Including a nonlocal kinetic model for parallel heat flux in UEDGE

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OUTLINE

Background :

Non-local parallel heat flow in divertor plasmas.

Lessons learned from laser heated plasma simulations.

Recent results :

Fokker-Planck simulations of heat flow.

Validation of our heat flow formula.

1-D run with UEDGE

Enhancement of ionization by non-Maxwellian effects.

Conclusion and future work : Need for $D_{\perp}(\mathbf{v})$.

Extra : Other edge plasma and PFC materials R&D at GRIF .

BACKGROUND

- Steep temperature gradients along field lines in divertors $\Rightarrow$ classical heat flow is invalid.
- Flux limiting is *ad hoc* and unsatisfactory.
- Kinetic simulations are prohibitive for routine use.
- The heat flow depends on the entire profile, not only on the local T_e gradient.
- The velocity distribution is non-Maxwellian $\Rightarrow$ enhanced ionization in the cold plasma
- Problem exists for divertor plasmas and laser heated plasmas, but “heating” mechanism is different : cross-field transport vs. laser absorption.

BACKGROUND (2)

- We developed a new non-local heat flow formula, for laser heated plasmas, including dependence on laser heating rate, α. (PRE **66**, 066414 (2002))
- Large effect if strong heating. (large α)
- Similar to other formulas in the literature if $\alpha = 0$.

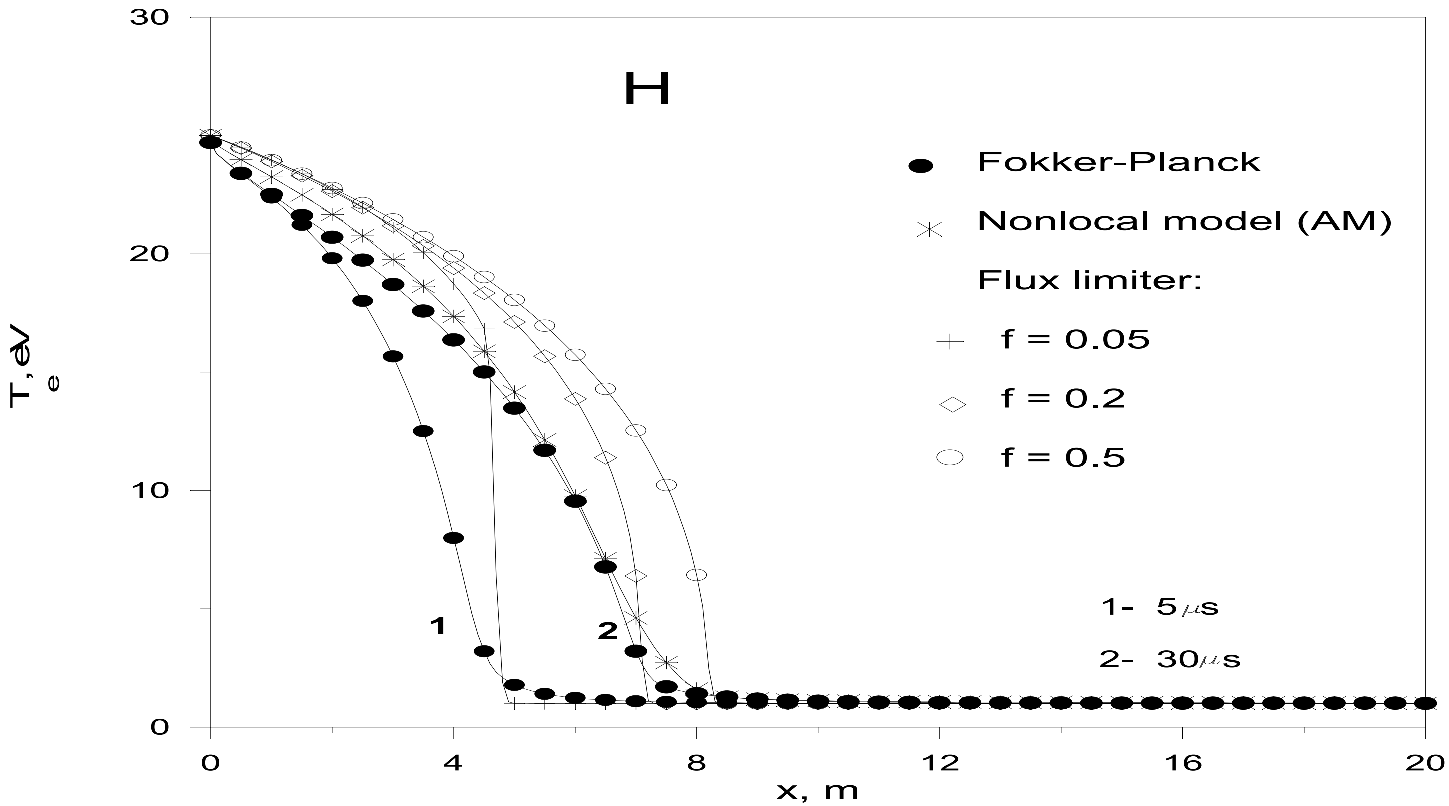
$$q(x)=\beta^{-1}(x)\int_{-\infty}^{+\infty} q_{SH}(x')\frac{w(\xi(x,x'),\alpha(x'))}{\lambda_e(x')}dx'$$

