"Beryllium wall erosion, transport, and tritium codeposition modeling of the FIRE tokamak"

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”Beryllium wall erosion, transport, and tritium codeposition modeling of the FIRE tokamak”

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- We analyzed beryllium first wall sputtering erosion, sputtered material transport, and T/Be codeposition for the Fusion Ignition Research Experiment (FIRE) design.

- Starting with a fluid code (UEDGE, Rognlien/Rensick) scrapeoff layer attached plasma solution, plasma D^0 neutral fluxes to the wall and divertor are obtained from the DEGAS2 neutral transport code.

- The D^+ ion flux to the wall is computed using both a diffusive term and a simple convective transport model.

- Sputtering coefficients for the beryllium wall are given by the VFTRIM-3D binary-collision code.

- Transport of beryllium to the divertor, plasma, and back to the wall is calculated with the WBC+ code, which tracks sputtered atom ionization and subsequent ion transport along the SOL magnetic field lines.

- Then, using results from a study of Be/W mixing/sputtering on the divertor (ITMC, Yacout/Hassanein), and using REDEP/WBC impurity transport code results, we estimate the divertor surface response.

- Finally, we compute tritium codeposition rates in beryllium growth regions on the wall and divertor for D-T plasma shots using surface temperature dependent Q/Be rates and with different assumed oxygen contents.

- Although there are necessarily some inconsistencies, the results should enable reasonable evaluation of FIRE wall performance issues and guide future research for similar near-term devices.

Key results:

1) Peak wall net erosion rates vary from ~ 0.3 nm/s for diffusion-only transport to 3 nm/s for diffusion plus convection.

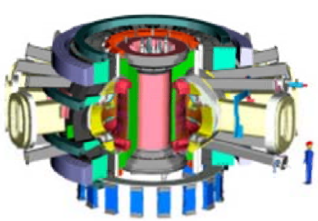
2) Inner and outer divertors, nominally tungsten, will turn into beryllium, at least between plasma transients.

3) T/Be codeposition rates vary from ~ .1 to 10 mgT/s depending on the model.

4) core plasma contamination from wall-sputtered beryllium is very low (< 0.02%).

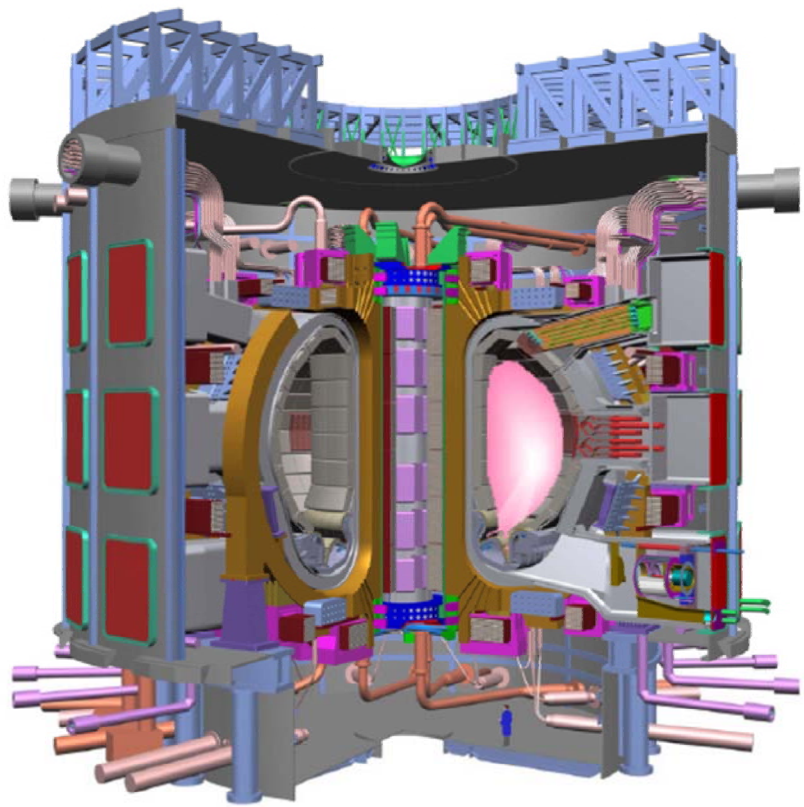
The next step in fusion research: a burning plasma experiment

