IMPURITY SEEDING SCENARIOS FOR FIRE

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MOTIVATION

- Explore ways to reduce the divertor plate heat loads.
- Most proposed methods rely on radiative processes from *inside* and *outside* the separatrix to reduce the heating power exhausted from the plasma core. In this work, we concentrate on radiation from *inside* the separatrix (*plasma mantle*) due to externally injected impurities (*impurity seeding*).
- Results from several experiments (TEXTOR, DIII-D, etc.), as well as transport simulations suggest that it is possible to radiate large amounts of power from the plasma mantle, without serious detrimental effects to the core power balance.
- Our group has performed simulations to explore the feasibility of impurity seeding for ITER and, most recently, we have been modeling impurity injection experiments in DIII-D.

Computational Model

- Our simulations have been performed with **GTWHIST,** the Georgia Tech version of the 1½-D transport code **WHIST** (W. Houlberg, ORNL).
- The code can calculate the transport of all the charge states of a number of impurity species, by solving the multi-charge state transport equations along with the main plasma particle and energy transport:

$$\frac{1}{V'}\frac{\partial}{\partial t}\left(V' n_q^Z\right)+\frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\tilde{\Gamma}_q^Z\right)=I_{q-1}^Z n_{q-1}^Z-\left(I_q^Z+R_q^Z\right)n_q^Z+R_{q+1}^Z n_{q+1}^Z-\frac{n_q^Z}{\tau_{\parallel q}^Z}+S_q^Z$$

- A fixed-shape transport model has been used in these simulations:

$$\chi_e = C\frac{a^2}{\tau_E}F(\rho), \quad \chi_i = 2\chi_e, \quad D=\chi_i, \quad F(\rho)=\left(1+\lambda\rho^2\right)\exp\left(a\rho^2+b\rho^4\right)$$

- The coefficient C is adjusted at each time step so that the global energy confinement time is $\tau_E = \min\left[\tau_{NA}, \tau_E^{ITER98H}\right]$.

Assumptions

- The current FIRE divertor design[1] calls for a passively cooled first wall and inner divertor plate and an actively cooled outer divertor plate.
- Under certain assumptions[1], it is possible to show that the total power to the outer divertor plate should be less than **11 MW** in order to keep the peak heat flux less than **25 MW/m²**.
- The total power to the outer divertor plate is equal to:

$$P_{div}^{out} = f_{out}\left(1-\gamma_{core}-\gamma_{div}\right)\frac{5+Q}{5Q}P_{fus}$$

where f_{out} is the fraction of the exhaust power that goes to the outer divertor plate and $\gamma_{core} \equiv P_{rad}^{core}/\left(P_{\alpha}+P_{aux}\right)$, $\gamma_{div} \equiv P_{rad}^{div}/\left(P_{\alpha}+P_{aux}\right)$, $Q \equiv P_{fus}/P_{aux}$

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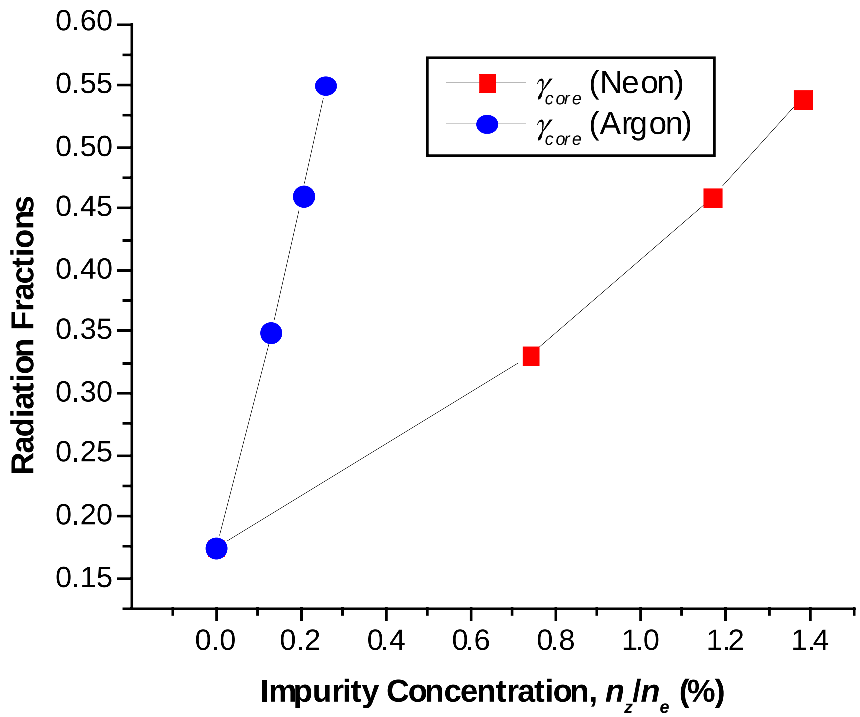
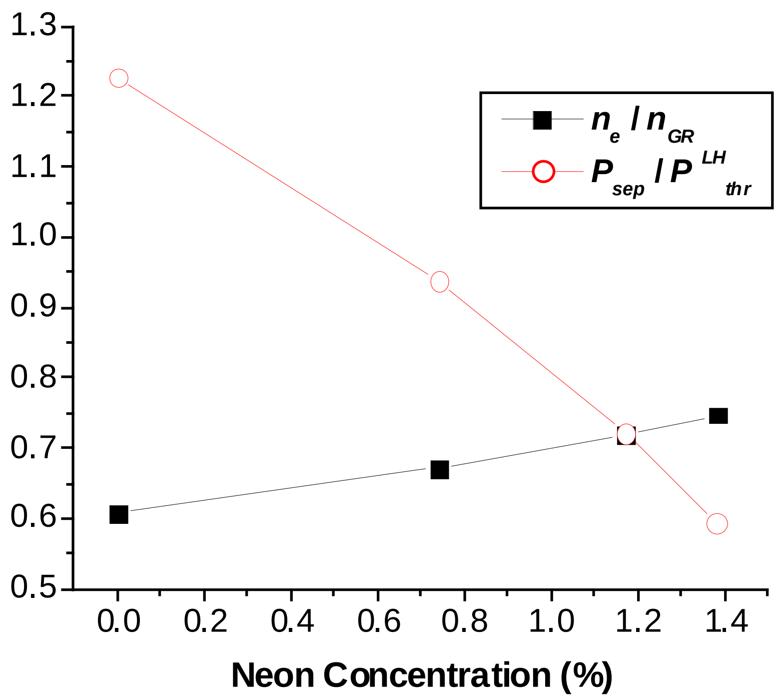
[1] M. Ulrickson, "FIRE Divertor Design," *presented at the FIRE Workshop*, March 1-5, 1999, PPPL

