# Edge plasma calculations are reviewed

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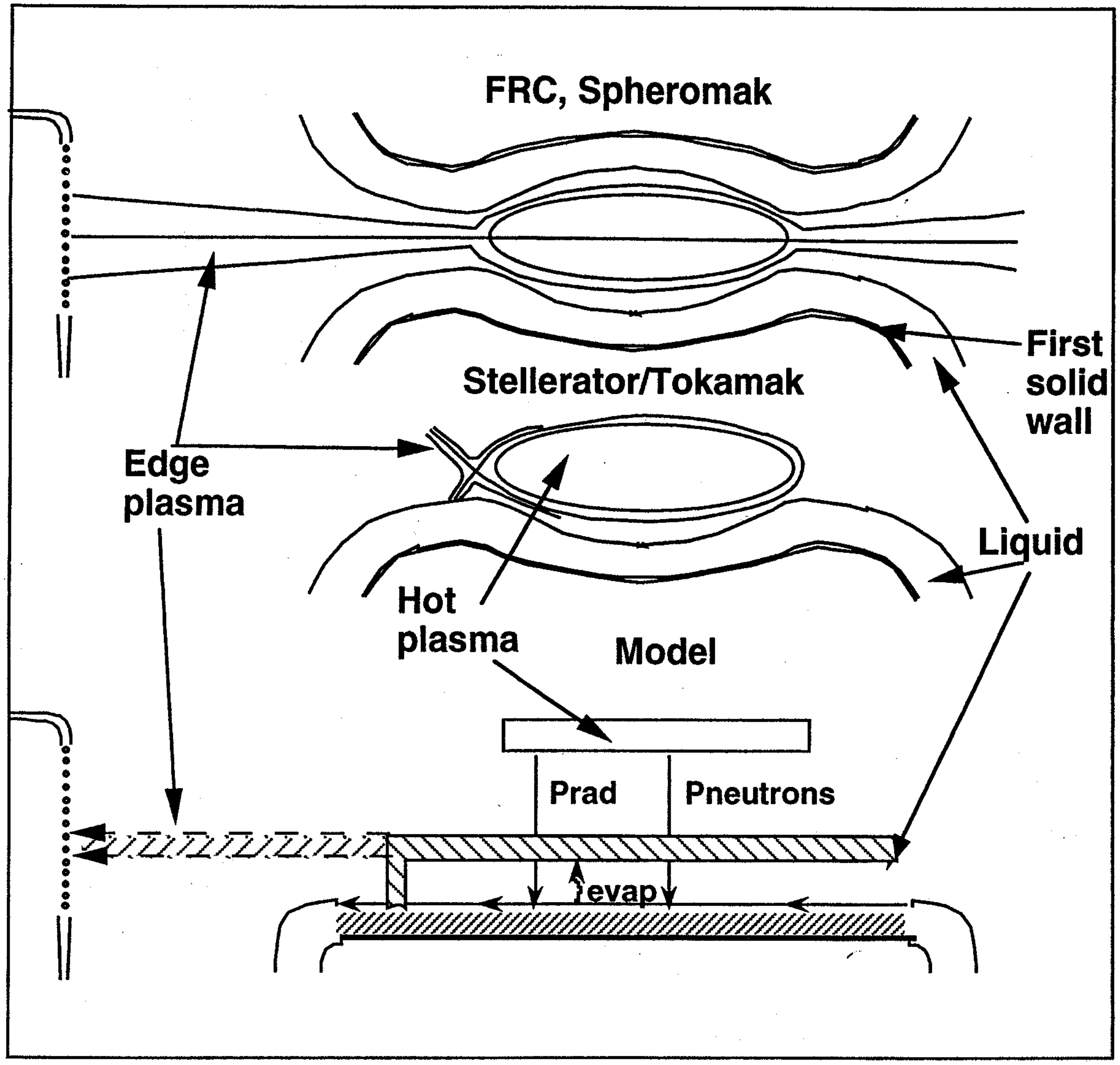
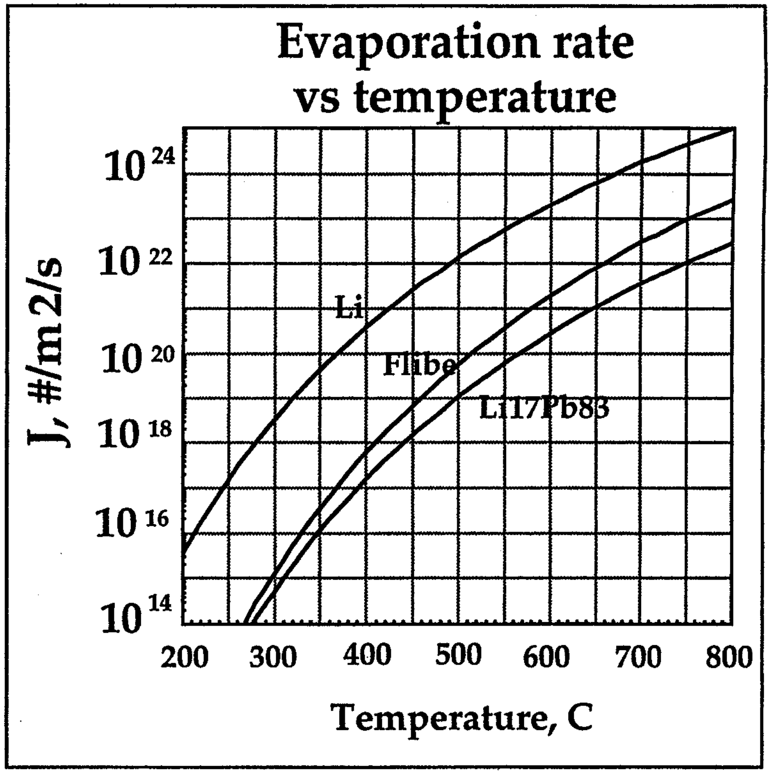
# Conclusions

