Local Recycling and Wall Equilibration in Tore Supra

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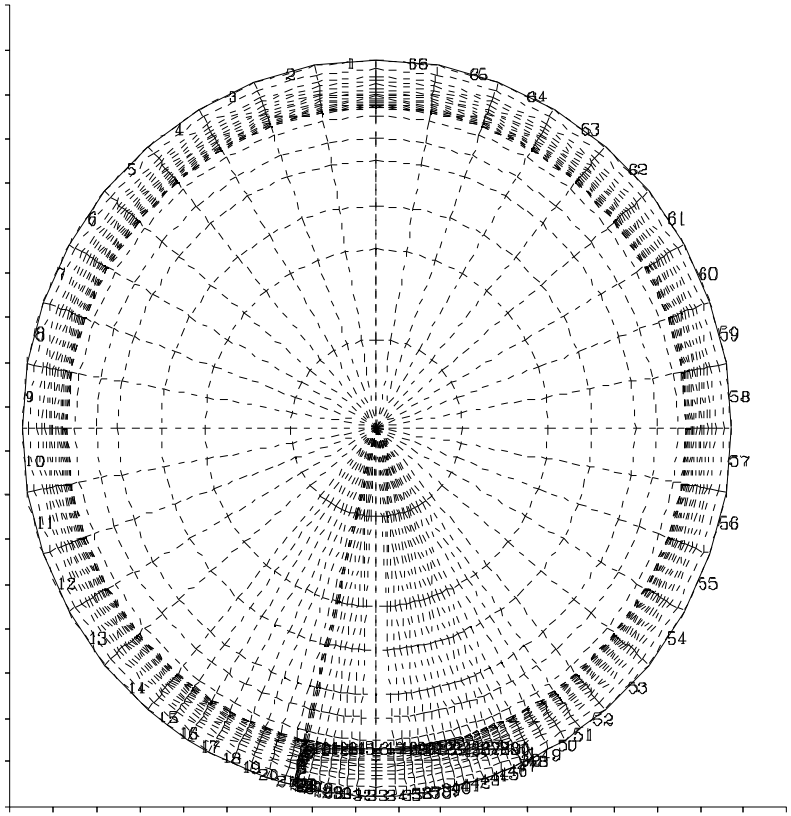
Abstract

- The recycling coefficient of the first wall of a fusion device is a space- and time-dependent parameter.
- The present paper is an analysis of the spatially dependent recycling coefficient as a function of time, using the Tore Supra vacuum vessel as an example.
- In the first step an analytical formula is constructed to simulate the recycling coefficient as a function of the trapped particle flux.
- In the second step, the vessel walls are subdivided into a computational grid of 73 segments. For each segment the incident neutral particle flux is calculated with the DEGAS neutrals-code using an analytic model for the plasma parameters and for the ion flux to the toroidal limiter.
- The incident particle fluxes and the recycling formula are then used to analyze the local and temporal recycling behavior of the wall.

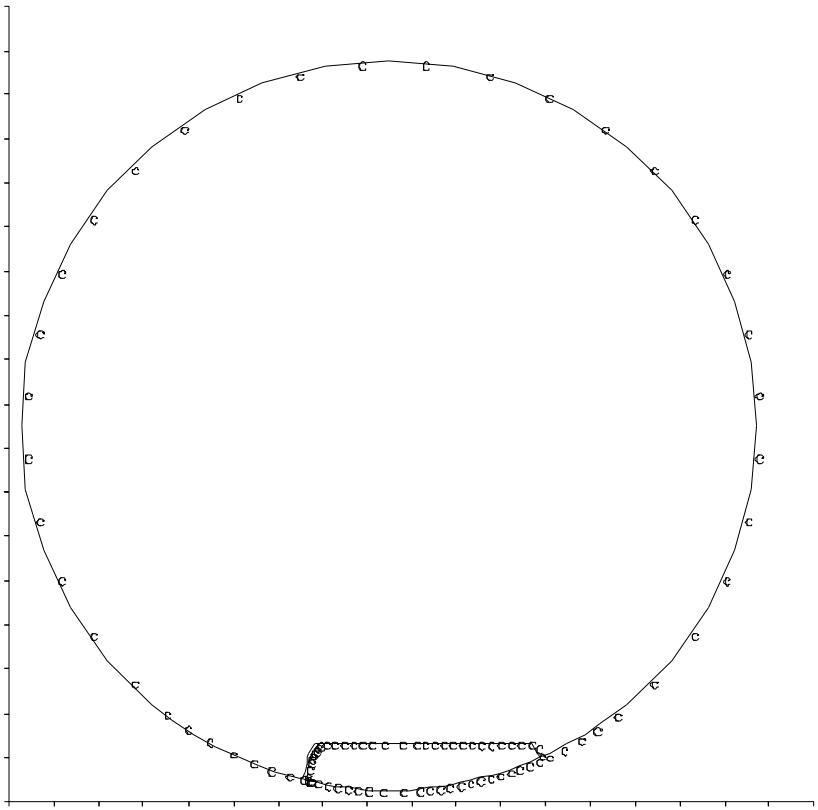
Plasma model and DEGAS neutrals transport results

- Analytic plasma model assumed with exponential profiles in the SOL and quadratic in the core plasma.
- Major (minor) radius of plasma = 2.4 m (0.72 m)
- n(0)=5 x 10^{19} m^{-3}, T(0)=2 keV, n(a)=1.25 x 10^{19} m^{-3}, T(a)=50 eV
- Particle flux decay length in SOL and at limiter = 2.3 cm
- Integrated ion flux to the limiter = 3 x 10^{22} s^{-1}
- Integrated core ionization (fueling) rate = 1.06 x 10^{22} s^{-1} . Total core charge exchange rate = (1.28 x 10^{22} s^{-1}).
- If core particle balance is assumed (core efflux = core fueling rate) then the assumed core particle confinement time is 0.1 s.

The plasma flux surfaces are taken to be concentric circles. Since pumping is from the inboard side, the plasma is slightly offset from the center of the limiter

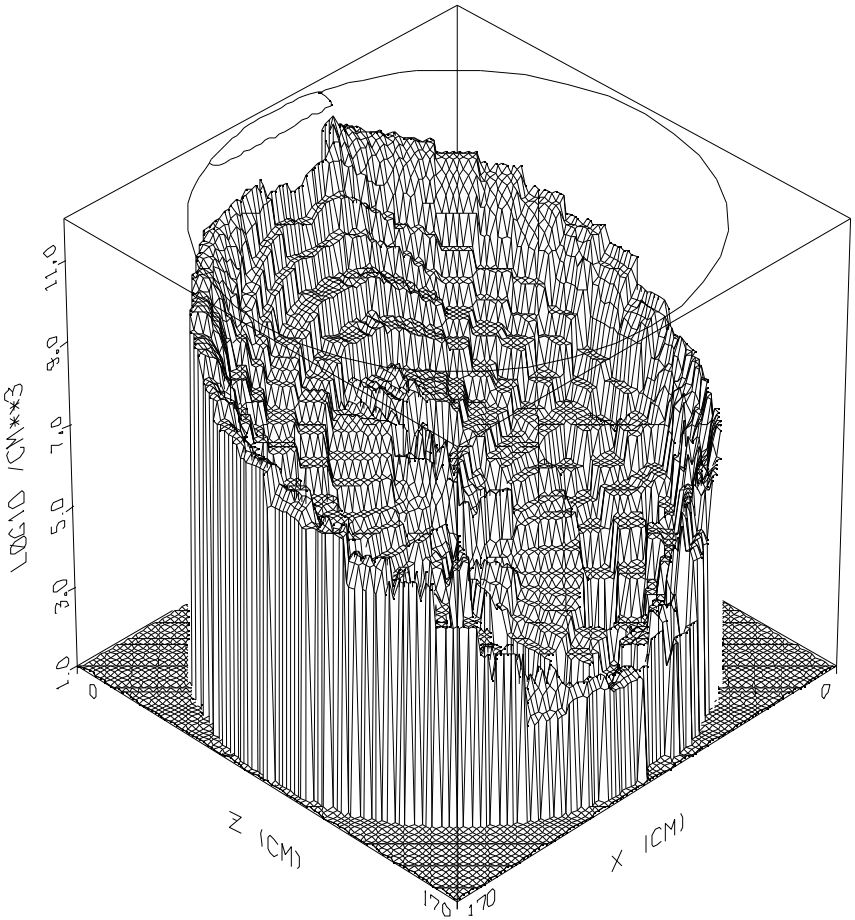


DEGAS grid

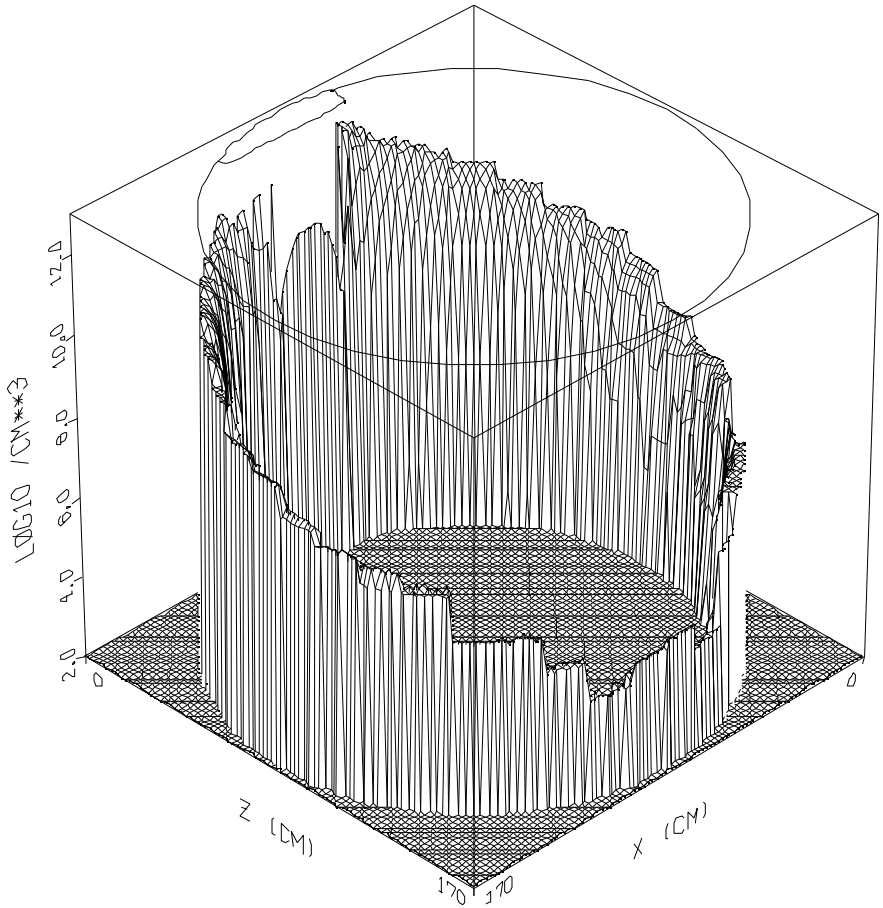


Wall and limiter segments used for DEGAS simulations

Densities of atomic and molecular deuterium resulting from D^+ recycling at the limiter. The strongly localized D_2^0 density at the side walls is due to D_2^0 desorption following D^0 impact with the walls.