$$\text{where: } \alpha=\frac{\text{Laser heating rate}}{\text{Relaxation rate by e-e collisions)}}\;;$$

q_{SH} = Spitzer-Härm heat flux

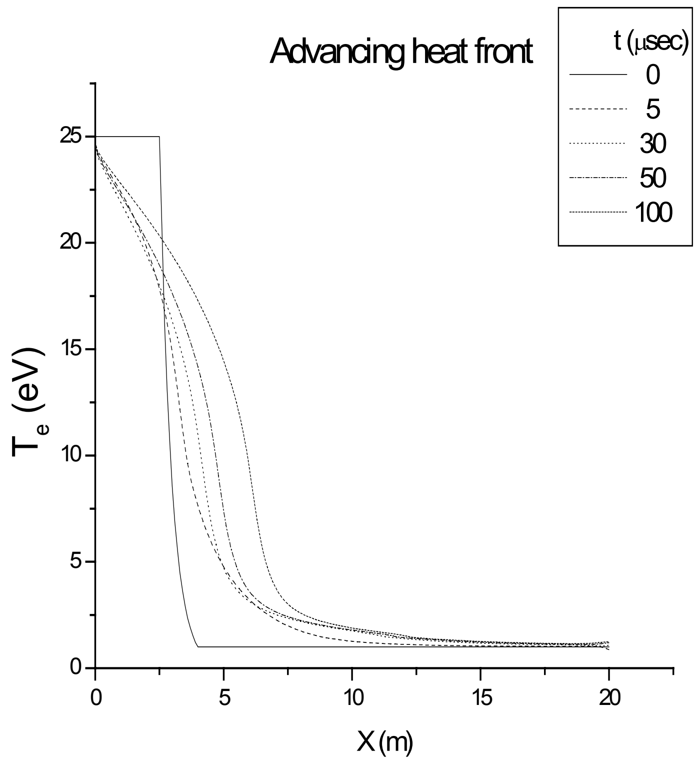
- In the following, we use the formula with $\alpha = 0$.