Three Options
(same scale)



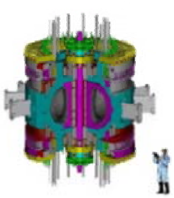
FIRE

US Based
Diversified International Portfolio



ITER-FEAT

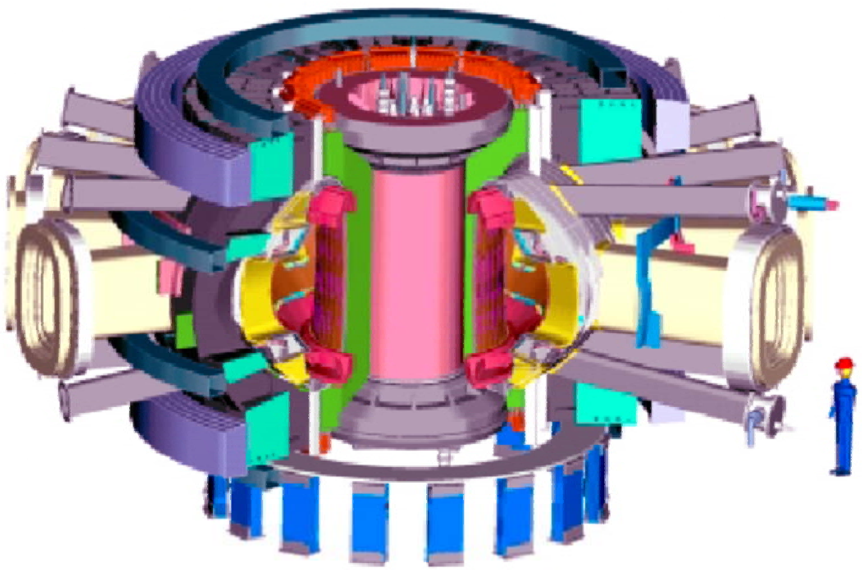
JA, EU or CA Based
International Partnership



IGNITOR

Italian Based
International Collaboration

Fusion Ignition Research Experiment (FIRE)