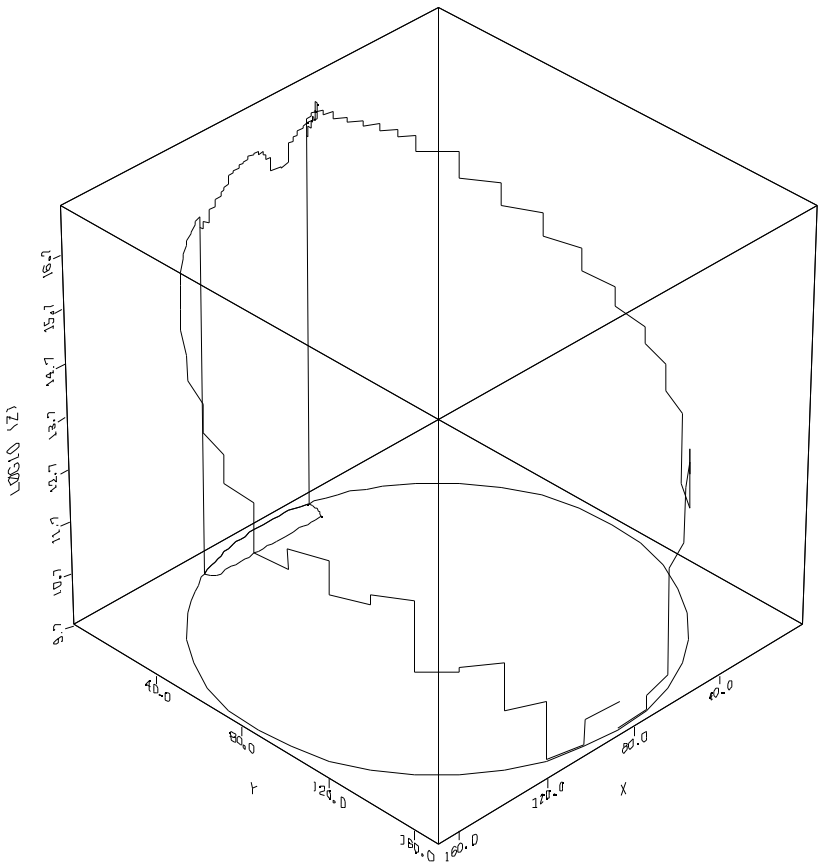


D^0 density

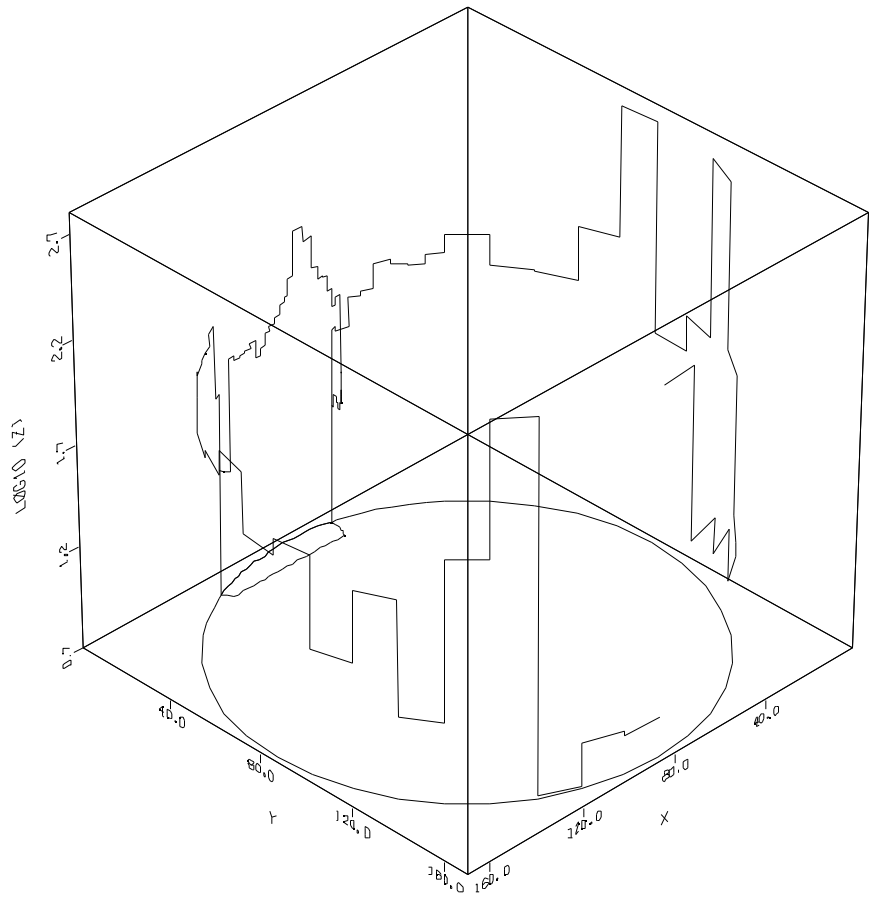


D_2^0 density

The flux of D^0 on the vacuum vessel walls decreases with distance from the limiter, but due to energetic charge exchange neutrals the average energy has a weaker dependence on poloidal angle

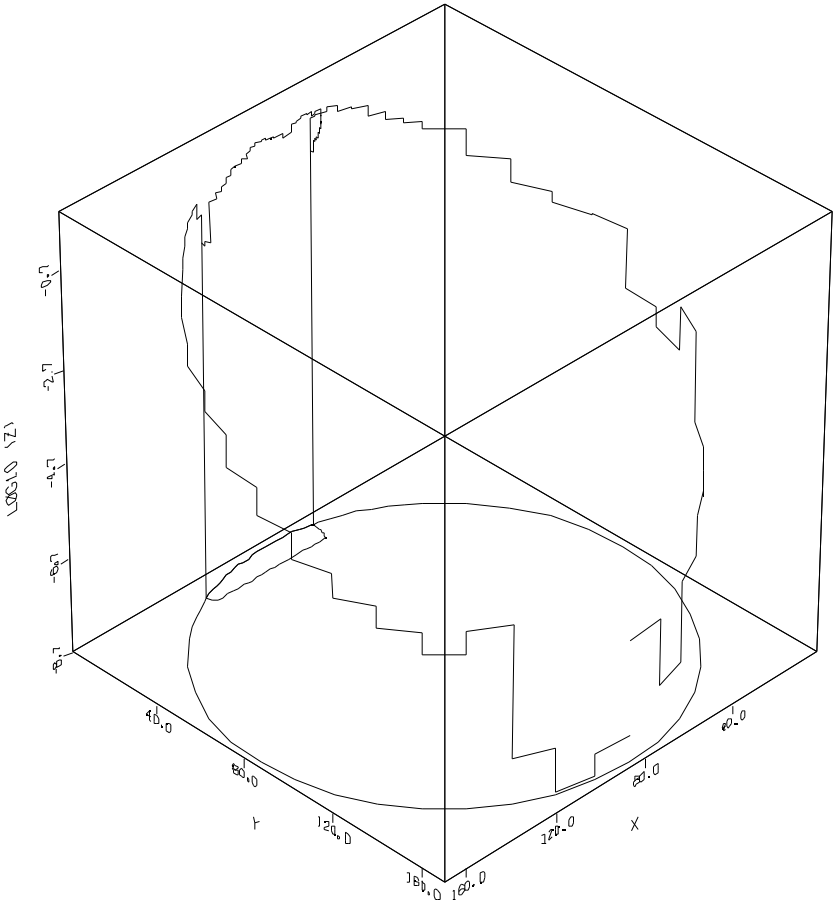


Flux on neutral D on walls

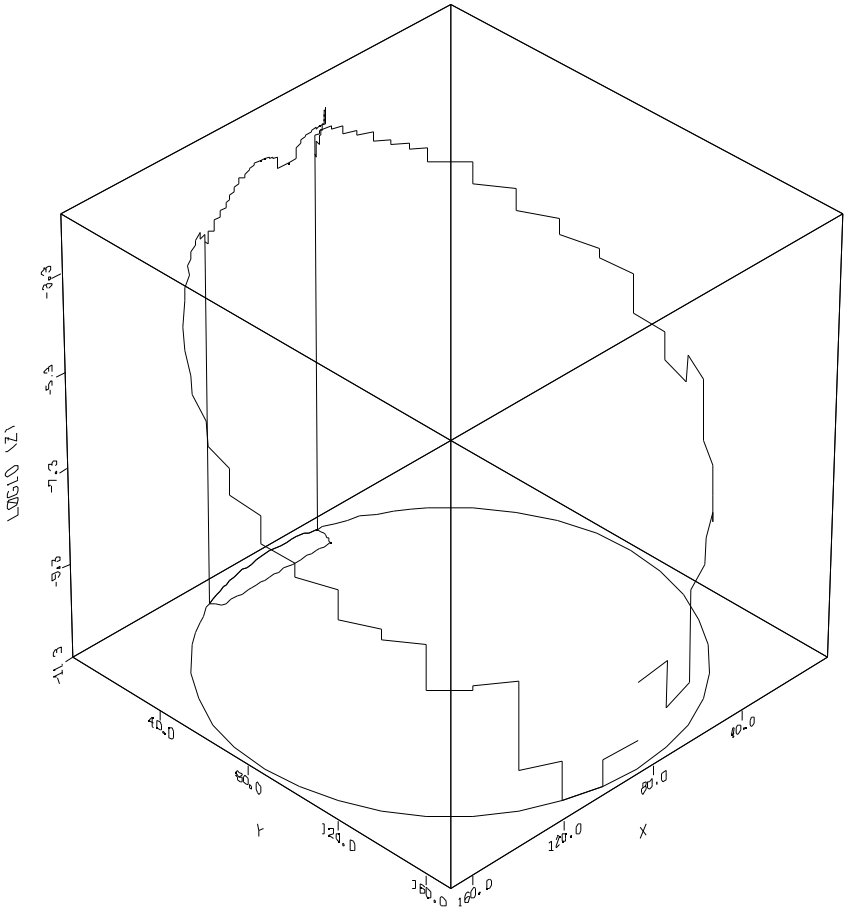


Average energy of neutral D on walls

The average neutral power and momentum flux on the walls have similar dependences upon poloidal angle. Both tend to decrease more slowly than the D^0 particle flux.