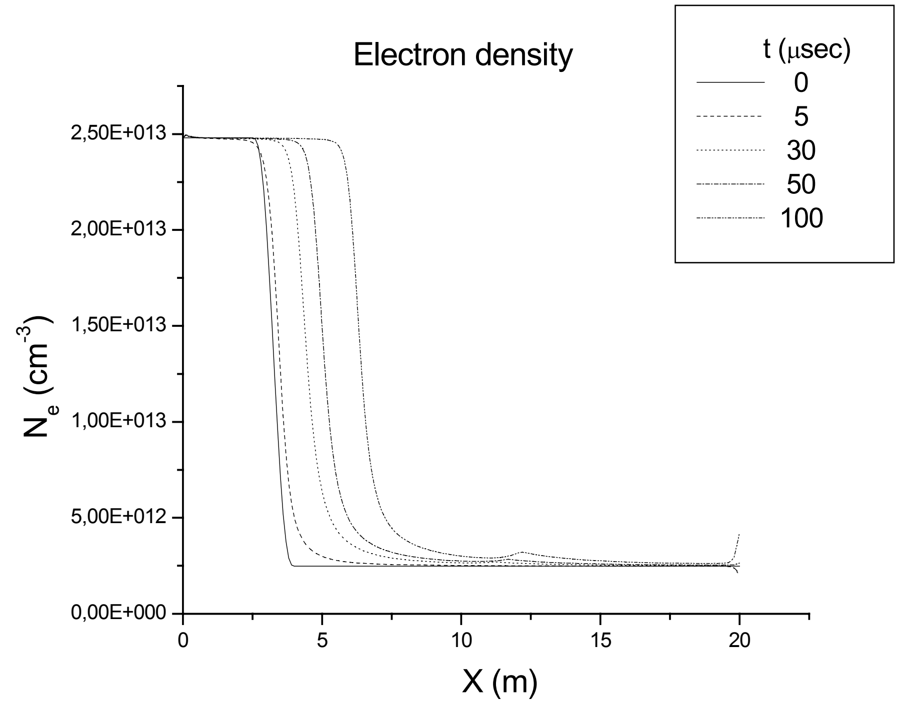
Validation of non-local heat flow formula



- Advancing heat front; fixed T_e at X=0 and 20 m: 25 eV and 1 eV.
- $N_e = N_i = 2.5\times10^{19}\ m^{-3}$, uniform; fully ionized.
- Nonlocal formula effective : good match to kinetic T_e profile.
- Flux limited diffussion : poor match, for any flux limiter f.

New simulation : advancing heat and ionization front



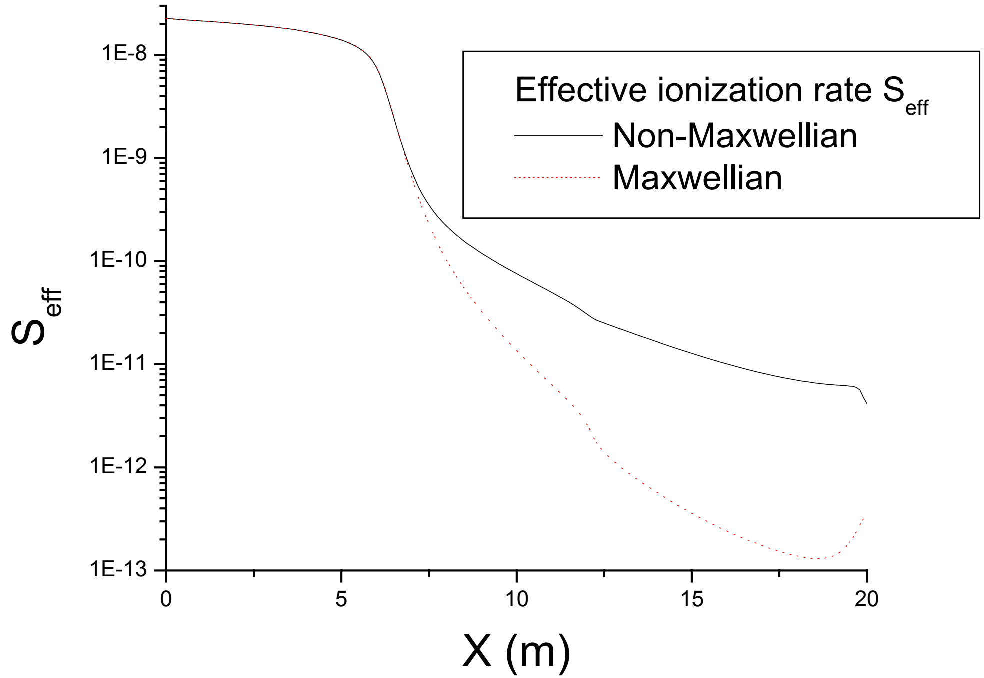


Same conditions as preceding, except partially ionized

$N_n + N_i = 2.5 \times 10^{19}$ m^{-3} , uniform.

