Impurity injection scenario in the burning plasma

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Outline

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- Impurity injection scenario in burning plasmas
- Summary

Introduction

Reduction of heat load onto the divertor plates

Enhancement of radiation loss by injecting seed impurity (f_{rad}~0.9)

High radiation loss around the main plasma edge is required.

Radiation loss in the core plasma

➔ High confinement is required to maintain the high temperature.

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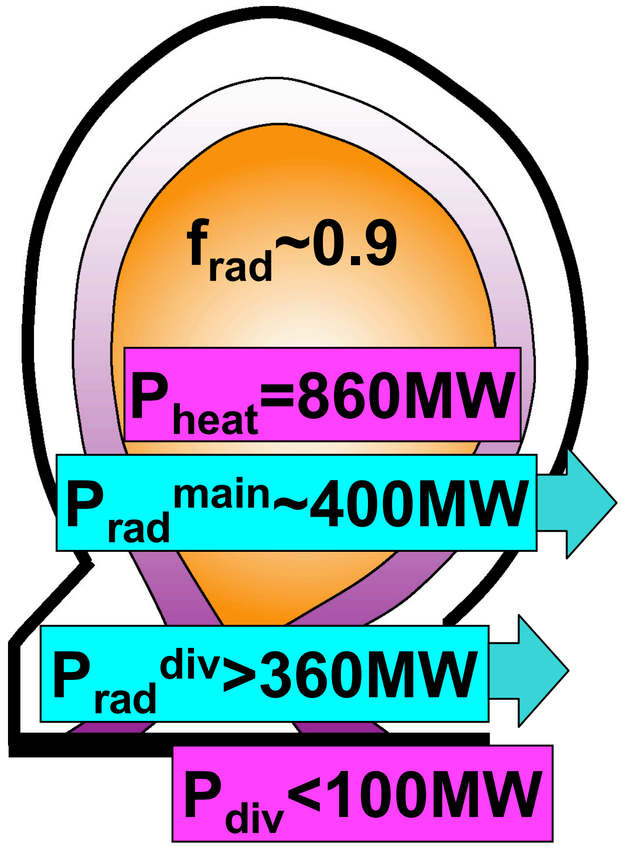
Suppression of impurity accumulation in the core plasma

Optimization of impurity injection scenario is important.

- Fusion output : 4GW
- External heating : 60MW

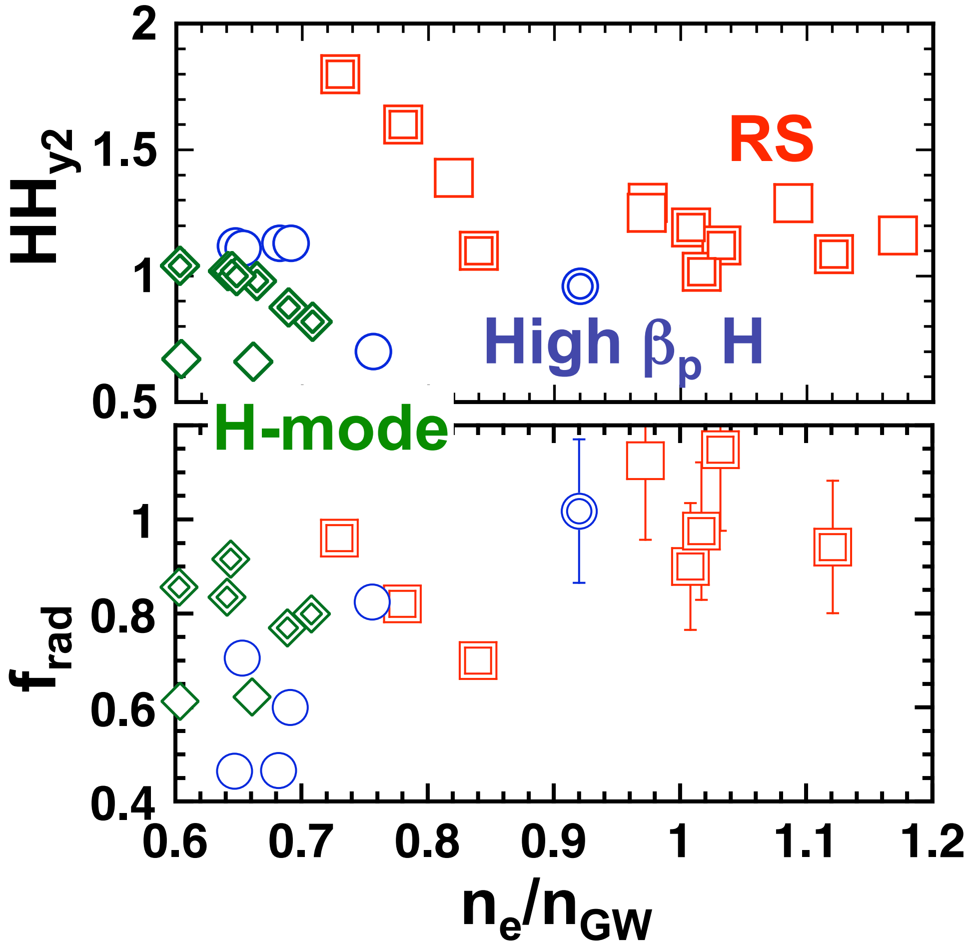


Example for A-SSTR2

High radiation fraction in JT-60U

JT-60U

- Operation regime has been extended to high density ($n_e/n_{GW} \gtrsim 1$) with high confinement ($HH_{y2} \gtrsim 1$) and high radiation loss fraction ($f_{rad}>0.9$) in AT plasmas with ITB.



