Neutral Penetration Physics
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REFERENCES

1. "Plasma-surface interactions" chapter in Wesson's *Tokamaks*.
   - Quick overview.
2. P.C. Stangeby and G. M. McCracken, *Nucl. Fusion* **30** (1990) 1225.
   - Detailed review; deals mostly with limiter configurations.
3. *Physics of Plasma-Wall Interactions in Controlled Fusion*, D. E. Post and R. Behrisch, Eds. (Plenum, New York, 1984).
   - AKA "The NATO book",
   - In depth discussion of every aspect of PSI,
   - Still a very useful reference.
4. C. S. Pitcher and P. C. Stangeby, *Plasma Phys. Control. Fusion* **39** (1997) 779.
   - Review of current status of experimental divertor physics.

PLASMA TRANSPORT

- Plasma diffuses into SOL across LCFS.
- SOL transport governed by:
  - Anomalous $\perp$ diffusion, $D_\perp$,
  - $\parallel$ flow velocity $\sim c_s$, along field lines to target.
- Balance between them determines density SOL width:

$$\lambda_n \simeq (2D_\perp L_c/c_s)^{1/2}.$$

- Pre-sheath extending from stagnation point to target accelerates ions to c_s at sheath,
  - Bohm sheath criterion.
- Ions accelerated through sheath & strike target,
  - $E_{ion} \simeq 3T_e + 1.5T_i$,
  - Details vary: many different sheath models.