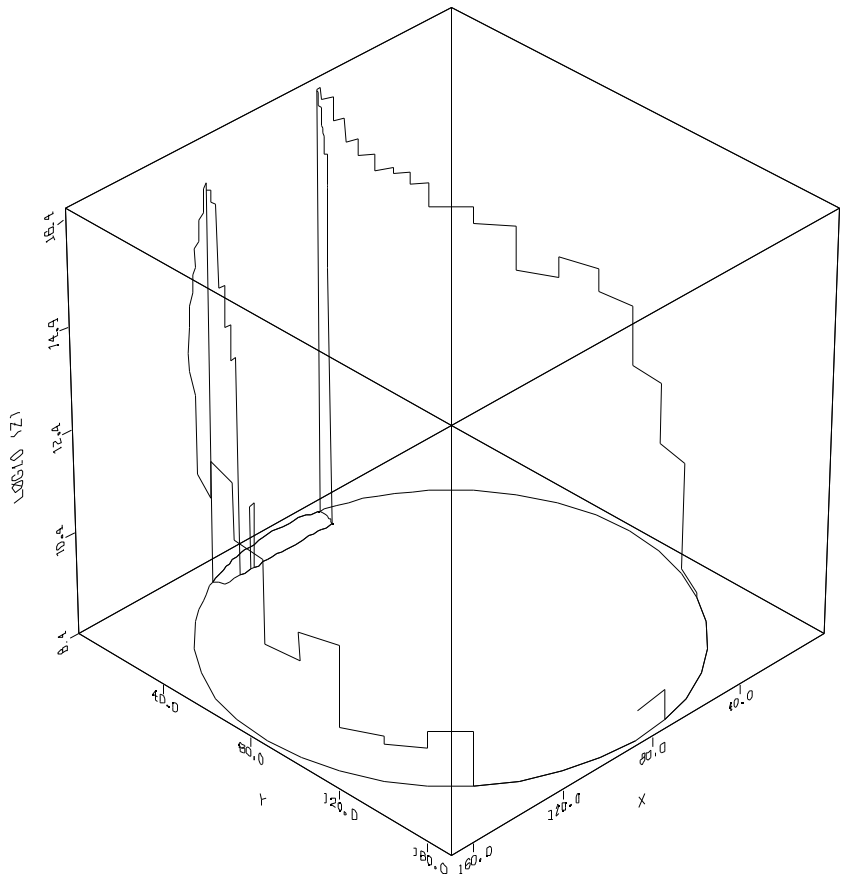


Average neutral power on walls

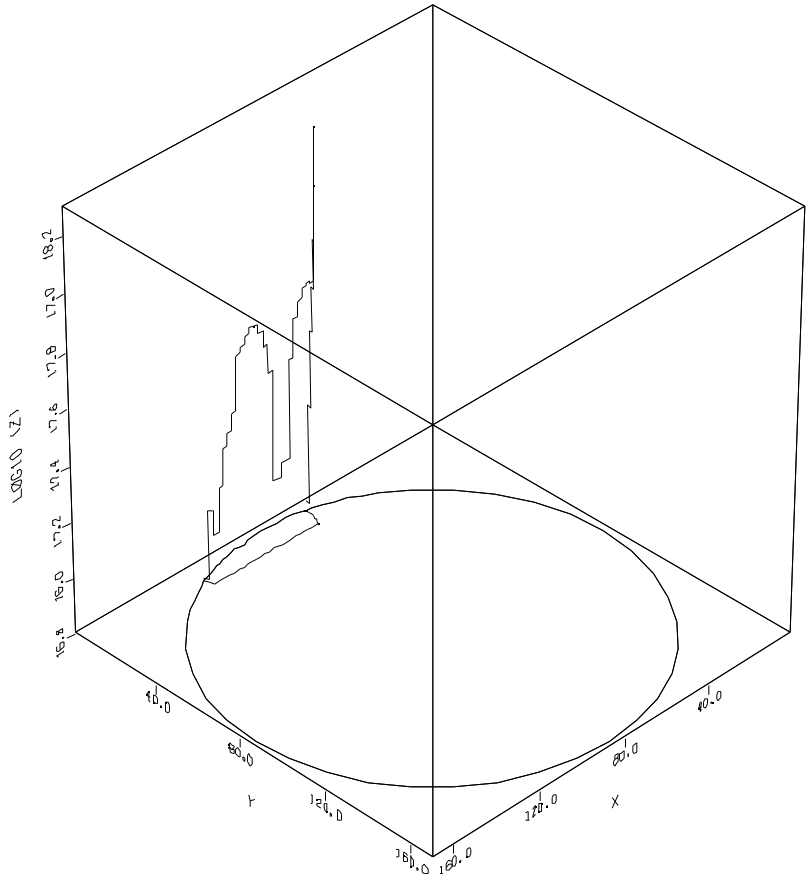


Momentum flux of neutral D on walls

The D^+ ion flux on the limiter is recycled into the plasma as atomic and molecular deuterium. The resultant D_2^0 flux is larger on the inboard side walls due to recycling from the inboard leading edge of the limiter in a cosine angular distribution.

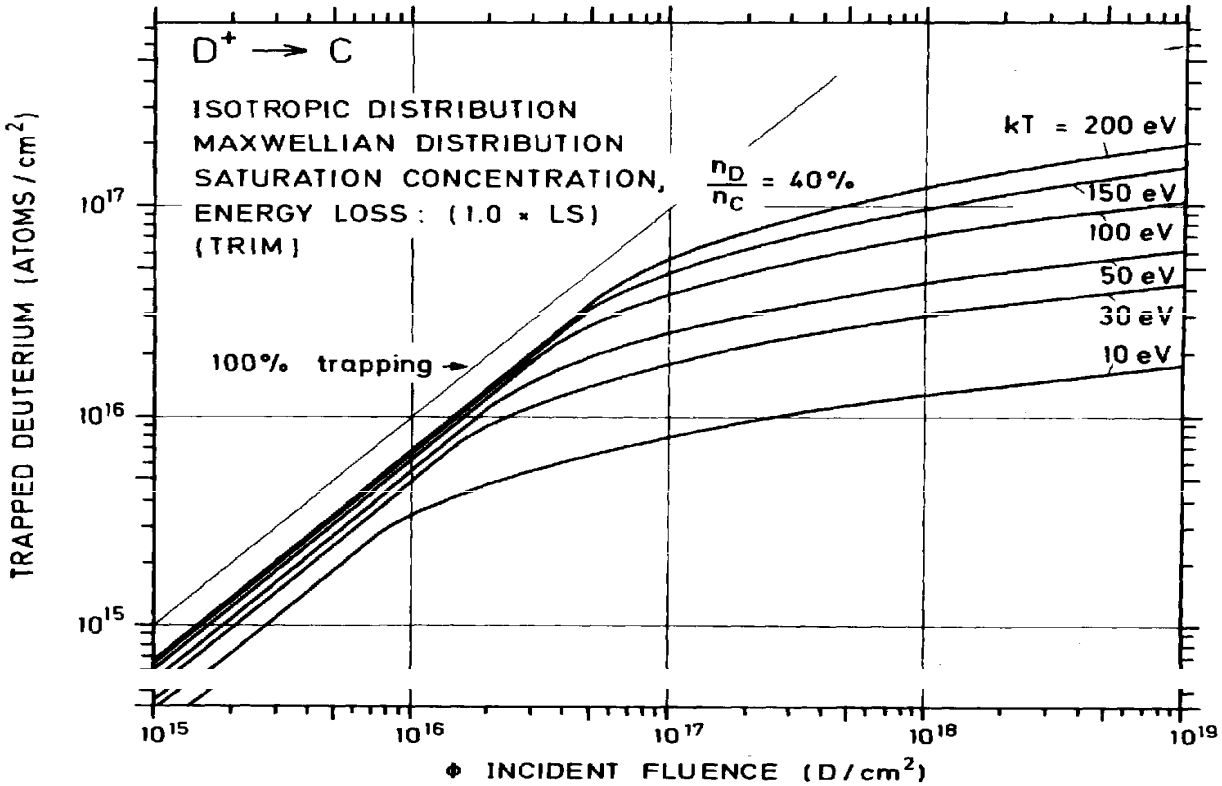


D_2^0 flux on walls



D^+ flux on limiter

Trapped Deuterium vs. Incident Fluence for Maxwellian Energy Distribution Has Been Calculated with TRIM.



W. Eckstein
Garching Report
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- These calculated trapping curves are used as the basis for an analytic formula to describe the fluence-dependent recycling coefficient.