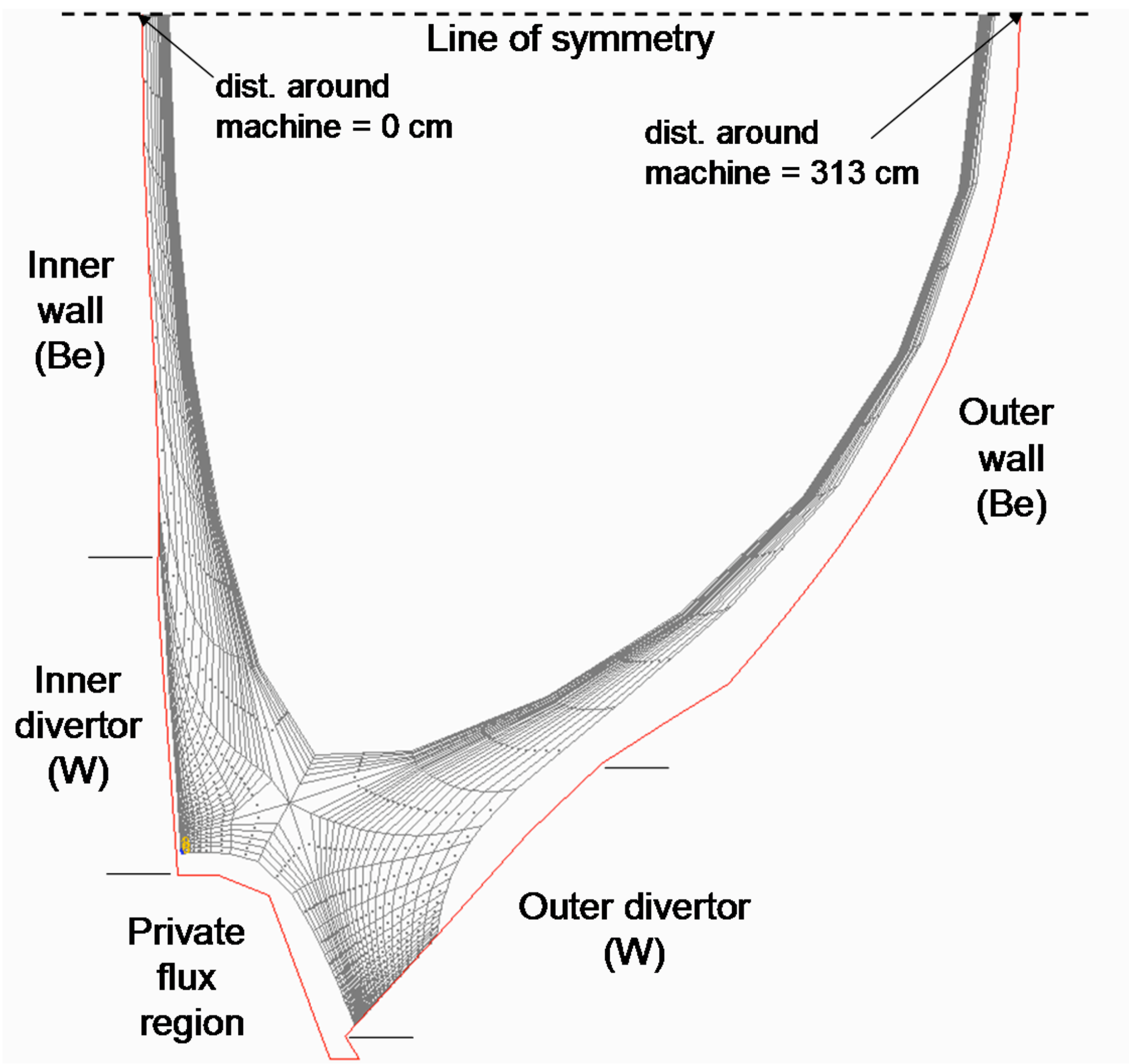
1,400 tonne

Design Features

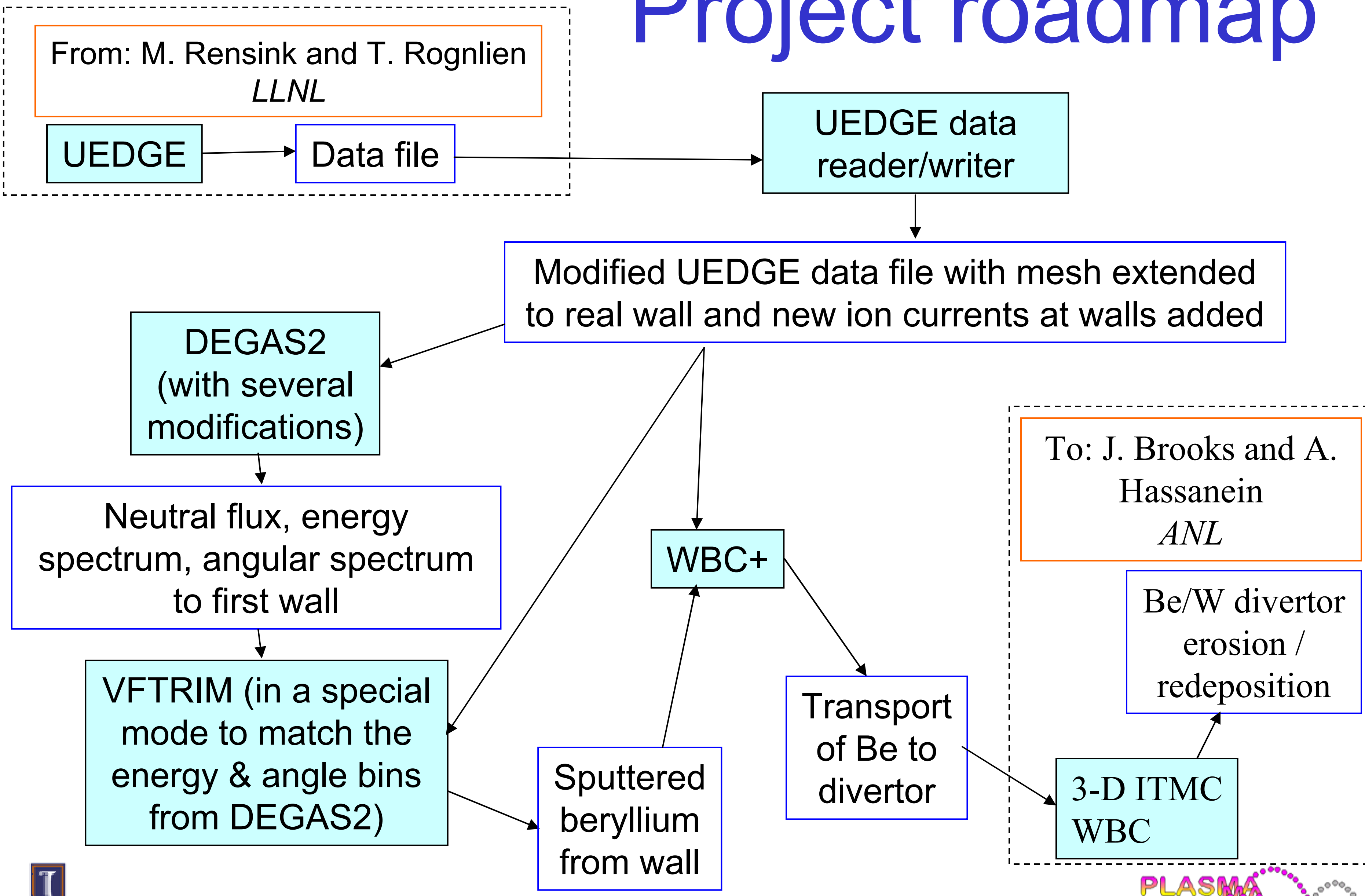
- R = 2.14 m, a = 0.595 m
- B = 10 T
- W_{mag} = 5.2 GJ
- I_p = 7.7 MA
- $P_{aux} \leq$ 20 MW
- Q $\approx$ 10, P_{fusion} ~ 150 MW
- Burn Time $\approx$ 20 s (2 tau_cr)
- Tokamak Cost $\approx$ $351M (FY02)
- Total Project Cost $\approx$ $1.2B(FY02) at Green Field site.

Mission: Attain, explore, understand and optimize magnetically-confined fusion-dominated plasmas.