**We need cross section information on D, T, He, Li, $BeF_2$, LiF and UEDGE calculations for open and closed field line edge plasmas.**

**For each confinement concept we need to see if a thick liquid layer can replace the usual solid first wall.**

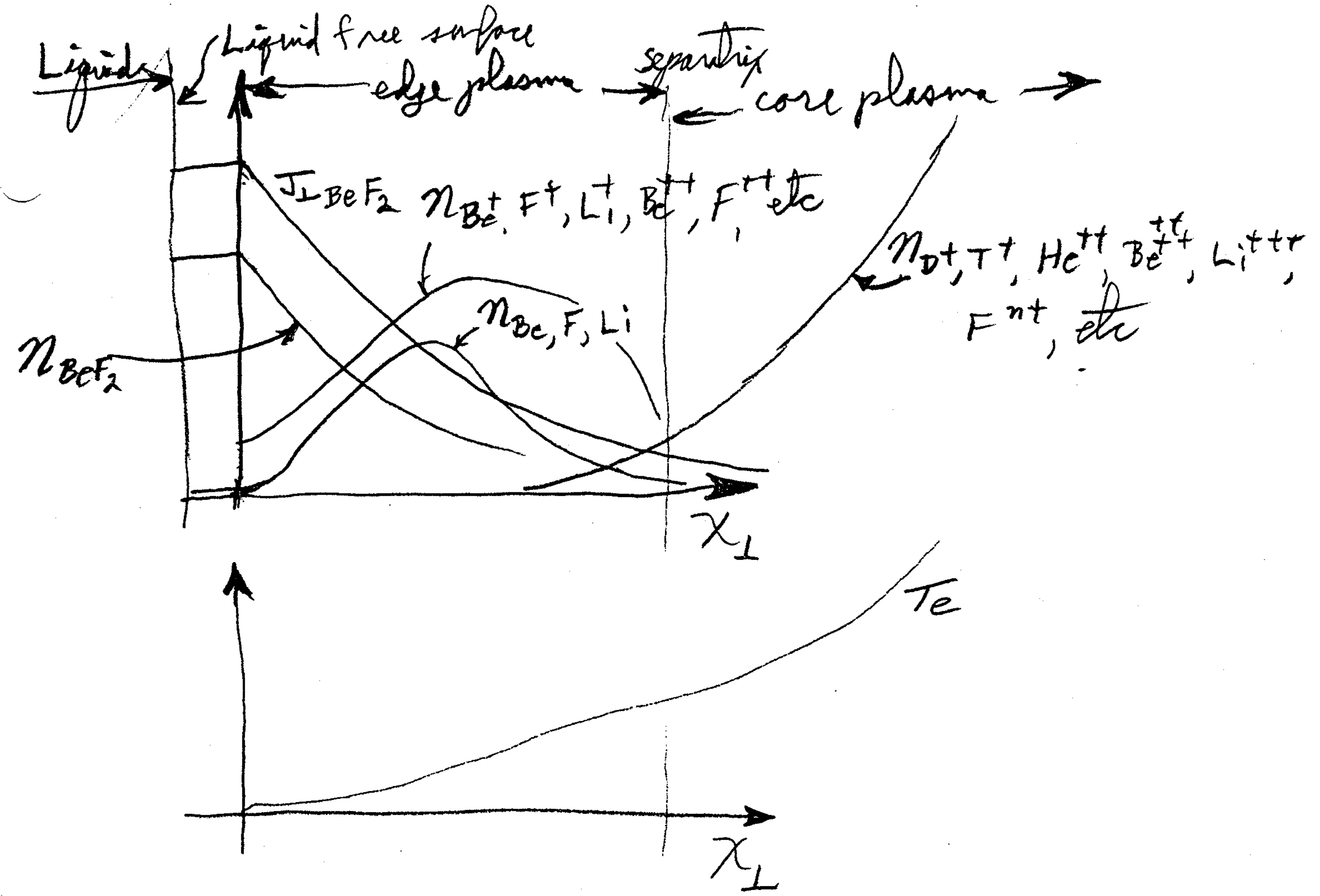
# Will the edge plasma adequately shield the hot plasma from evaporation?