The Recycling Coefficient as a Function of the Trapped Fluence n_{tr} Is Described as a tanh-Function

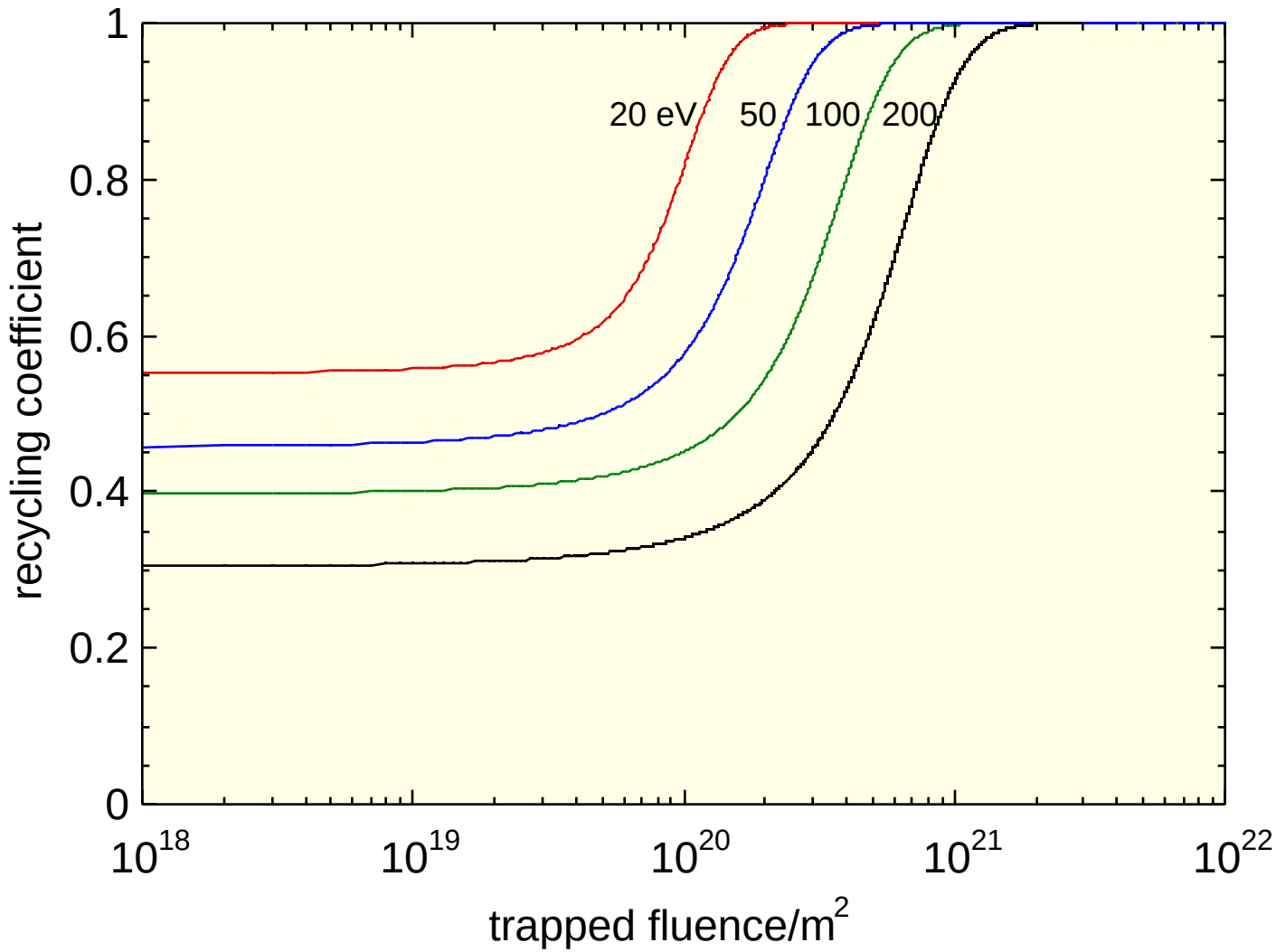
$$R(n_{tr}) = a \tanh\left(\frac{n_{tr} - n_{sym}}{\delta}\right) + c$$

Table I: Recycling parameters for different particles energies

Energy eV	a	c	n_{sym} ($x10^{20}$)	δ ($x10^{20}$)
20	0.23	0.77	0.9	0.5
50	0.29	0.71	1.6	1.2
100	0.326	0.674	3	2.4
200	0.385	0.615	5.5	4.8

a,c - determine initial value of R
n_{sym} - corresponds to penetration depth
δ - corresponds to depth distribution

Recycling Coefficients for Different Energies as a Function of Trapped Particle Number



Particle Trapping Rate as a Function of Incident Particle Flux ϕ_{inc}

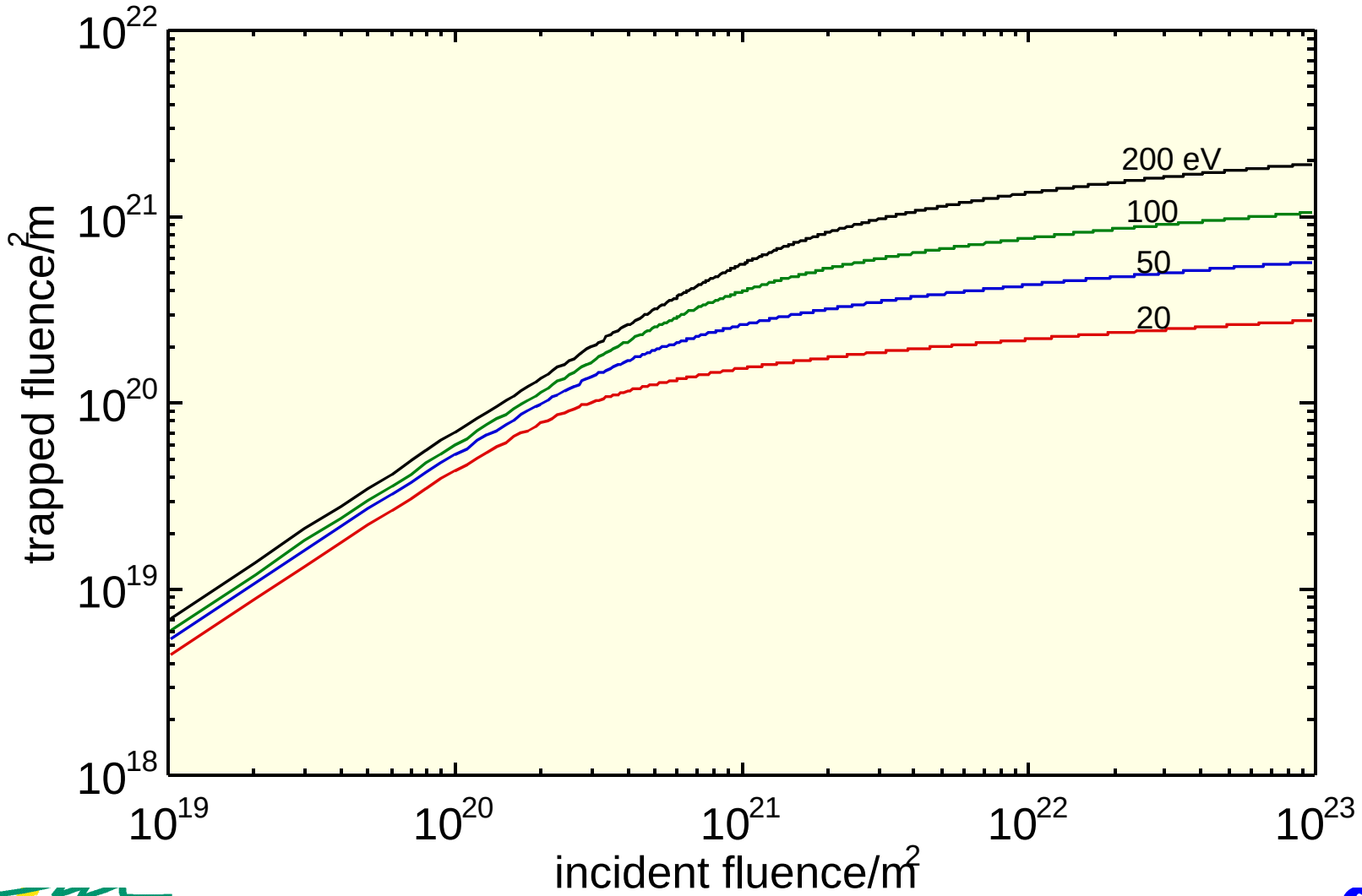
$$\frac{dn_{tr}}{dt} = \varphi_{inc}\left(1 - a\tanh\left(\frac{n_{tr} - n_{sym}}{\delta}\right) + c\right)$$ *

Assuming φ_{inc} = constant, the trapped particle fluence becomes a function of time !

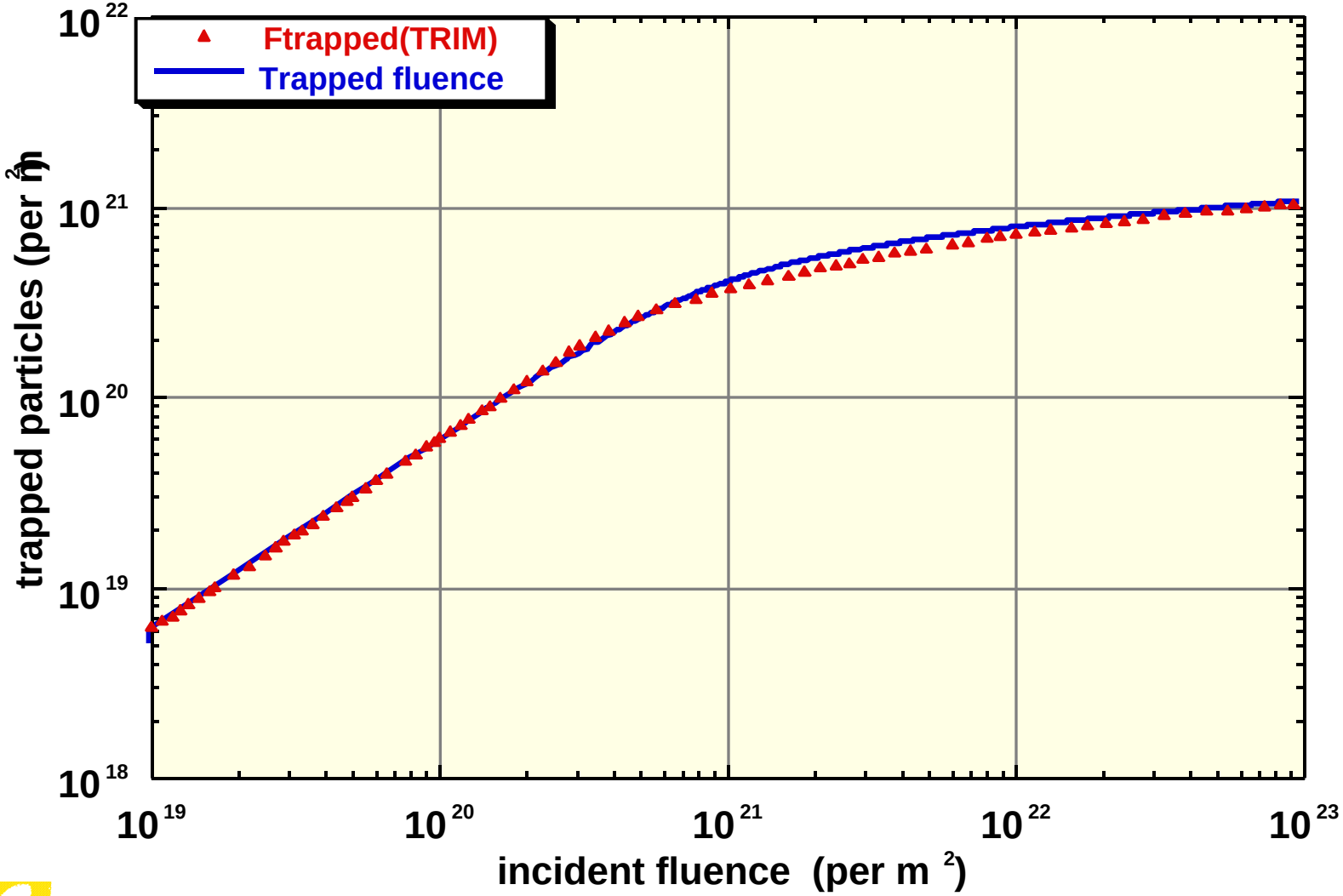
Solving this differential equation for four different energies, yields the corresponding trapping curves.

