FIRE Erosion/Redeposition Modeling

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FIRE Erosion/Redeposition Modeling

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FIRE 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.
- Planned/in-progress work: Erosion of beryllium first wall, erosion of Be/W mixed-material divertor. Detached plasma erosion (with T. Rognlien LLNL).

REDEP/WBC Analysis of pure-tungsten divertor:

- 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.

REDEP/WBC Analysis of pure-tungsten divertor:

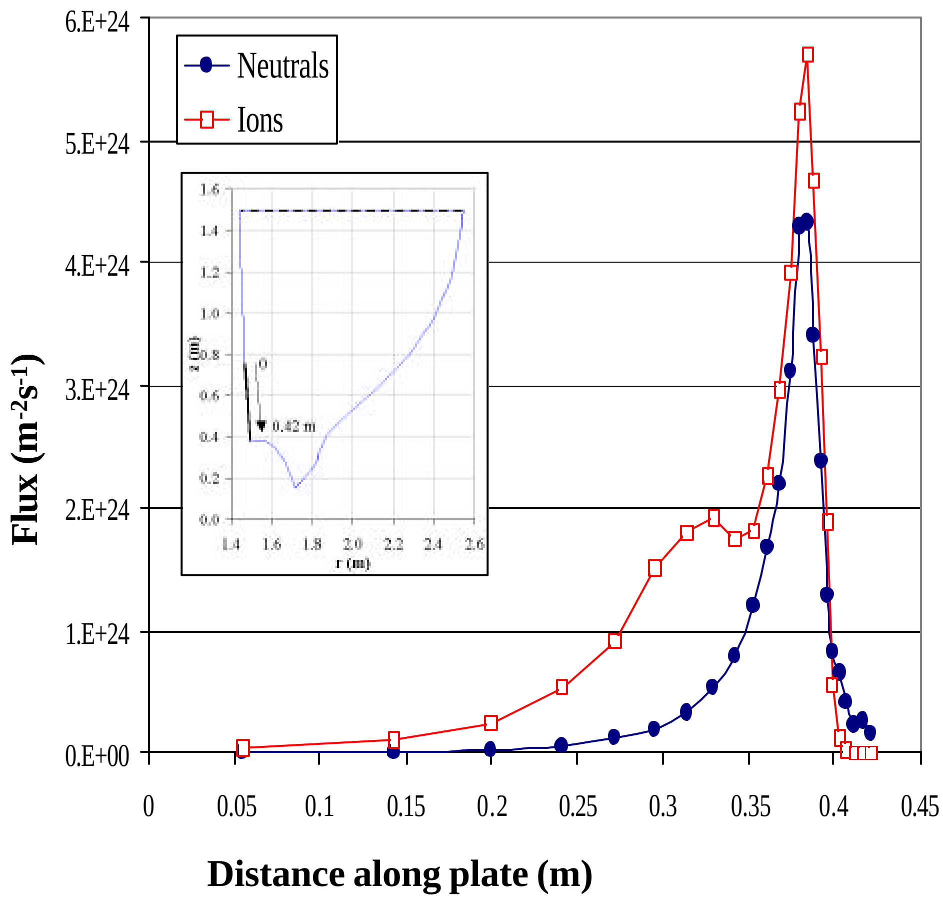
- WBC redeposition parameters used as input to REDEP (integral equation type) code for computation of self-consistent gross and net erosion rates over entire outer divertor region.
- Results are favorable-essentially zero net erosion and plasma contamination predicted.