FIRE Plasma Facing Components and computational geometry



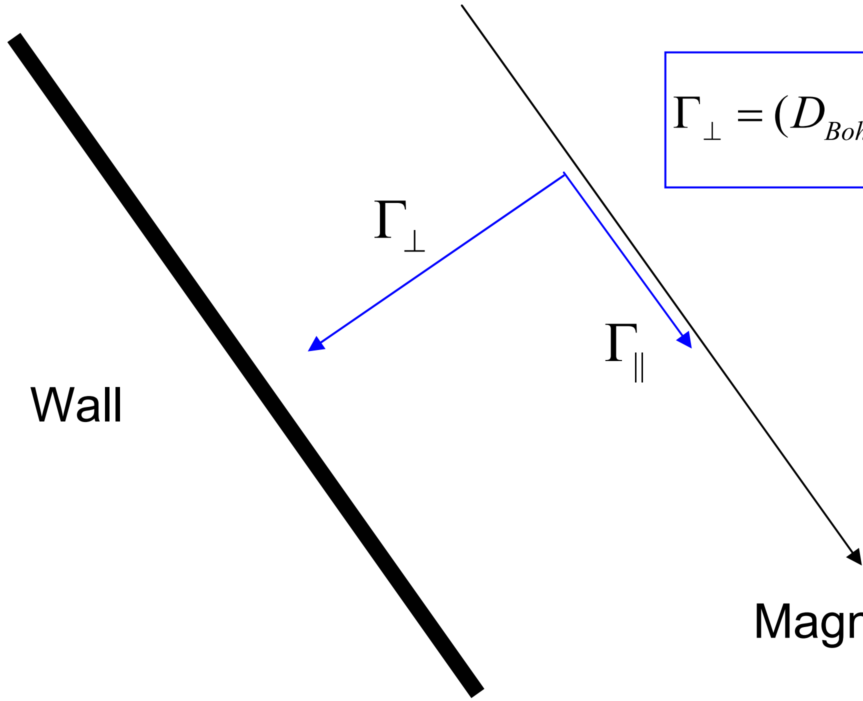
Project roadmap



ILLINOIS

PLASMA MATERIAL INTERACTION GROUP
University of Illinois at Urbana-Champaign

Revised model for ion flux to wall



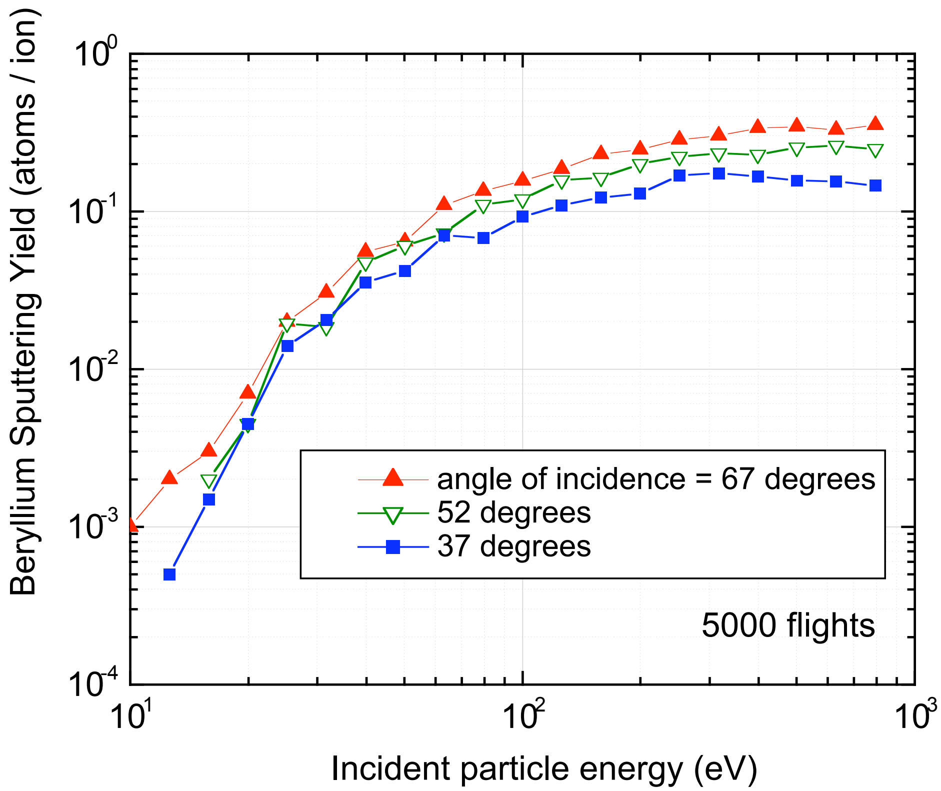
$$\Gamma_\perp = (D_{Bohm} + D_{anomalous})\nabla n_i = (D_{Bohm} + D_{anomalous})\frac{n_i}{\lambda_n}$$