(* The analytical solution is too complicated to reveal any functional correlations. Hence, we solve the DE numerically!)

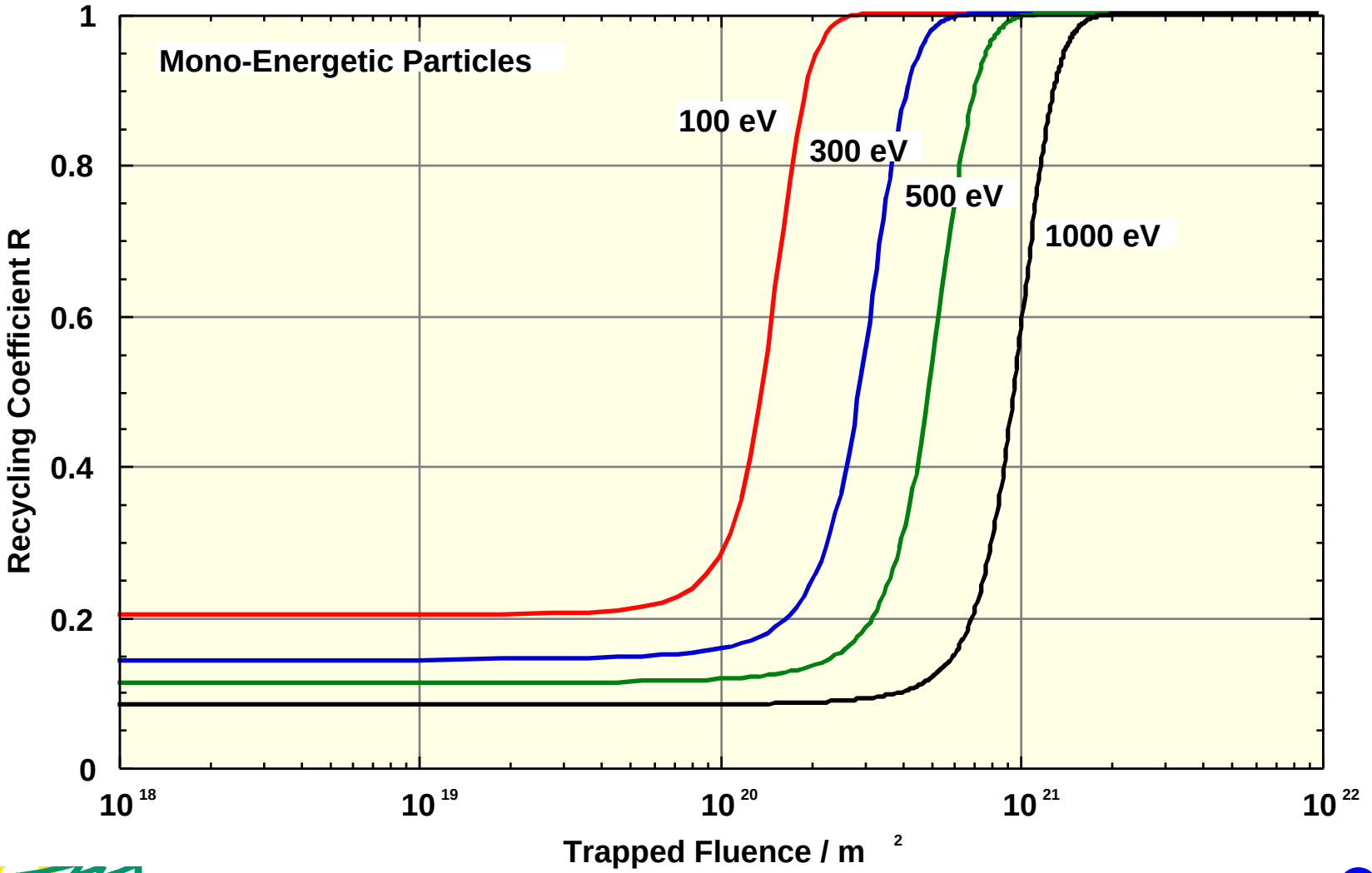
Trapped Particle Fluence as a Function of the Incident Fluence ϕ_{inc} for Maxwellian Particle Energies



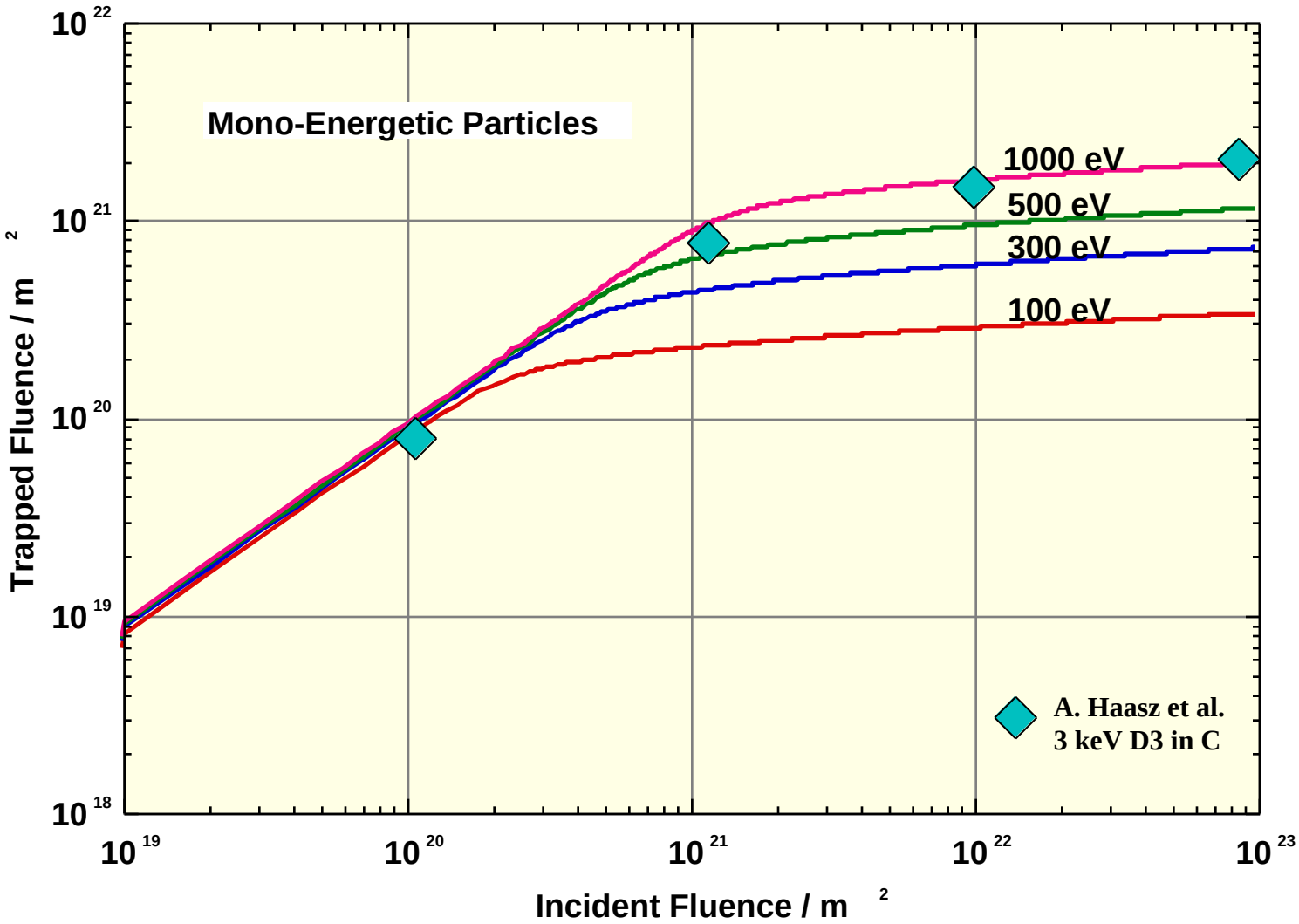
Comparison of tanh-Trapping Curves with Eckstein's TRIM Curves for 100 eV Maxwellian Particles