Ionization, excitation, and reverse processes included in the kinetic simulation, including ionization via excited states (up to n=4).

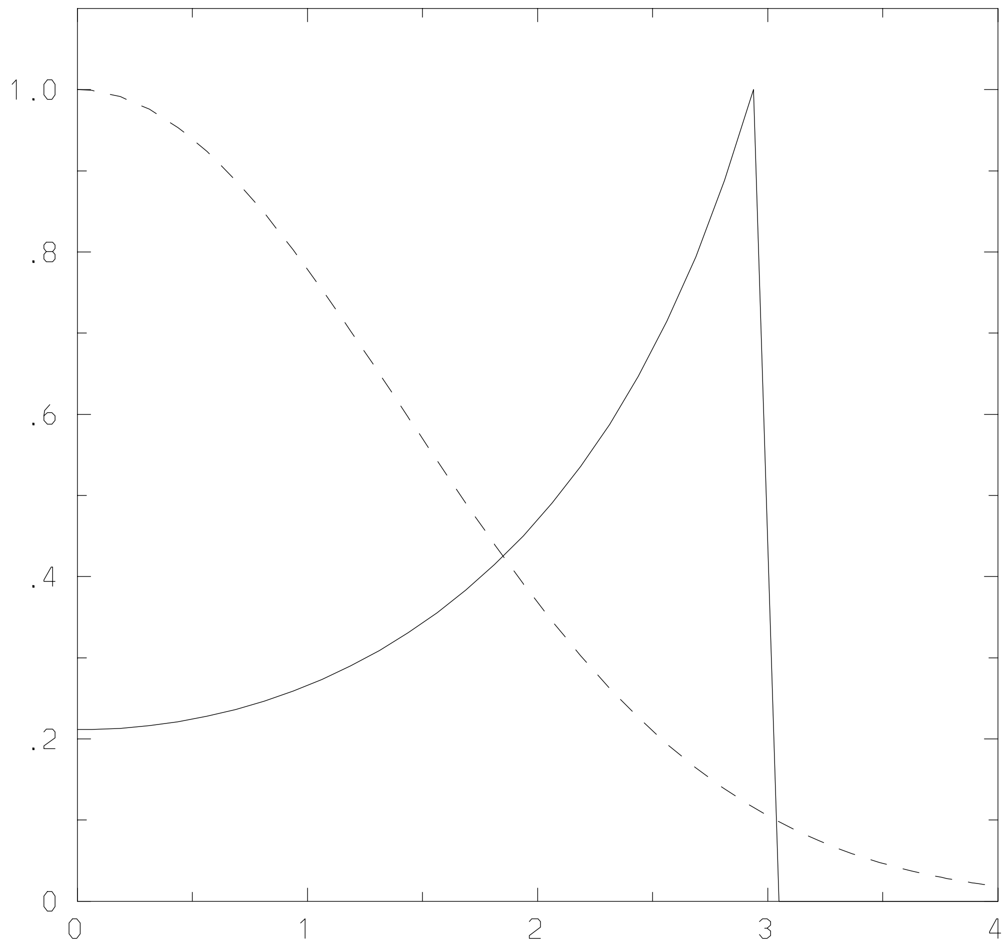
Effective ionization rate enhanced in the cold plasma by fast electrons streaming from the hot plasma



Effective ionization rate computed with Stotler's IRLS model.
Same effective rates as those tabulated (vs. N_e and T_e) for UEDGE, if Maxwellians are assumed .
Includes energy levels n=1-30 for atomic hydrogen.
Full coupling of this model into kinetic code is ongoing.
Aim: obtain a non-local formula for S_{eff} .