$$D_{Bohm} \cong 0.06\frac{T_e}{B}$$

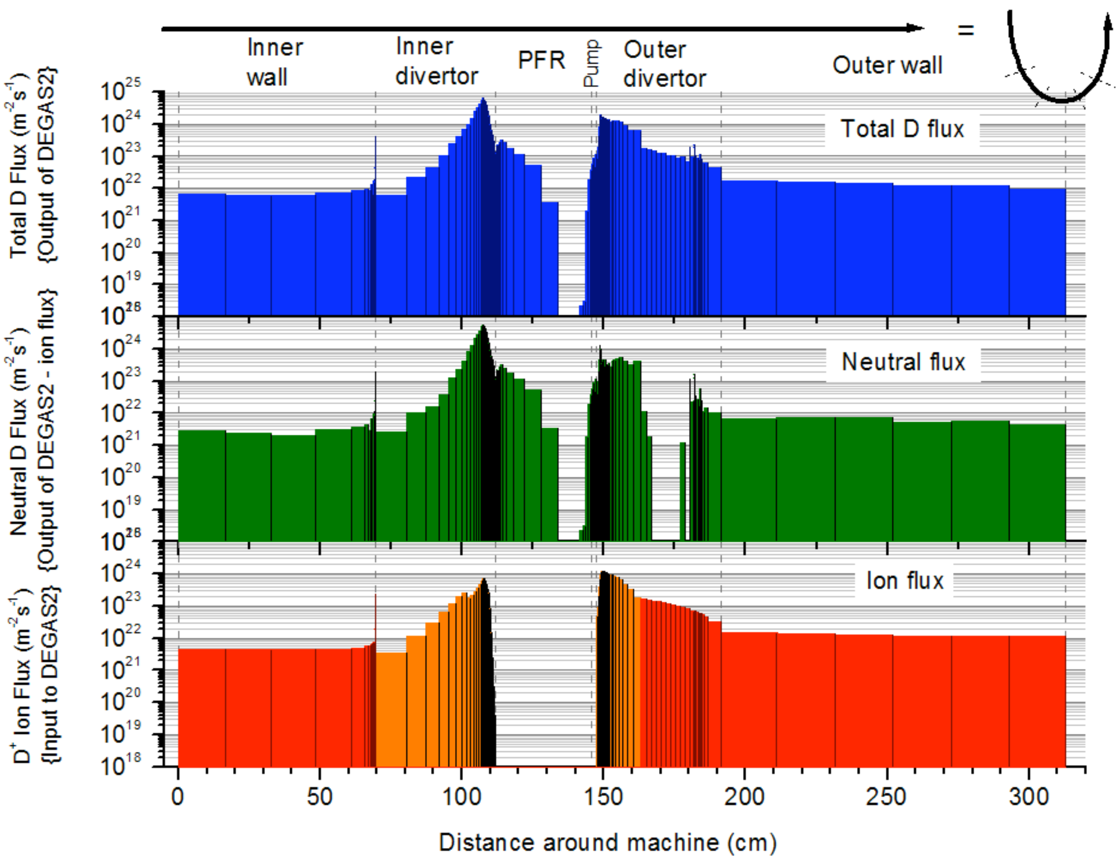
$$D_{anomalous} \cong 0.1\frac{m^2}{s}$$

- Anomalous transport is accounted for by adding a term in the perpendicular flux equation
- The anomalous diffusion coefficient was chosen to match what is typically used in UEDGE

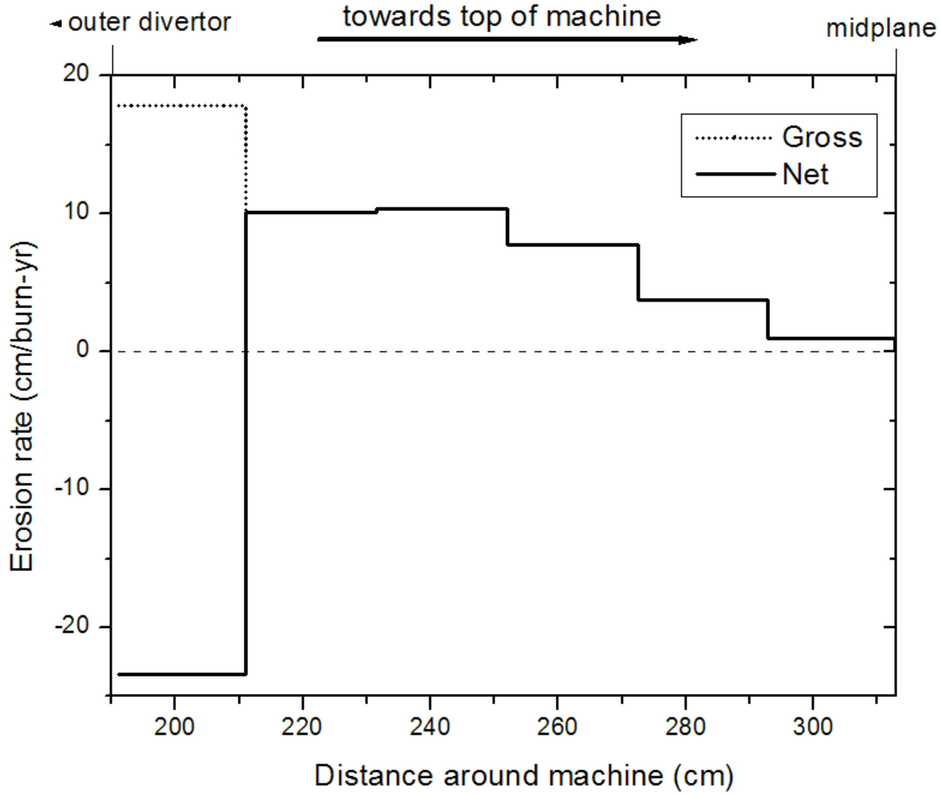
Sputtering yields for D^+ on Be from VFTRIM-3D with incident energies between 10 and 1000 eV, and incident angles of 37º, 52º, and 67º.