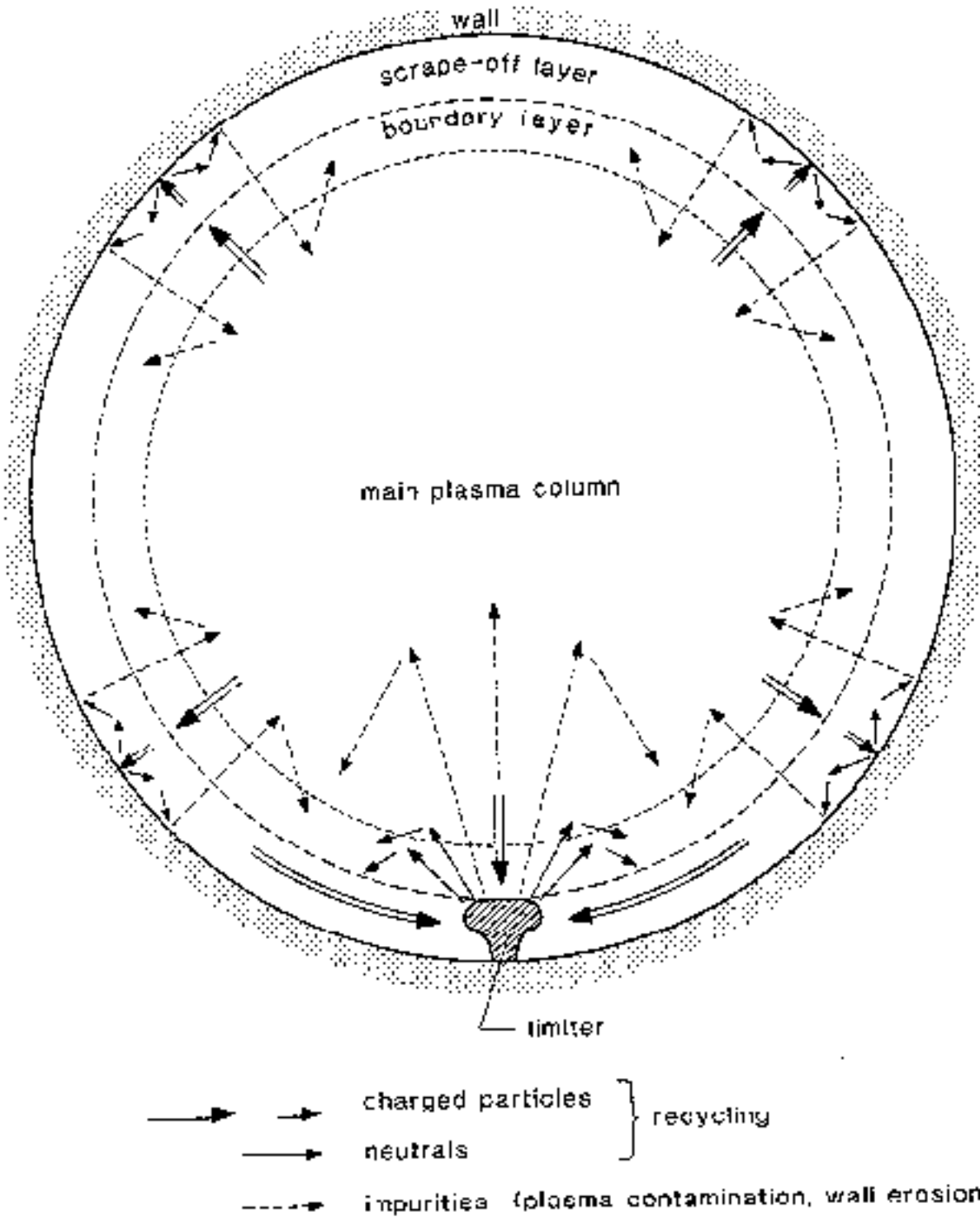

Fig. 12. Plasma-wall interaction and its consequences (schemat

From "The NATO Book"

PLASMA-SURFACE INTERACTION

- Ions neutralized near surface,
  - $\Rightarrow$ processes same for ions & neutrals.
- Particle collides with atoms in solid,
- Possible outcomes include:
  1. Backscattered with most of its incident energy,
  2. Slowed down & trapped (absorbed),
  3. Knocks out a surface atom (impurity),
  4. Chemically interacts with surface (e.g., CH_4 production).
- Consider (1) and (2) for now.
- Backscattering or reflection modeled with
  - Reflection coefficient(incident energy & angle),
  - Reflected velocity distribution(incident energy & angle),
  - I.e., energies $\sim$ 1–100 eV.
- Desorption
  - Adsorbed H recombines into H_2,
  - Released from surface at wall temperature, $\sim$ 0.03 eV,
  - Modeling usually assumes equilibrium.

NEUTRAL TRANSPORT

- Ions striking target provide source of neutral atoms & molecules,
  - Spatial distribution determined by ion flux to target,
  - Velocity distribution determined by process, e.g.,
    - Reflection (atoms),
    - Desorption (molecules).
  - Atoms undergo:
    - Ionization, $\mathrm{H} + \mathrm{e} \rightarrow \mathrm{H}^+ + 2\mathrm{e}$
    - Charge exchange, $\mathrm{H} + \mathrm{H}^+ \rightarrow \mathrm{H}^+ + \mathrm{H}$
  - Molecules:
    - $\mathrm{H}_2 + \mathrm{e} \rightarrow \mathrm{H} + \mathrm{H} + \mathrm{e}$
    - $\mathrm{H}_2 + \mathrm{e} \rightarrow \mathrm{H}_2^+ + 2\mathrm{e}$
    - $\mathrm{H}_2 + \mathrm{e} \rightarrow \mathrm{H} + \mathrm{H}^+ + 2\mathrm{e}$
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    - $\mathrm{H}_2^+ + \mathrm{e} \rightarrow \mathrm{H} + \mathrm{H}$
    - Because of low energies, typically occur close to target.
    - Dissociation products: $E \sim$ few eV.
  - Neutral flux decays with distance away from target due to ionization,

$$\Gamma(s) = \Gamma_0 \exp\left(-\int_{s_t}^{s} n_e \langle \sigma v \rangle_{\mathrm{ion}} ds / v_0\right).$$

  - For H, $\langle \sigma v \rangle_{\mathrm{ion}}/v_0 \simeq 3 \times 10^{-19}\ \mathrm{m}^2$, $T_e = 10$–1000 eV,
  - Roughly, $\lambda_{\mathrm{pen}} \sim (3 \times 10^{-19} n_{e,a})^{-1}$,
  - To keep $\lambda_{\mathrm{pen}} \leq 0.1a$,

$$\bar{n}_e a > 5 \times 10^{19} \mathrm{m}^2,$$

  - See Stangeby & McCracken and refs. therein.