Modeling of neutral particles

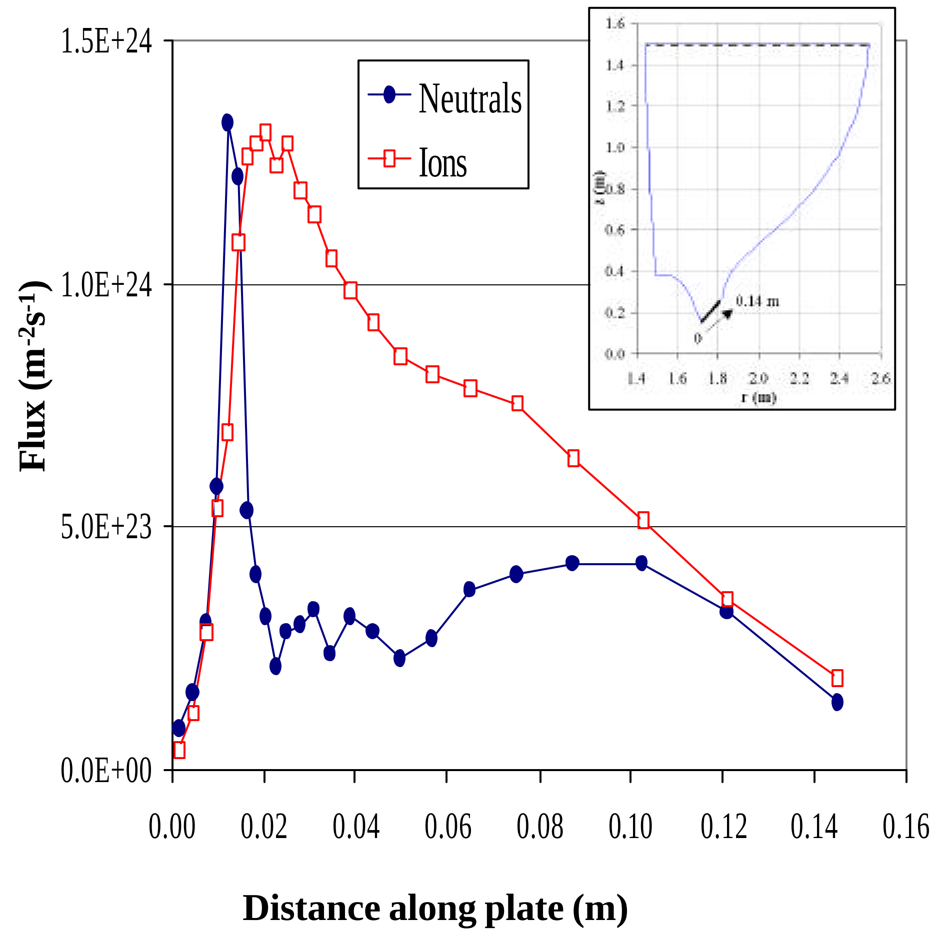
- DEGAS2 Monte Carlo neutral transport code
  - Several advantages over predecessor (DEGAS)
    - High speed
    - Flexibility
    - Ease-of-use
    - Well documented
- UEDGE plasma solution used as input (T. Rognlien).
- DEGAS2 gives:
  - Neutral flux to walls
  - Neutral energy spectrum to walls
- These outputs are passed on to J. Brooks to do erosion/redeposition modeling