Flux of deuterium to FIRE walls/divertors. Convective transport included.

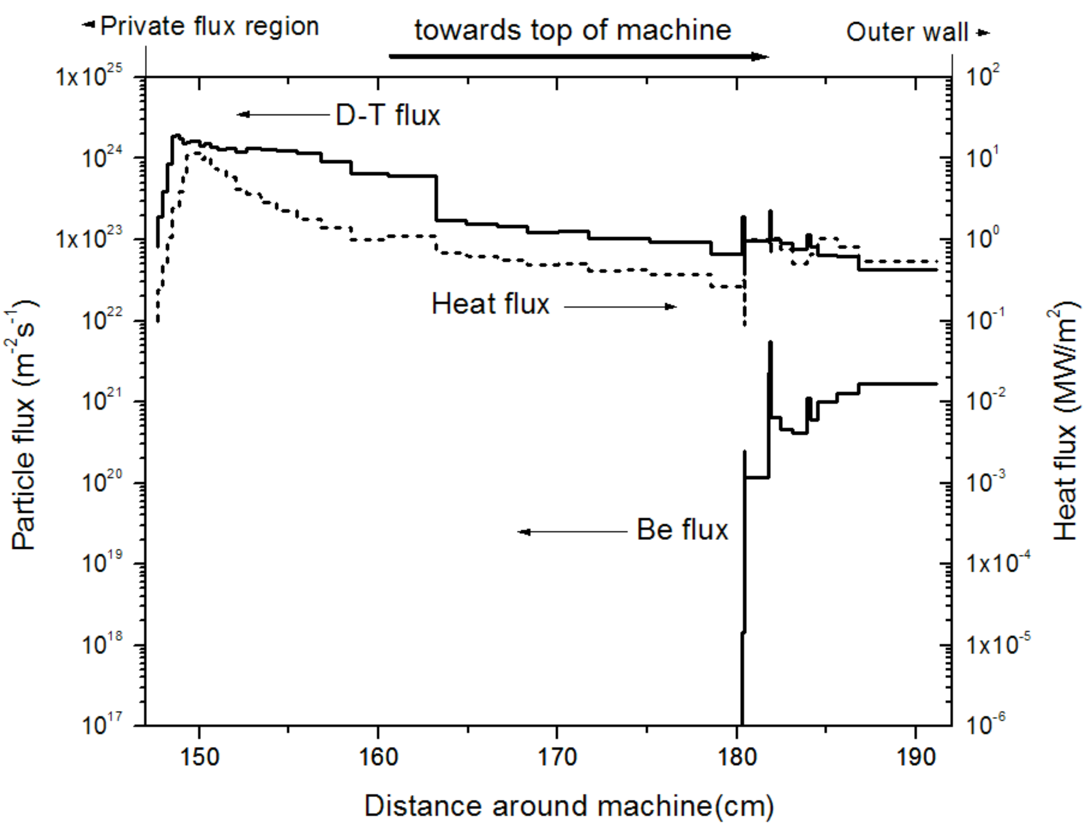


Net erosion rate, **outer wall** for convective transport case.



