Influence of pellet shielding on disruption mitigation in ITER

P2.040

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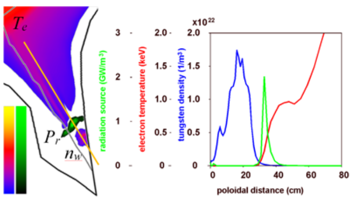
ABSTRACT

- Disruption mitigation by shattered Ne pellet injection (SPI) through 3 upper port launchers or through 1 equatorial launcher has been simulated taking into account shielding of the pellet
- The shielding of pellets with 2 kPa·m³ Ne has minor effects on the radiation power and on wall heat load.
- Critical Ne amount, which provides full core plasma energy radiation (the threshold) is reduced by a factor of 2 compared to the result without shielding.
- The thresholds are 3×31 Pa·m³ for upper injection and 62 Pa·m³ for the equatorial injector.

ANALYSIS OF THE PLASMA SHIELDING PHYSICS

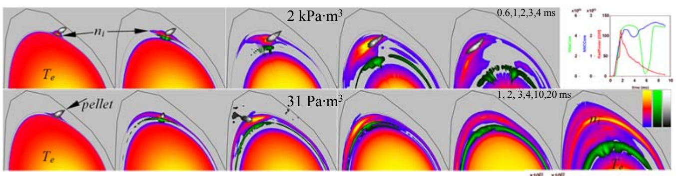
- Plasma shielding is a complex physical phenomenon which drastically reduces heat flux from the hot plasma to the solid material and the amount of vaporized material
- physical model that describes plasma shielding should take into account the following processes:
  - ✓ Heating, melting and vaporization of the solid material
  - ✓ Ionization of the vaporized material forms the plasma shield
  - ✓ heating of the plasma shield by hot hydrogen plasma of the core
  - ✓ magneto-hydrodynamics of the plasma shield in strong magnetic field
  - ✓ ionization-recombination and excitation-radiation dynamics in the plasma shield
  - ✓ photonic radiation cooling of the shield



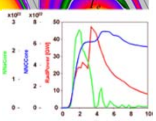
- The main features of the shield between a hot plasma and a solid:
  1. the shield consists of vaporized and ionized solid
  2. there are three different regions inside the shield:
     a. cold dense plasma near the solid surface
     b. hot rarefied plasma far from the surface
     c. intermediate region with maximum radiation power
  3. conversion of the hot plasma heat flux into radiation inside the intermediate region
  4. the plasma of the shield expands along magnetic field and diffuses across the field
  5. heat flux to the solid and the amount of vaporized material are reduced on 2-3 orders of magnitude

SIMULATION OF SPI WITH SHIELDING

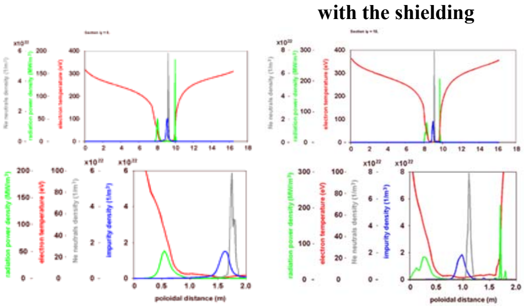
- The shattered pellet was simulated using the Monte Carlo (MC) technique
- Shattered pellet is simulated with Ne gas of artificially high density, which corresponds to the pellet density
- MC particles at a velocity of 500 m/s randomly distributed inside the angle of 20°
- Turbulent cross-transport is fitted to ensure ~2 ms cooling time for the core electrons
- Radiative cooling time for the core ions is larger and it grows with the decrease of injected Ne amount

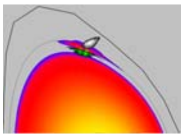


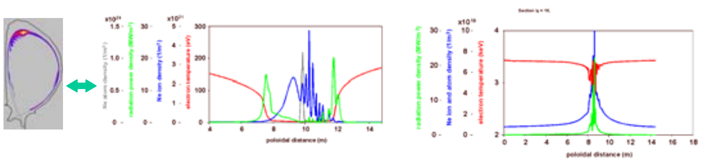
- After crossing the separatrix neutral Ne is ionized by the hot core plasma
- The Ne plasma shields neutral Ne from further ionization
- Thermal energy E_{th} of the core plasma is transported along the magnetic field
- E_{th} *is* spent for Ne ionization and for the radiation.
- The cooling front structure is similar to the shield of the divertor