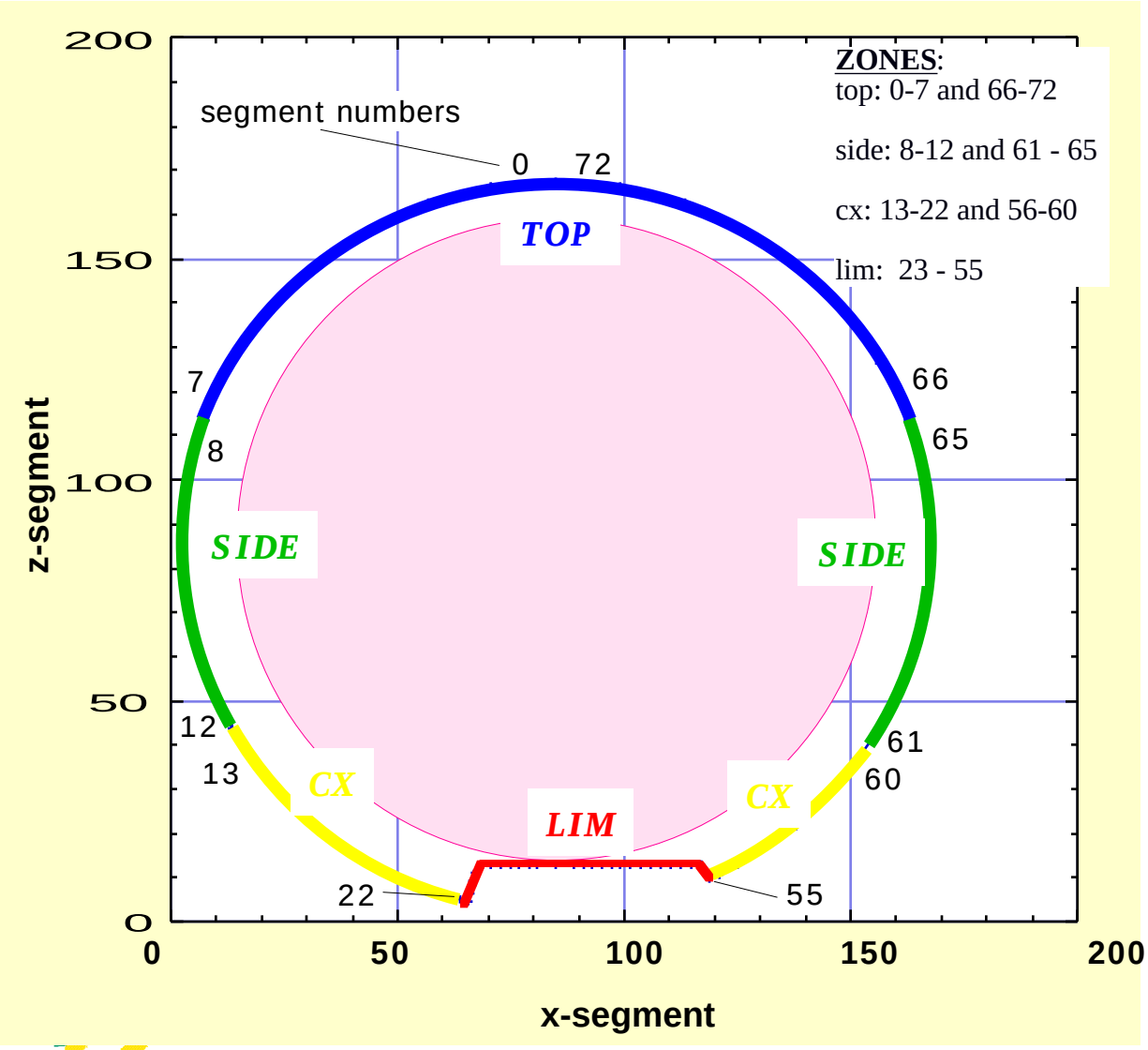
Recycling Coefficients for Mono-Energetic D-Particles



Trapping Curves for Mono-Energetic D-Particles Agree Well With TRIM Curves and Experimental Results



The Tore Supra Vacuum Vessel Is Divided into 73 Segments Which are Grouped Into 4 Zones



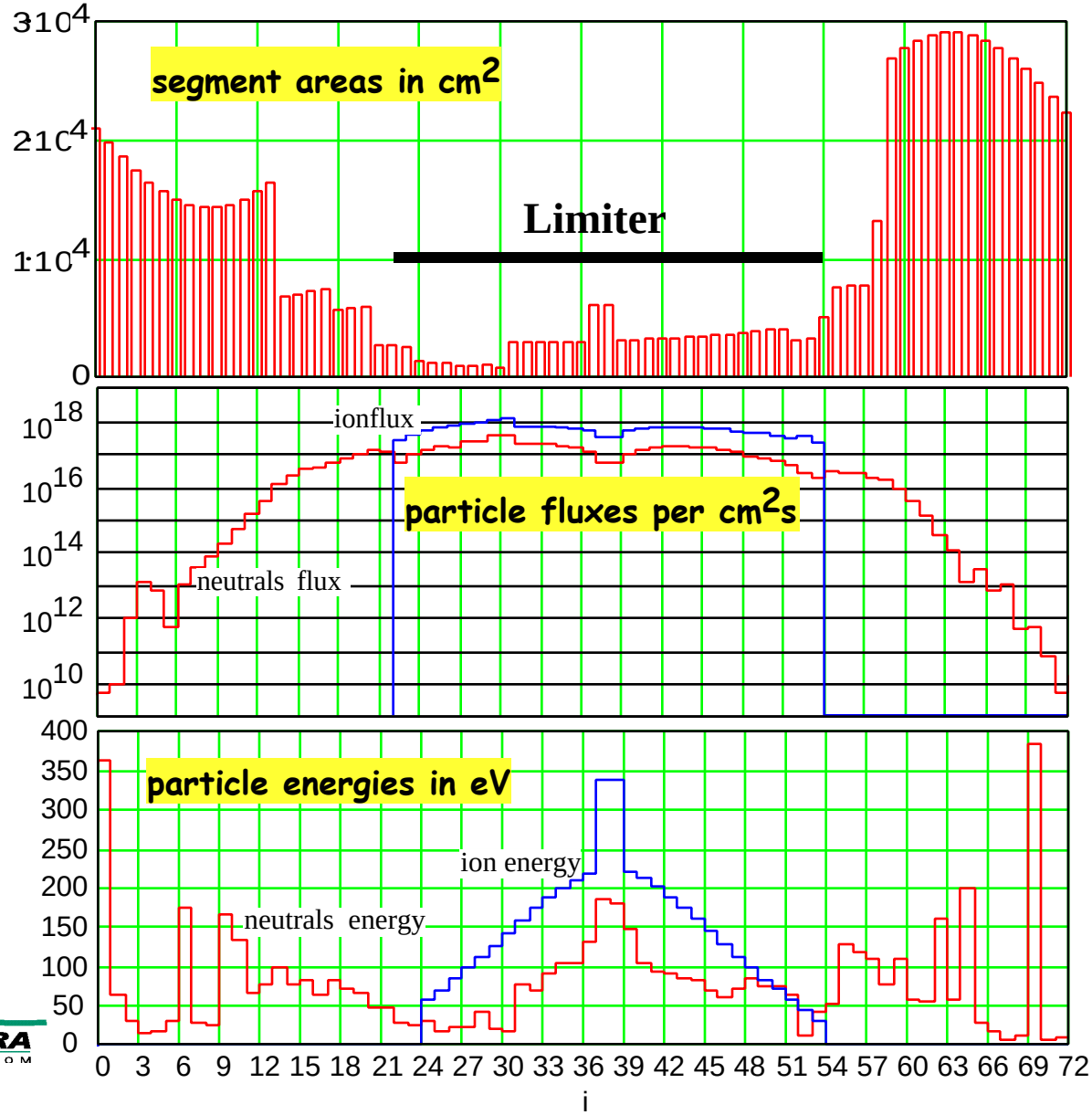
The DEGAS grid of the vacuum vessel consists of 73 wall "SEGMENTS".

The segments are grouped into 4 "ZONES" with fluxes approximately of the same order of magnitude.

The limiter-zone receives both ion-and neutral fluxes.

Trapped particle numbers, recycling coefficients, and recycling fluxes are calculated for each of the 73 segments.

Segment Areas, Fluxes, Particle Energies as Functions of the Segment Number



ZONES:

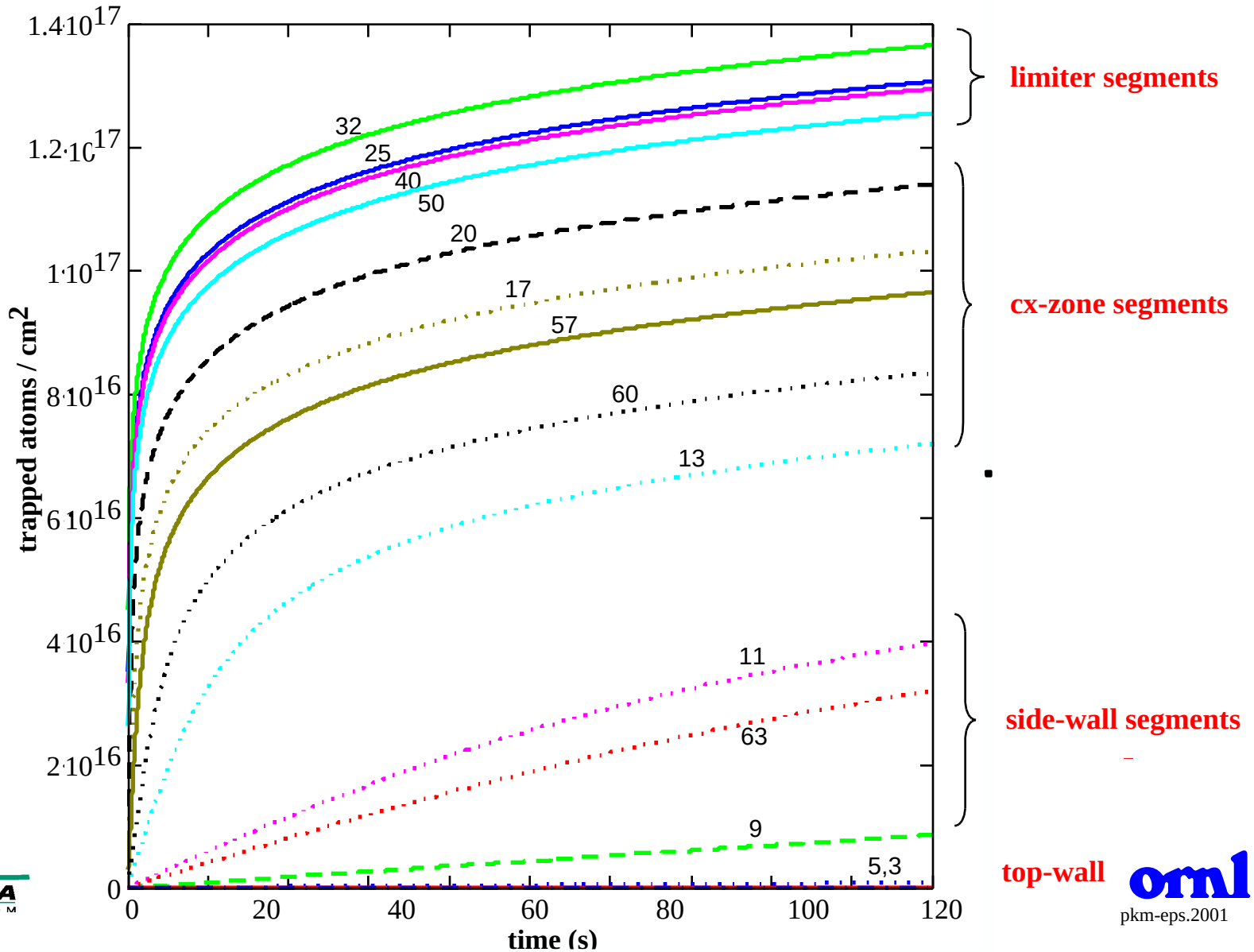
top: 0-7 and 66-72

side: 8-12 and 61 - 65

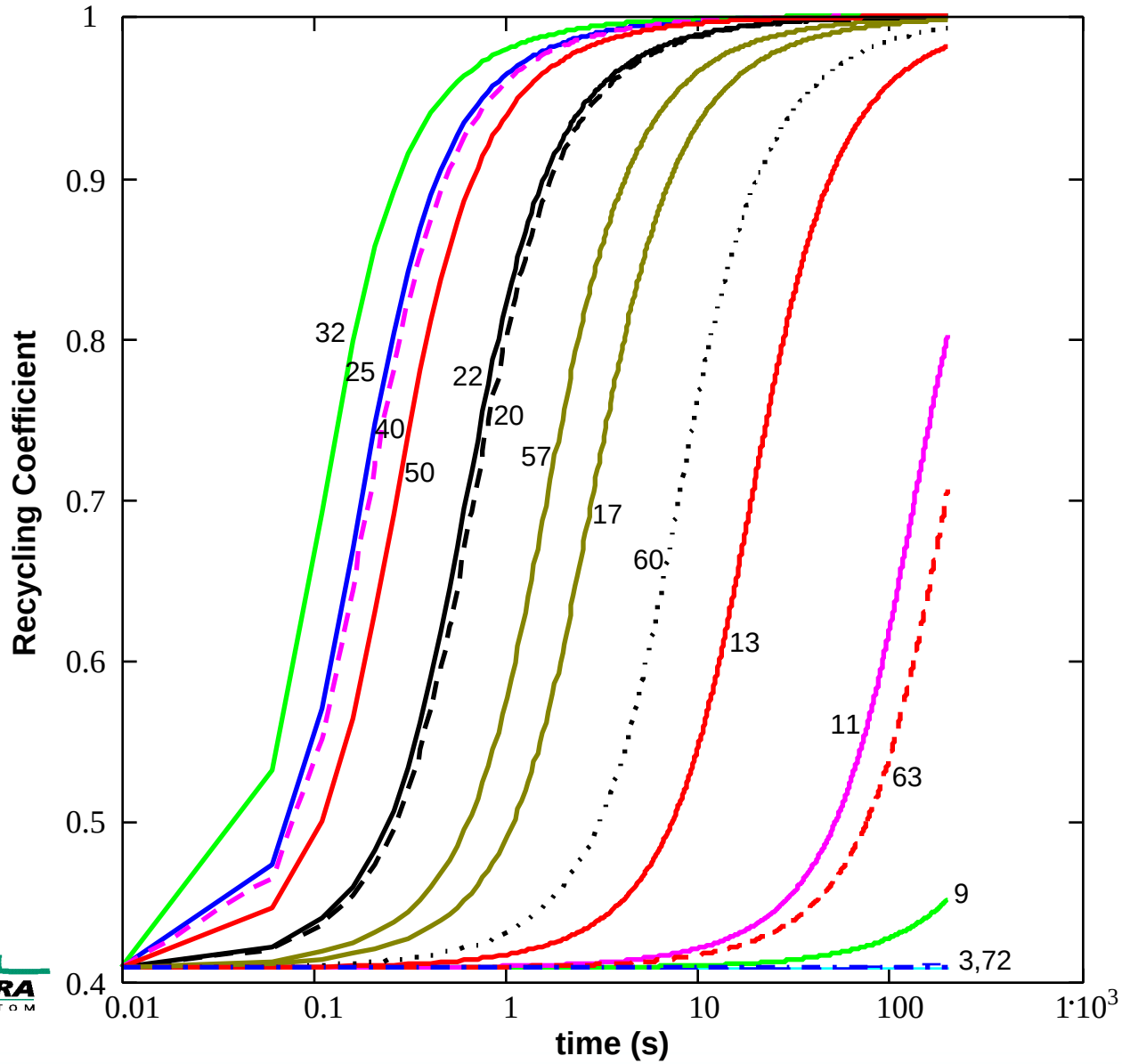
cx: 13-22 and 55-60

lim: 23 - 54

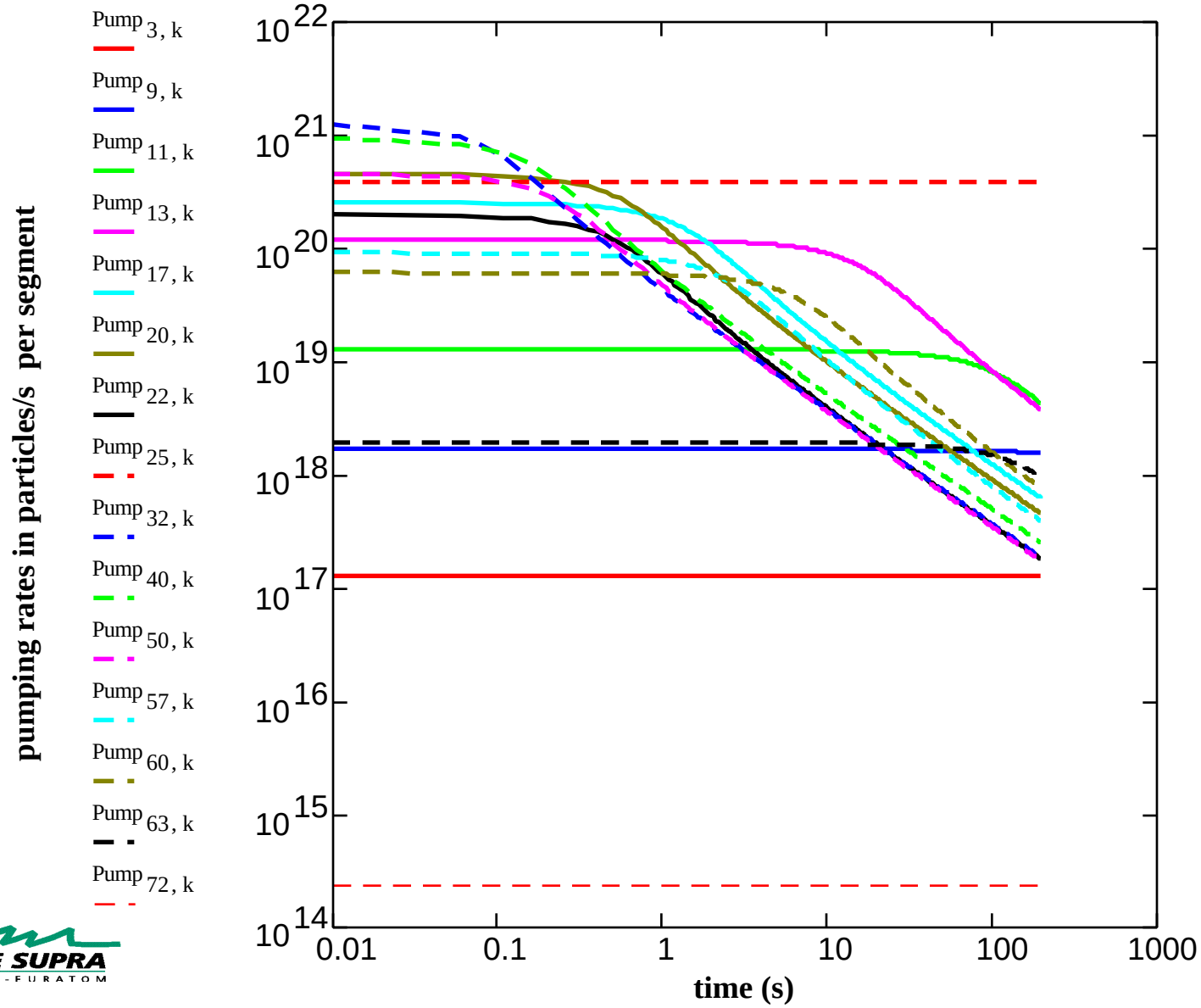
Number Of Trapped Atoms Per Unit Area For Selected Typical Segments



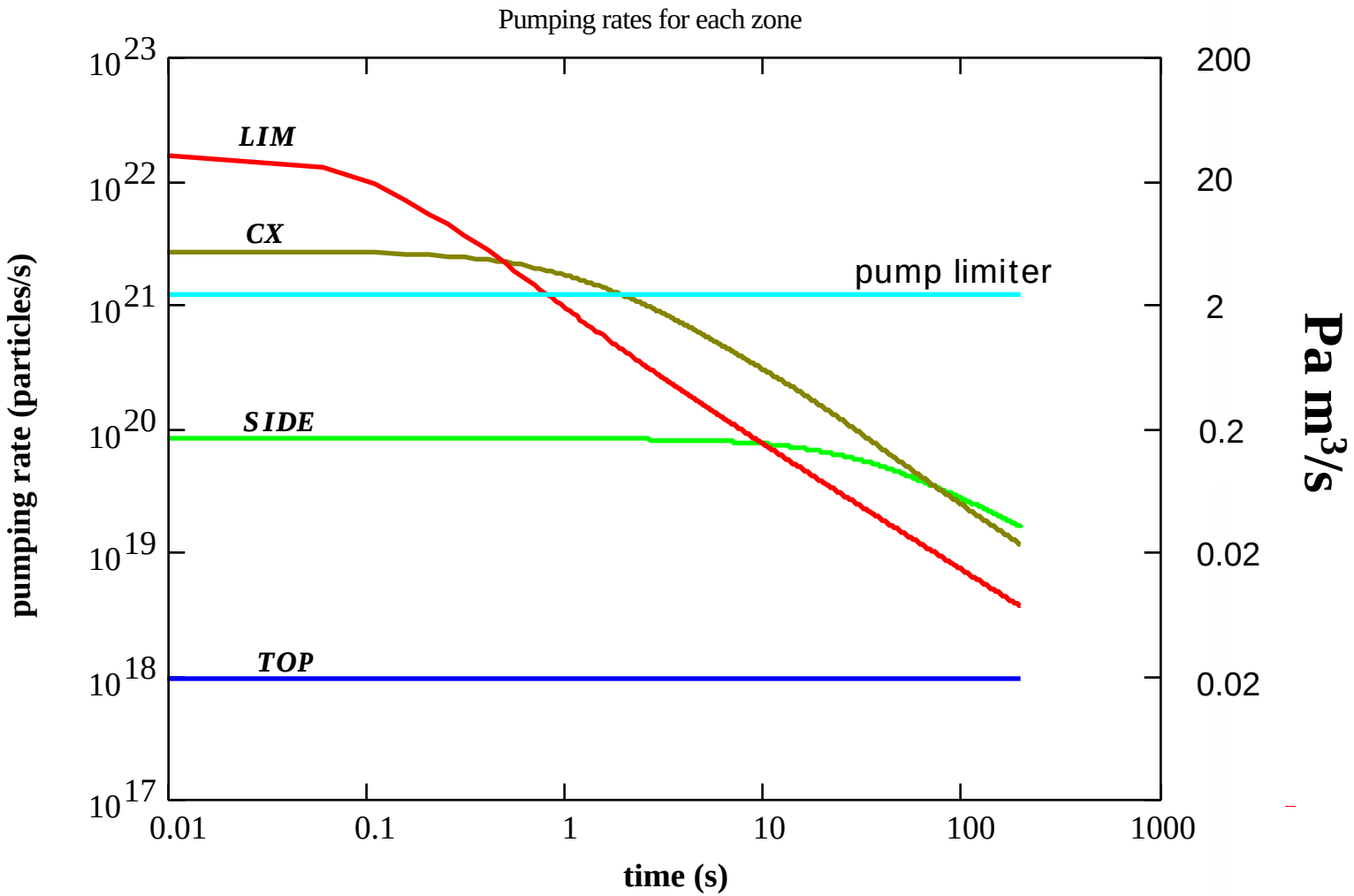
Recycling Coefficients as Functions of Time For Selected Typical Segments