1-D UEDGE Simulation

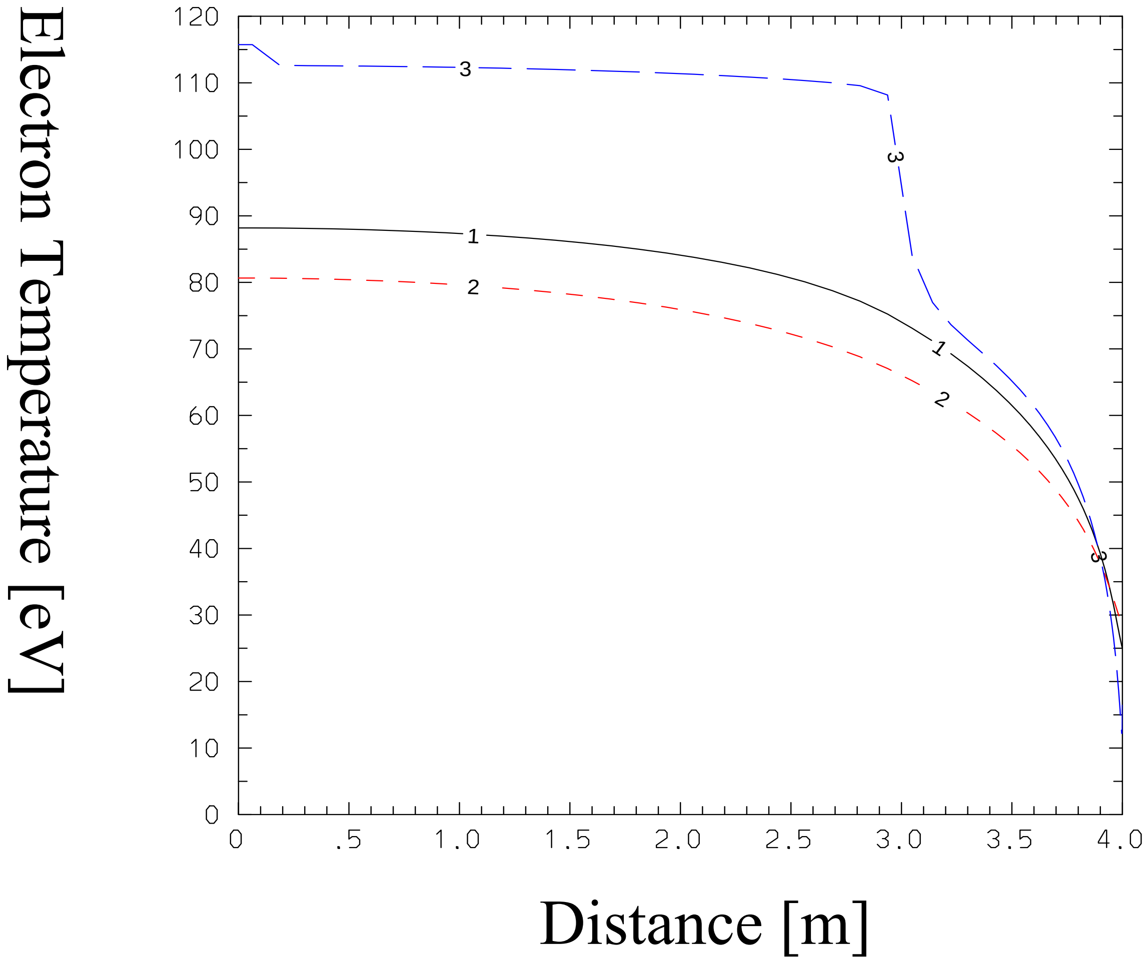
Power Source profile emulates cross field transport
Peaks at X-point, X=3 m (poloidal X), then drops.