Evaporation rate vs temperature

**Edge plasma modeling**

**Theory, experiments, DIII-D**
**UEDGE, DEGAS, . . .**
**How much evaporated material will penetrate thru the edge plasma?**



Edge plasma is dominated by ionized evaporating species and leaking $D^+, T^+$. Keeping Te hot enough to ionize is crucial. Knowing Te is crucial.

### Temperature rise of the liquid surface as it passes through the chamber

| | $\Delta T$with deep penetration | $\Delta T$without deep penetration |
|---|---|---|
| Li | 26 °C | 91 |
| Flibe | 164 | 463 |
| $Li_{17}Pb_{83}$ | 140 | 140 |

$n_\alpha/n_e$ = 0.1
$n_{Li}/n_e$ = 0.05 $Z_{ave.}$ = 3
$n_{Flibe}/n_e$ = 0.005 $Z_{ave.}$ = 7.3 for $BeF_2$
$n_{Li_{17}Pb_{83}}/n_e$ = 0.0001 $Z_{ave.}$ = 82 for Pb

$F_{allowed} = \dot{N}_{Li\text{-}allowed}/\text{evaporation rate}; \dot{N}_{Li\text{-}allowed} = n_{Li}/n_e \times n_e/n_\alpha \times \dot{N}_\alpha$

$F_{attenuation} = \dot{N}_{Li\text{-}allowed}/\dot{N}_{Li\text{-}evaporation} = \exp-(L n_e \sigma v_e/v_o)$
$T_{edge}$ = 0.4 keV
$n_e$ = $4\times10^{13}$ cm$^{-3}$ at separatrix
$\sigma v_e$ ~$3\times10^{-8}$ cm$^3$/s = ionization by electrons
L = average thickness of edge plasma ~ 1 cm

### Predicted ionizing ability of the edge plasma

| | Li | Flibe | $Li_{17}Pb_{83}$ |
|---|---|---|---|
| $F_{attenuation}$ | $2.1\times10^{-4}$ | $3.7\times10^{-9}$ | $9.5\times10^{-20}$ |
| $v_o$; m/s | 1420 | 618 | 274 |
| Temperature, K | 666 | 855 | 743 |
| $F_{allowed}$ | $7.3\times10^{-3}$ | $1.9\times10^{-2}$ | $1.1\times10^{-4}$ |

References

1. R. W. Moir, "Liquid first walls for magnetic fusion energy configurations," *Nuclear Fusion* 37 (1997) 557-566.
2. N. C. Christofilos, "Design for a High Power-Density Astron Reactor," *J. Fusion Energy* 8 (1989) 97-105.
3. R. W. Moir, "Rotating Liquid Blanket for a Toroidal Fusion Reactor", *Fusion Engineering and Design* 5 269 (1987).
4. R. W. Moir, "The Logic Behind Thick, Liquid-Walled, Fusion Concepts," *Nuclear Engineering and Design* 29 (1995) 34-42.
5. R. W. Moir, "Rotating Liquid Blanket with No First Wall for Fusion Reactor", *Fusion Technology* 15 674 (1989).