Flux to both divertors

Inner divertor

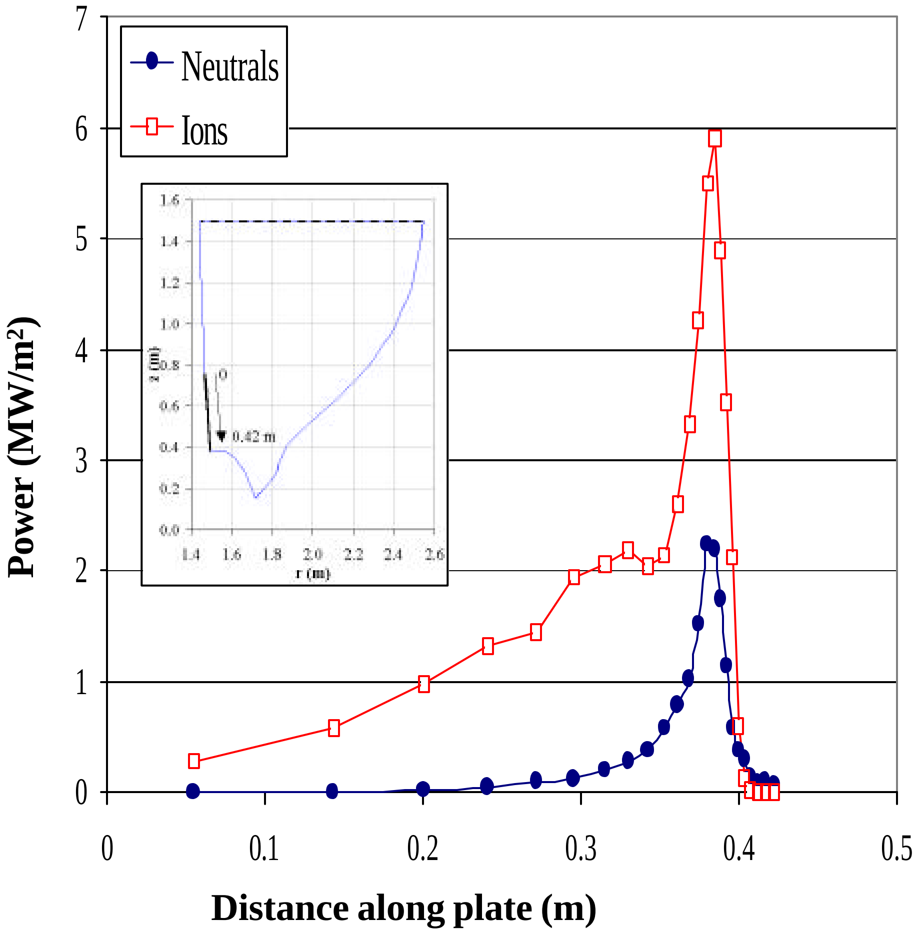


Outer divertor

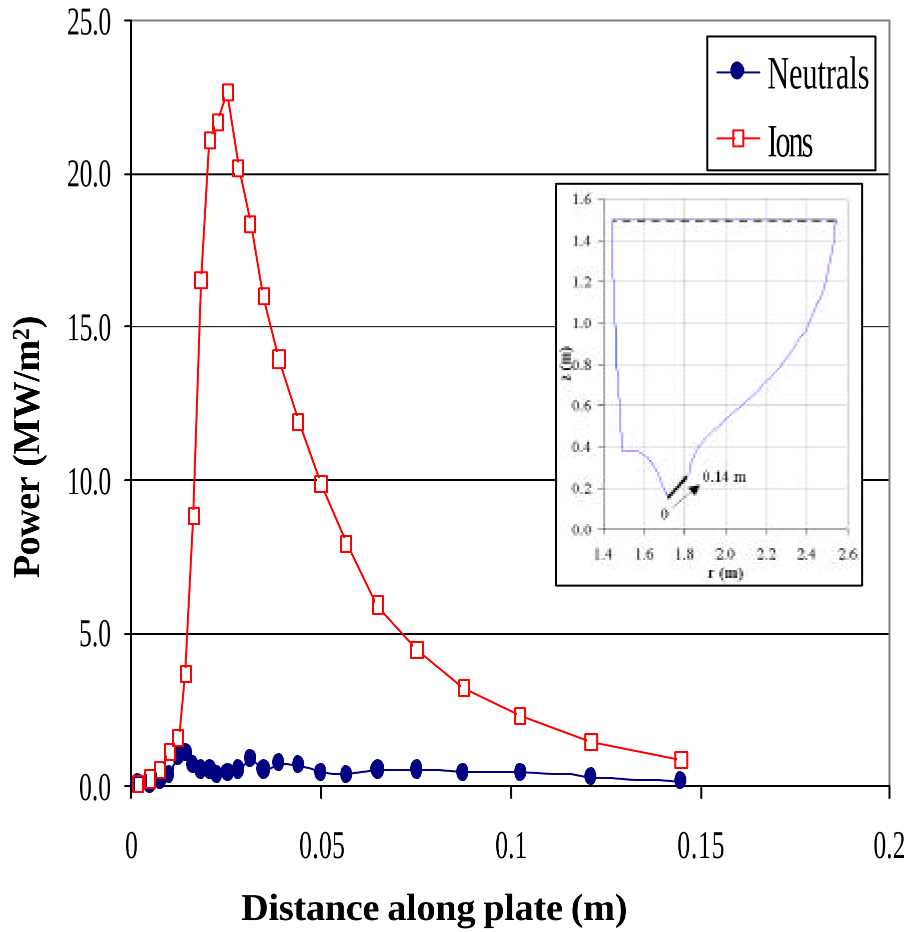


Power deposited to both divertors

Inner divertor



Outer divertor



WBC/FIRE Sputtered Tungsten Analysis

- Fire divertor geometry, B = 10 T, $\alpha = 1.3\,°$
- Calculation at separatrix, D-T plasma, T_e = 15 eV, N_e = $5x10^{21}$ m^{-3}
- Pure-tungsten surface, sputt. atom energy spectrum = Thompson model w/ cutoff (for O^{+6} impingement)
- Number of histories = 10,000