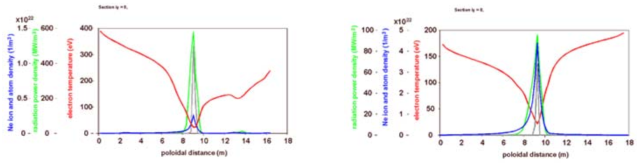
with the shielding




Poloidal coordinate

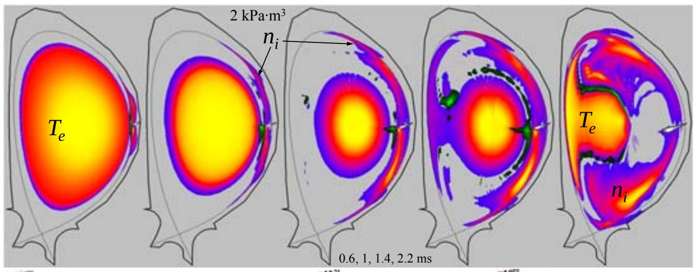


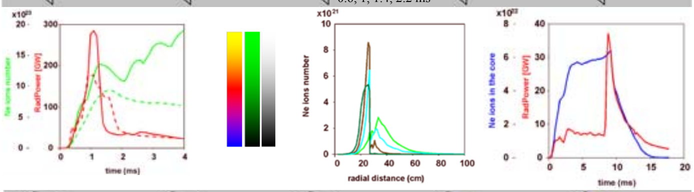
without the shielding

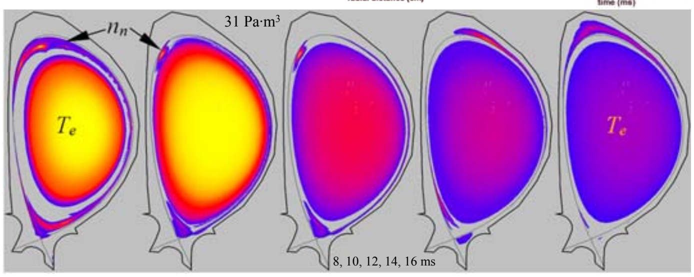


THRESHOLD Ne CONTENT IN THE PELLET

- Simulations performed with the TOKES code have shown that not all the thermal energy is radiated, when injected neon quantity is below a critical threshold.
- The pellet with subthreshold Ne content of 31 Pa·m3 is fully ionized after crossing the separatrix
- The cooling wave propagates radially due to the Ne plasma diffusion only
- Nevertheless, the q=2 magnetic surface is cooled and the TQ starts.
- Radiation cooling proceeds, but the amount of Ne plasma is so small, that it fully diffuses out of the core.
- The Ne plasma provides a sink for the thermal energy of the core plasma.
- After disappearance of this sink from the core the cooling process is drastically slowed down, leaving ~30% of the thermal plasma energy inside the core.
- The same mechanism is observed for the injection from the upper port plugs







CONCLUSIONS

- Simulations of the Ne pellets injection into an ITER discharge with 280 MJ of thermal plasma energy, using 3 upper port injectors or the equatorial injector, have been performed.
- The simulations takes into account the plasma shielding of the Ne pellet fragments
- A parametric study, varying the Ne quantity from 2 kPa·m³ to a critical value which guarantees radiation of more than 90% of the core plasma thermal energy, has been performed.
- Shielding of large pellets with 2 kPa·m³ of Ne has only a minor effect on the radiated power in case of upper injection because the amount of injected Ne is much larger than required for dissipation of the TQ thermal energy.
- But, for the equatorial injection, which proceeds much faster and hence generates larger peak radiated power, this maximum is reduced by 40%, due to shielding, which slows down the process.
- The critical neon quantity is reduced by a factor of 2 due to the shielding effect.
- The critical Ne quantities are 3×31 Pa·m³ for the upper injection and 62 Pa·m³ for the equatorial one

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