## Liquid wall evaporation rates for Tokamak and Field Reversed Configuration

| $P_{\mathrm{fusion}}$ | Evaporation rate Tokamak | Evaporation rate FRC or Spheromak | Ref. |
|---|---|---|---|
| 12 GW | | $\frac{\dot{\mathrm{Li}}}{\dot{\mathrm{He}}}=68$ | 1 |
| 3 GW | $\frac{\dot{\mathrm{BeF}}_2}{\dot{\mathrm{He}}}=37$<br>=0.34 allowed<br>attenuation required =0.0092 | | 2 |
| 4.4 GW | | $\frac{\dot{\mathrm{Li}}}{\dot{\mathrm{He}}}=71$, $\frac{\dot{\mathrm{BeF}}_2}{\dot{\mathrm{He}}}=2.6$, $\frac{\dot{\mathrm{Pb}}}{\dot{\mathrm{He}}}=9.3$ | 3 |
| | | Allowed impurity input rate to core plasma | |
| | =0.5 | =5 =0.5 =0.01 | 3 |
| | | Attenuation required of edge plasma | |
| | | =0.07 =0.19 =0.0011 | 3 |

Ref. 1. N. C. Christofilos, *J. Fusion Energy* 8 (1989) 97-105.
2. R. W. Moir, *Fusion Technology* 15 (1989) 674-679.
3. R. W. Moir, *NuclearFusion* 37 (1997) 557-566.

$$\frac{n_{He}}{n_e} = 0.1 \qquad \dot{\mathrm{He}} = 0.32 \times 10^{21}/\mathrm{s} \cdot \mathrm{GW}_{\mathrm{fusion}}$$

$$\frac{n_{Li}}{n_e} = 0.05 \qquad \frac{n_{BeF_2}}{n_e} = 0.005 \qquad \frac{n_{Pb}}{n_e} = 0.0001$$

Assume lifetime of impurities is 0.1 of the helium ash lifetime.

$$\frac{\dot{\mathrm{Li}}}{\dot{\mathrm{He}}} = \frac{n_{Li}}{n_e}\frac{n_e}{n_{He}}\frac{10\mathrm{s}}{1\mathrm{s}} = 0.05\mathrm{x}(1/0.1)\mathrm{x}10 = 5.0$$

$$\frac{\dot{\mathrm{BeF}}_2}{\dot{\mathrm{He}}} = \frac{n_{BeF_2}}{n_e}\frac{n_e}{n_{He}}\frac{10\mathrm{s}}{1\mathrm{s}} = 0.005\mathrm{x}(1/0.1)\mathrm{x}10 = 0.5$$

$$\frac{\dot{\mathrm{Pb}}}{\dot{\mathrm{He}}} = \frac{n_{Pb}}{n_e}\frac{n_e}{n_{He}}\frac{10\mathrm{s}}{1\mathrm{s}} = 0.0001\mathrm{x}(1/0.1)\mathrm{x}10 = 0.01$$

