)
Inner Divertor	8	13.4	31	96
Outer Divertor	4	6.8	16	48

Disruption Specifications

- Current Quench Phase
  – Magnetic stored energy 35 MJ
  – Current decay time 2-6 ms
  – Average energy deposition to first wall 0.5 MJ/m2
  – Toroidal peaking factor 2:1
  – Thermal modeling predicts <0.1 mm melting of Be per disruption.

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Disruption Specifications

- Halo currents
  - The product of maximum halo current and the toroidal peaking factor is constant for the worst case
  - The maximum halo current at the worst location is 200 kA

Particle Fueling and Pumping

- **Particle fueling requirements**
  - **Plasma particle content 10^{22}**
  - **Energy confinement time 0.65 s (0.5-0.8 s)**
  - **Particle confinement 2-10 t_E**
  - **Fueling efficiency 50%**
  - **Maximum fueling rate 75 Pa m^3/s**
- **Pumping rate required to remove He**
  - **Fusion burn rate $10^{20}/s$ (200 MW)**
  - **He fraction in divertor 2% with wall recycling 0.5**
  - **Pumping rate required 100 Pa m^3/s**

Summary

- UEDGE modeling predicts 20-25 MW/m^2 heat flux on the outer divertor
- UEDGE shows the divertors can be detached
- There is no predicted erosion of W divertor plates
- Disruption conditions are specified
- Particle fueling of 75 Pa m^3/s is required
- Particle pumping of 100 Pa m^3/s is required