WBC/FIRE Sputtered Tungsten Analysis

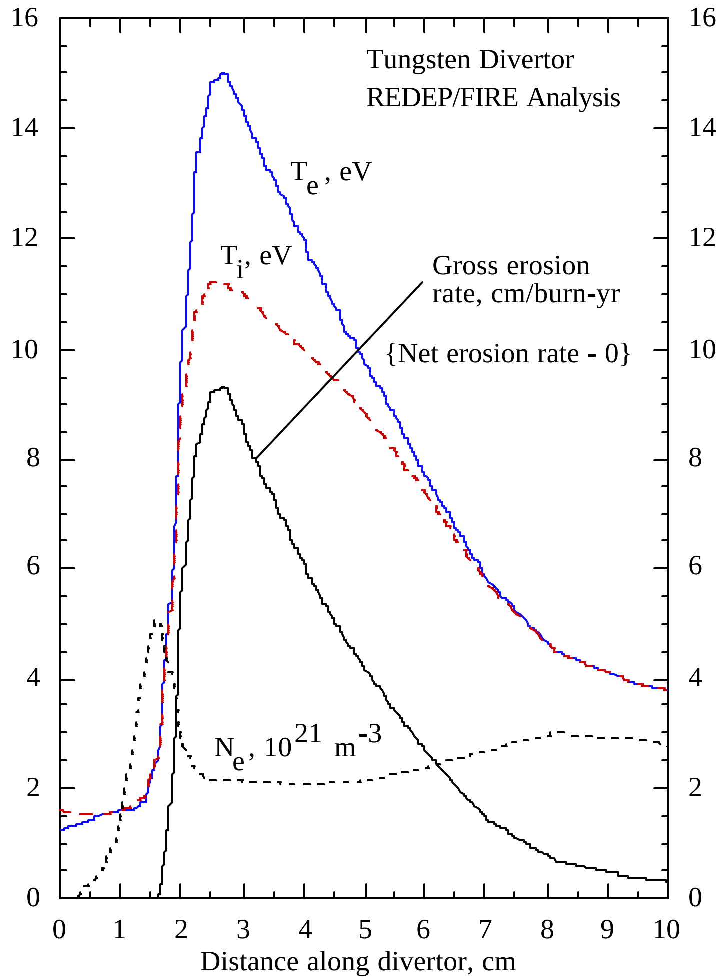
Parameter*	Value
Neutral ionization distance**	2.4 x10^{-5} m
Charge state	2.8
Transit time	0.10 μs
Elevation angle	33°
Energy	267 eV
Poloidal distance from launch point (standard deviation)	0.7 mm
Redeposition fraction (for 1 cm near-surface-cutoff)	1.000

* except where noted denotes average value for redeposited ions
** Normal to surface

WBC/FIRE Sputtered Tungsten Analysis

- **Very fast, 100 % redeposition predicted, with favorable self-sputtering related parameters (energy, incidence angle).**

WBC/FIRE Sputtered Tungsten Analysis



- **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.**

Current focus

- Beryllium/tungsten erosion issues
- Hope to get a new detached plasma solution
- Meanwhile, use current solution to compute the following:
  - Beryllium sputtering from the first wall
  - Sputtered Be transport to the divertor
  - Sputtering properties of resulting Be-W mixture
  - Erosion/redeposition of resulting mixed material divertor

Conclusions

- According to the preliminary, integrated REDEP analysis, tungsten is an excellent FIRE divertor material choice, from the sputtering erosion/redeposition standpoint.
- For the plasma regime analyzed there is essentially zero net erosion and plasma contamination. This is due to intense local redeposition of sputtered tungsten, for the very high near-surface plasma densities postulated.
- Gross tungsten sputtering is due mostly to plasma impurities (oxygen) and self-sputtering, and not plasma fuel ions.

Conclusions

- Most sputtered tungsten is ionized in the (magnetic) sheath. Strong frictional forces and/or sheath electric field then cause very fast ion redeposit.
- Key issues being analyzed are erosion of the beryllium wall, transport of Be to divertor, erosion of resulting Be/W divertor surface, detached plasma regime effects.