**Assumptions to be checked:**

$$\frac{\tau_{\text{He edge}}}{\tau_{\text{He ash}}} = 0.1\ ?$$

$$\frac{\tau_{\text{Li}}}{\tau_{\text{He}}} = 1\ ?$$

$$\frac{\tau_{\text{Be}}}{\tau_{\text{He}}} = 1\ ?$$

$$\frac{\tau_{\text{F}}}{\tau_{\text{He}}} = 1\ ?$$

$$\frac{\tau_{\text{Pb}}}{\tau_{\text{He}}} = 1\ ?$$

$$\frac{n_{\text{He}}}{n_e} = 0.1\ ?$$

$$\frac{n_{\text{Li}}}{n_e} = 0.05\ ?$$

$$\frac{n_{\text{Be}}}{n_e} = 0.005\ ?$$

$$\frac{n_{\text{F}}}{n_e} = 0.005\ ?$$

$$\frac{n_{\text{Pb}}}{n_e} = 0.0001\ ?$$

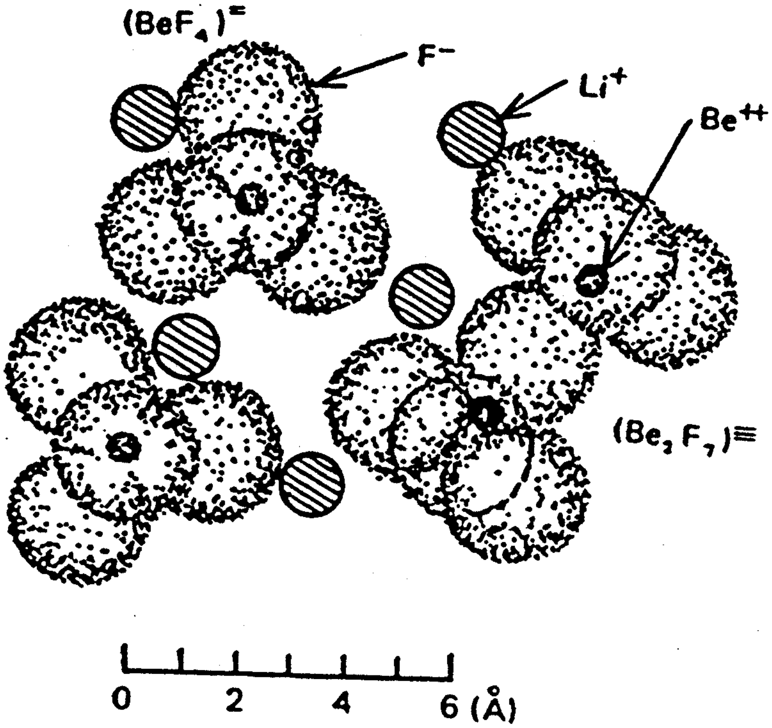


Fig. 2 − 3　溶融Flibeの構造模型

## 6.8 Chemical Kinetics for Flibe

After the fusion capsule burn ends in the HYLIFE reactor, x-rays emitted by the fusion material are absorbed in a thin surface layer around the inside edge of the Flibe curtain. The energy distribution in this layer is highly nonuniform, decaying exponentially with distance into the fluid. Over the short time in which the energy is deposited and the layer vaporizes, heat conduction and mass diffusion effects are small and the energy distribution remains nonuniform. At the surface and for some distance into the layer, the energy supplied is much greater than that required for vaporization, and thus dissociation and some ionization of the Flibe is expected. The elementary gas phase reactions will include:

$LiF + M^* \rightarrow Li + F + M$ (-579 kJ/mol) 6.00eV (1)
$Li_2F_2 + M^* \rightarrow 2LiF + M$ (-261 kJ/mol) 2.70 (2)
$Li_3F_3 + M^* \rightarrow Li_2F_2 + LiF + M$ (-233 kJ/mol) 2.41 (3)
$Li_2 + M^* \rightarrow 2Li + M$ (-102 kJ/mol) 1.06 (4)
$Li + M^* \rightarrow Li^+ + e^- + M$ (-526 kJ/mol) 5.45 (5)
$BeF_2 + M^* \rightarrow BeF + F + M$ (-705 kJ/mol) 7.30 (6)
$BeF + M^* \rightarrow Be + F + M$ (-573 kJ/mol) 5.94 (7)
$Be + M^* \rightarrow Be^+ + e^- + M$ (-895 kJ/mol) 9.27 (8)
$F_2 + M^* \rightarrow 2F + M$ (-159 kJ/mol) 1.65 (9)
$F^- + M^* \rightarrow F + e^- + M$ (-334 kJ/mol) 3.46 (10)
$F + M^* \rightarrow F^+ + e^- + M$ (-1687 kJ/mol) 17.48 (11)
$LiBeF_3 + M \rightarrow LiF + BeF_2 + M^*$ (250 kJ/mol) - 2.59 (12)

where the resulting energy release is given in parenthesis (evaluated at 298 K, Chase, 1985). The inverse of the above dissociation reactions are three body recombination reactions, which require that a third molecule M participate in the collision, and exit at an excited state M* to remove the energy of chemical recombination. The rate of the dissociation reactions, and the corresponding inverse recombination reactions, is governed primarily by the pressure and temperature of the gas. The probability of two and three body collisions is larger at higher pressures, and thus reactions occur more rapidly. This qualitative effect is expressed analytically as the law of mass action for an elementary reaction step,

$$\omega = k \prod_{i=1}^{N} c_i^{n'_i} \qquad (11)$$

where $\omega$ is the reaction rate, k is the reaction-rate constant, N is the number of species involved in the reaction, and $n_i$ and $c_i$ are the stoichometric coefficient and the molar density of species $M_i$, for a reaction which can be written as

# Flibe (Li2BeF4) is a mixture of LiF and BeF2

Phase Diagram