Beryllium growth and T/Be codeposition occurs on part of the wall, erosion on other parts.

Flux of beryllium to **outer divertor** for convective case.



- Be will deposit on low heat flux region of divertor

Selected erosion/redeposition parameters from WBC analysis of FIRE outer divertor w/beryllium surface, at strike point
(T_e = 15 eV, n_e = 2.17 x10^{21} m^{-3}, B = 10 T)

Parameter[a]	Value
Neutral ionization distance (average)[b]	0.15 mm
Energy	74 eV
Transit time	0.11 μs
Elevation angle	34 °
Charge state	1.4
Redeposition fraction (for 1 cm near-surface cutoff)	1.00

[a] Except where noted denotes average value for redeposited beryllium ions.
[b] Normal to surface

Tritium codeposition rates

- Q/Be trapping rate is a strong function of surface temperature and oxygen content [1]
- Use Mayer et al. data [2] for “abundant oxygen”
- Use Causey et al. data [1] for “low/no oxygen”
- Use Q/Be = 0 for “hot regions”
- Use Ts = 250 °C for “cold regions” (prelim.)

1. R.A. Causey, J. Nucl. Materials 300(2002)91, R.A. Causey, D.S. Walsh, J. Nucl. Mater. 254(1998)84.

2. M. Mayer, J. Nucl. Mater 240(1997)164., M Mayer et al, J. Nucl. Mater. 230(1996)67.

Tritium codeposition estimates *(DRAFT)*

D-T ion wall transport assumption	Q/Be trapping data assumption	Codeposition rate***	No. of 20 second shots needed to reach 1 gT
with convection	**Mayer et al.* ("abundant" oxygen)**	**1.9×10^{21} tritons/s = 9.7 mgT/s**	**5 shots**
"	**Causey et al.** (low/no oxygen)**	**3.2×10^{20} tritons/s = 1.6 mgT/s**	**31**
diffusion only	**Mayer et al.* ("abundant" oxygen)**	**1.1×10^{20} tritons/s = 0.54 mgT/s**	**92 shots**
"	**Causey et al. ** (low/no oxygen)**	**1.8×10^{19} tritons/s = 0.09 mgT/s**	**554**

* (Q/Be ~0.3 @ 250 °C), M. Mayer, J. Nucl. Mater 240(1997)164., M Mayer et al, J. Nucl. Mater. 230(1996)67.

** (Q/Be ~0.05 @ 250 °C), R.A. Causey, D.S. Walsh, J. Nucl. Mater. 254(1998)84.
*** $0.5*(Q/Be)*(I_{inner\text{-}divertor} + I_{outer\text{-}divertor} + .65*I_{outer\text{-}wall})$

Future Work:

- None, funding terminated

CONCLUSIONS

- This work represents a state-of-the-art attempt at computation of a highly complex subject, that of wall material erosion/transport/codeposition, combining numerous plasma and plasma-material-interaction codes.

- The FIRE beryllium coated first wall is predicted to work well from the plasma contamination standpoint, with essentially all but a trace amount of wall-sputtered beryllium depositing on the divertors or back on the wall.

- Wall erosion rates are high, for the plasma regime studied, but tolerable due to the low duty-factor. Erosion is high due to high fluxes of D-T ions/atoms, high sputter yields for beryllium, and relatively low local redeposition.

- A large fraction of wall-sputtered material goes to the inner and outer divertor. The divertor surfaces, nominally tungsten, would become in-situ coated with beryllium, as least between plasma high power transients.

- A key concern is tritium codeposition in redeposited growth areas of beryllium. This is highly dependent on whether or not convective transport of D-T ions to the wall occurs. It is also dependent on background oxygen level and surface temperatures. **In the best case tritium codeposition in FIRE appears to be acceptable and in the worst case is unacceptable.**

- An outstanding question for FIRE or like device is whether beryllium is needed on the wall. Based on a rough extrapolation of the beryllium results here for iron, a stainless steel (Fe) wall would not impair plasma performance through sputtering, and would avoid tritium codeposition concerns.