Electron temperature profile very different with non-local heat flux

e and i input power: 1e5 W

standard flux limit
no flux limit
nonlocal



SUMMARY AND CONCLUSION

- The electron kinetic code FPI was used to develop and validate nonlocal formulas for heat flow.
- Advancing heat front: fluid and kinetic (FPI) simulations . showed the validity of the nonlocal heat flux formula, and invalidity of flux limiting, for any flux limiter.
- This nonlocal formula was implemented in UEDGE. Considerable change seen, compared to classical calculation.
- Large enhancement of the ionization rate in the cold plasma, due to non-Maxwellian effects.

FUTURE WORK

- Ongoing: develop nonlocal formulas for non-Maxwellian modifications to the ionization rate, sheath potential, *etc*.

- Assumption here: source heating << e-e relaxation.

- Simulations on laser plasmas show that removing this limitation changes nonlocal heat flow. **But** there, heating is by laser absorption, preferentially into slow electrons ($\propto 1/v^3$).

- Challenge to gyro-kinetic code modelers: what is the energy dependence of cross-field transport? Given this dependence, we will be able to modify our nonlocal heat flow formula accordingly. This could modify the physics shown here.

- Future : 2-D kinetic simulations, with appropriate prescription for cross-field transport, to obtain 2-D non-local formulas.

Other edge plasma and PFC materials R&D at INRS

- Most collaborations with European groups.
- Simulations of ITER edge plasma with code B2. (H. Pacher)
- Probes development and installation on several Tokamaks (C. Boucher)
- Nitrogen ion beam implantation of carbon PFC's.
  Results: Reduced chemical erosion rate and
  Improved H retention. (G. Ross)

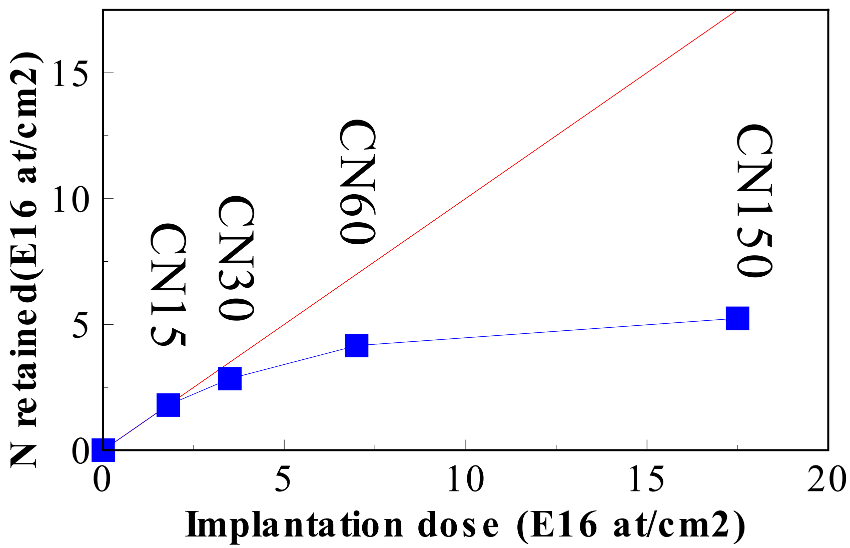
N implantation for the improvement of C properties used as PFC's