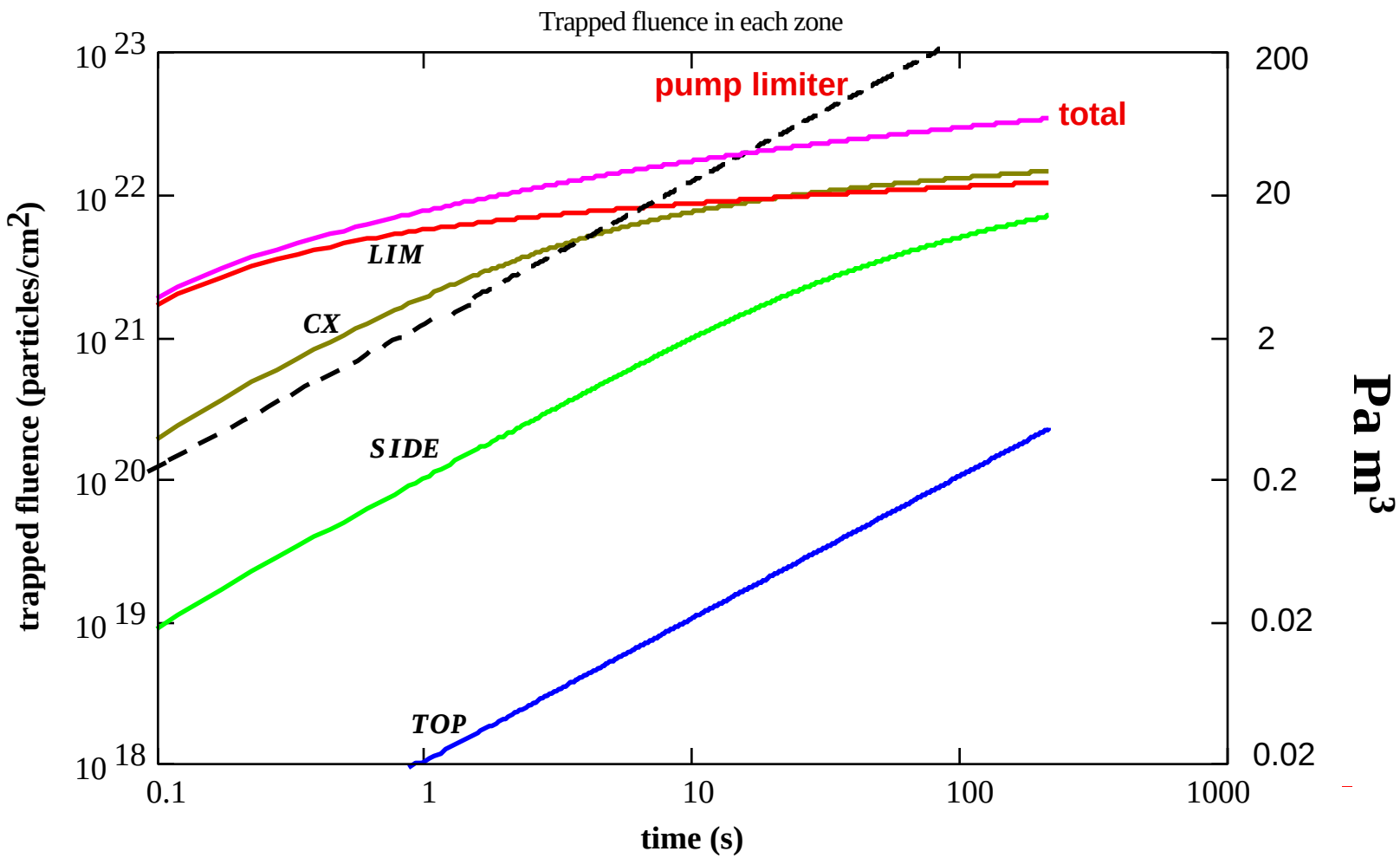
Pumping Rates as Functions of Time For Selected Typical Segments



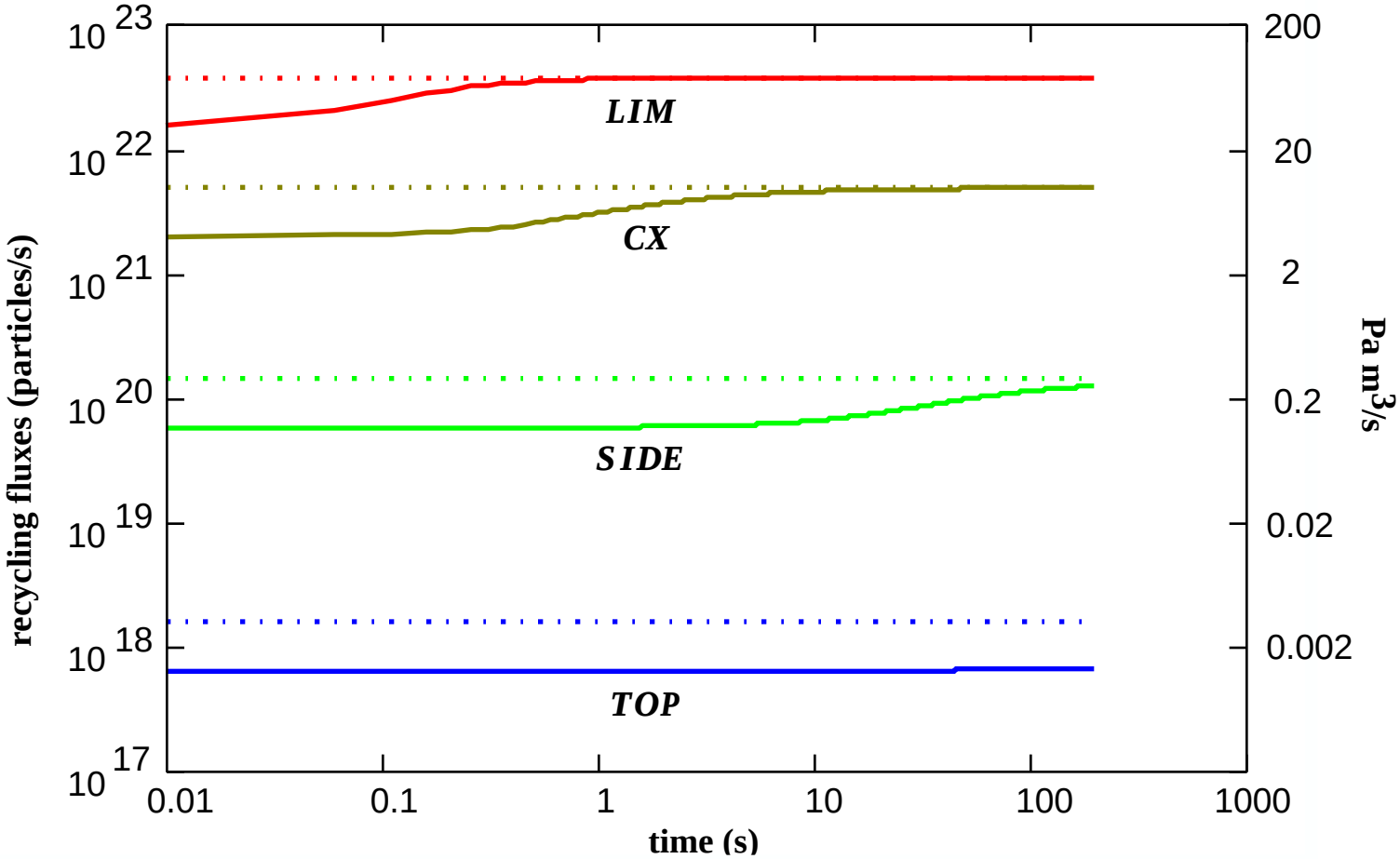
Pumping Rates as Functions of Time For the 4 Zones and the Pump Limiter Exhaust



Trapped Particle Fluence as Function of Time For the 4 Zones Compared with the Pump Limiter Exhaust



Recycling Fluxes From Each Zone (Particles/s) As a Function of Time



Summary and Conclusions (1)

- Detailed local analysis (73 segments) of particle trapping and recycling in Tore Supra indicates that the segments can be grouped - according to the received particle fluxes - into four major zones (this is configuration-specific).
- Each of these zones has its own equilibration time reaching from ~0.1 s on the limiter surfaces to more than ~ 10,000 s in the upper parts of the vessel.
- As an example, for a typical discharge in Tore Supra the calculated recycling coefficients for the four zones indicate the following characteristic times for equilibration:
- ~0.1 s limiter zone
- ~10 s in the cx-zone
- ~100 s in the side-wall zone
- ~1000's to 10,000's of seconds in the top wall zone

Summary and Conclusion (2)

- The long time constants are a consequence of the low fluxes and the zones with the lowest fluxes may be negligible for shorter pulse-lengths.
- The plasma response to the wall equilibration time is given by $\tau_p^* = \tau_p/(1-R)$ which can be forced to shorter times by changing R through external pumping.
- Future work will include
  - analysis of multi-shot sequences,
  - energy-dependent recycling coefficients
  - use of time-dependent recycling coefficients in plasma edge codes,
  - recycling analysis including external pumping.
  - Self-consistent plasma and neutrals transport models.