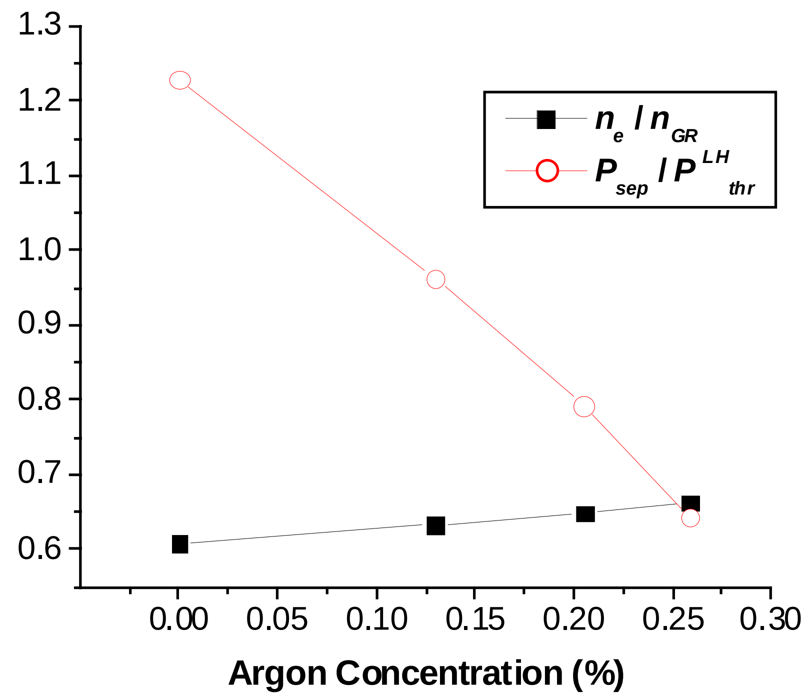
- The core radiation fraction for the reference design operating point (with contributions from the fuel bremsstrahlung and from 3% of intrinsic Be impurities) is equal to 17.5%.
- This can be increased by injecting Ne or Ar impurities into FIRE



- These amounts of Ne or Ar would lower the required divertor radiation fraction from about 60% to 32.4%, while keeping the total power to the outer divertor plate within design limits.
- The central Z_{eff} ranges from 1.41 to 2.3 for the case of Ar and from 1.41 to 3.0 for the case of Ne.
- In order to maintain the reference FIRE operating point, while accommodating the higher core radiation losses, it was necessary to assume a confinement improvement. The required H_{98} confinement enhancement factor was in the range of 1.1 – 1.22 for the case of Ar and in the range of 1.1 to 1.29 for the case of Ne.
- Two other important considerations that have to be taken into account:
  - fuel dilution increases the ratio n_e / n_{GR}
  - The increased radiation from the plasma core can reduce the net power crossing the separatrix to levels even below the threshold for the *L*-to-*H* transition.

- For the *L*-to-*H* threshold power, the expression $P_{thr}^{LH} = (0.9/A_i)\, n_{20}^{0.75} B R^2$ has been used
- The P_{sep} / P_{thr} ratio drops below 1 for both Ne and Ar. However, this is not as restrictive as it may appear. There is a lot of uncertainty in the various threshold power scaling expressions and the impurities could be injected after *H*-mode has been attained, therefore benefiting from the *H*-to-*L* hysterisis effect.





CONCLUSIONS

- We have performed simulations to evaluate **FIRE** operation with impurity seeding.
- Our results show that both Neon and Argon could be used to increase the radiation from inside the separatrix, with Argon being a better choice from the point of view of fuel dilution. Other impurity species will be examined in the future.
- The core radiation fraction can be increased from its reference value of 17.5% (with no external impurities) to 46 % with the injection of 0.2% Ar impurities. This would lower the required divertor radiation fraction from about 60% to 32.4% while keeping the total power to the outer divertor plate within design limits.
- An impurity seeded radiating mantle can play an important role in increasing the flexibility of the **FIRE** power exhaust system.