Motivation

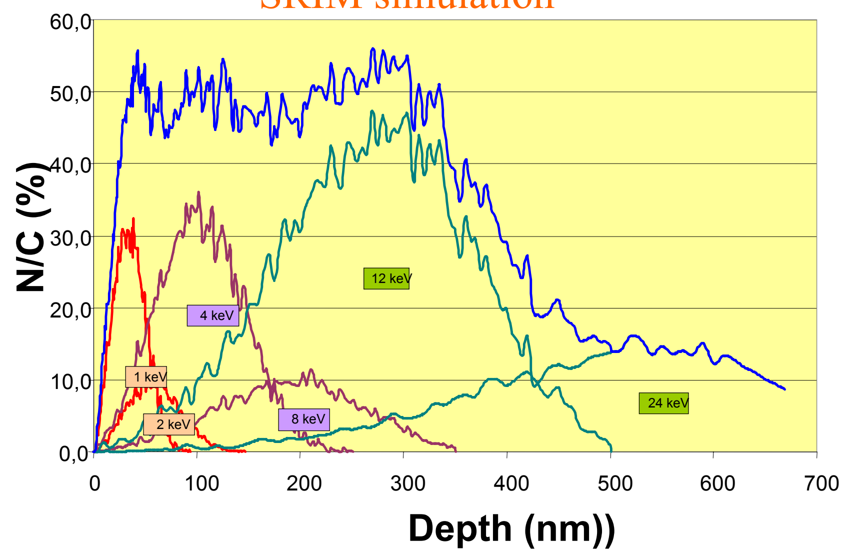
- Carbon has been widely used for PFC's in different tokamaks.
- C erosion by H and O at high T, and poor H (tritium) retention are major obstacles for tokamak use.
- Properties of the C_3N_4 are promising for PFC's and have inspired that work.
- N implanted C as PFC's could be made in tokamaks between the discharges.
- N is a low-Z element compatible with its use as PFC's in a tokamak.

Sample preparation

C was deposited on Si wafers by sublimation of a C filament (2×10^{-7} Torr.)



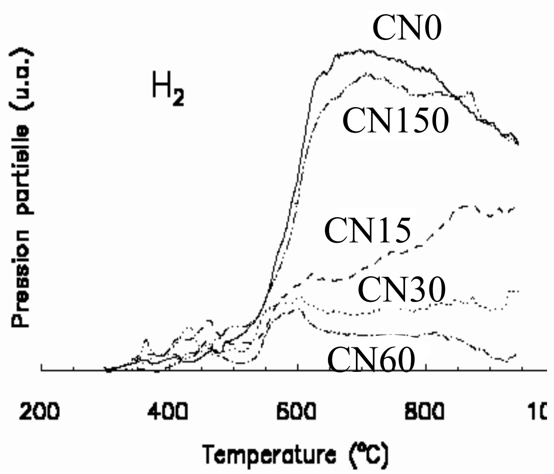
SRIM simulation

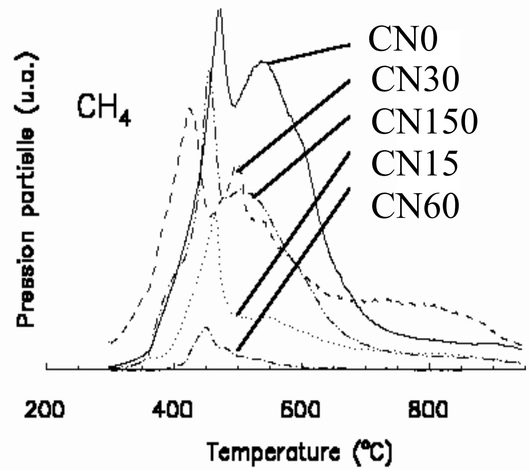


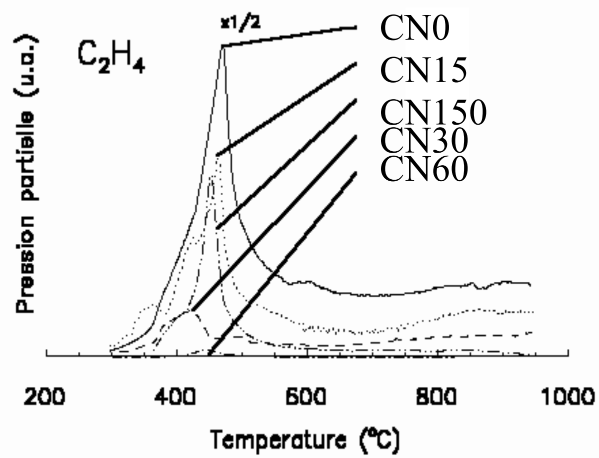
Results:

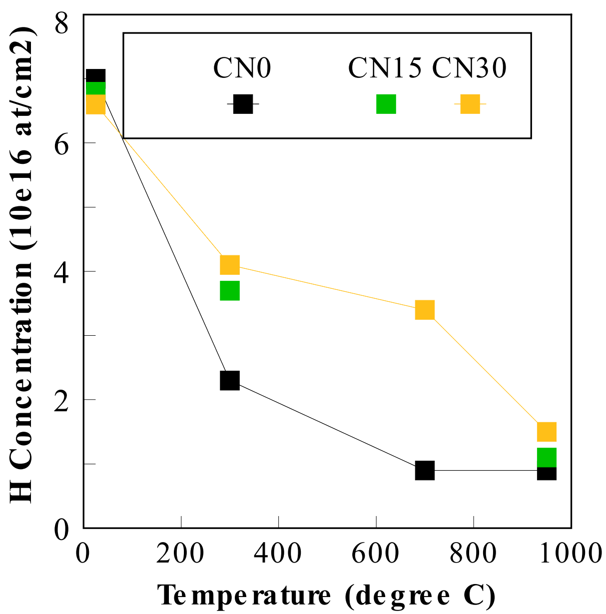
H retention (irradiation and high T) is improved

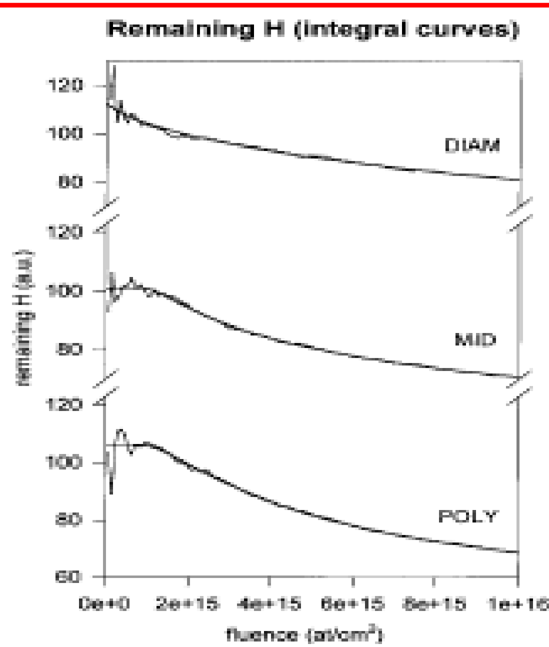
Chemical erosion is decreased

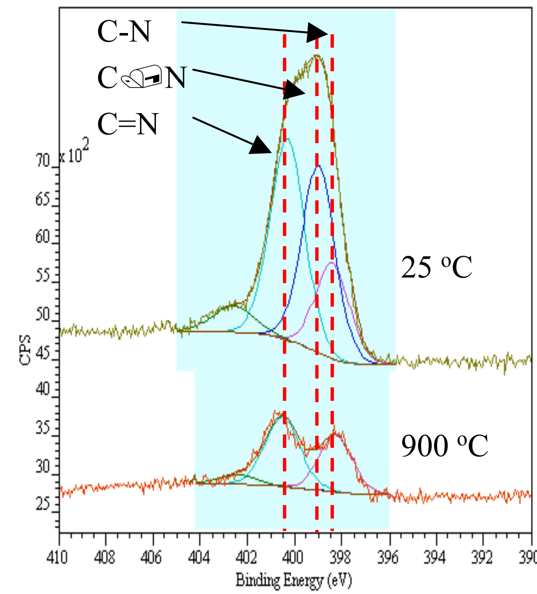












C -N → sp_3 → DIAM

C=N → sp_2 → MID

C≡N → sp_1 → POLY