RS
- Intrinsic metal impurity
- Ne seeding

High β_p H
- Ar seeding

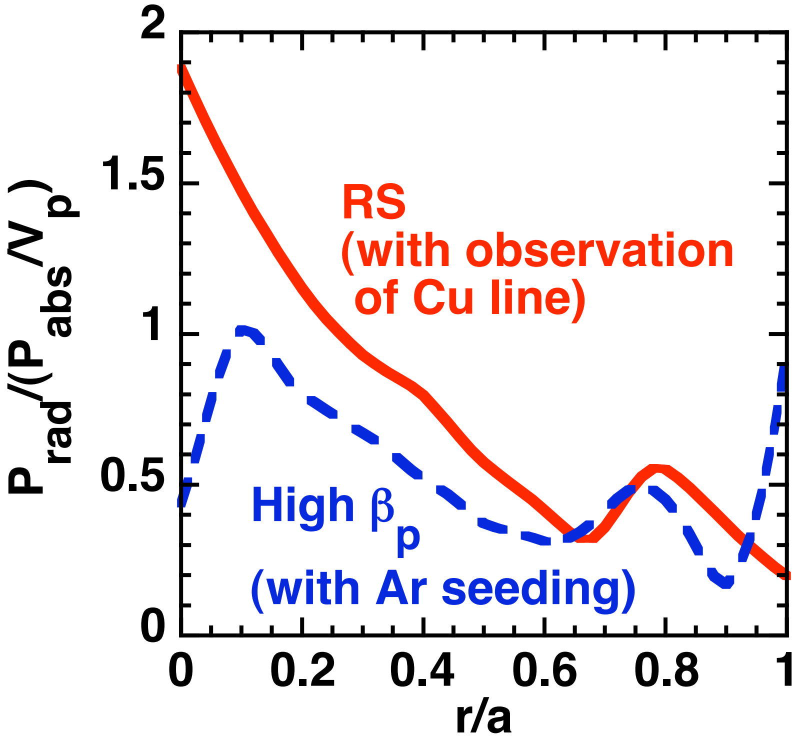
H-mode
- Ar seeding

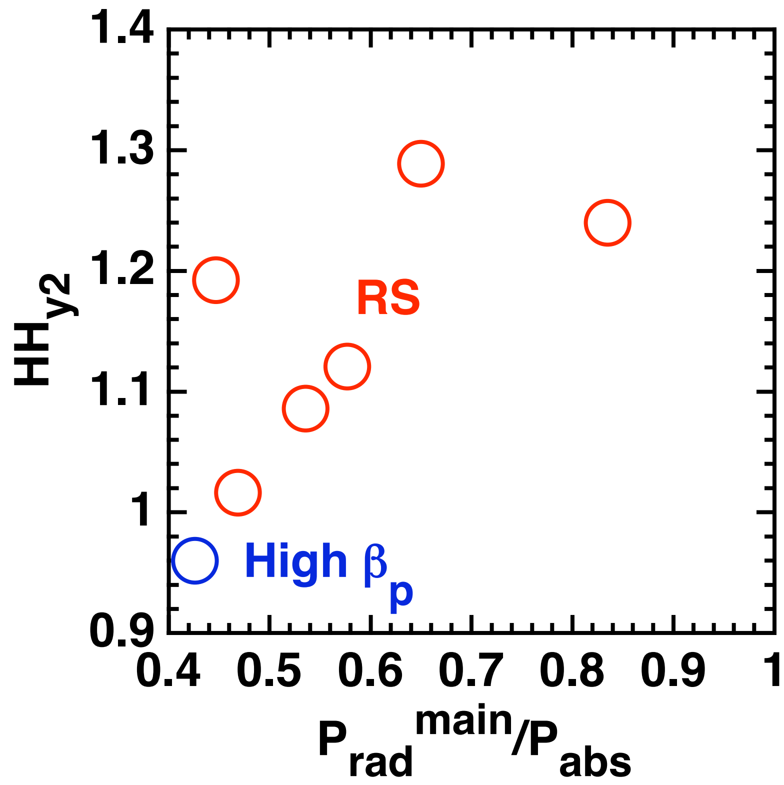
Double lines : with impurity seeding

Radiation profile in JT-60U

JT-60U

- Radiation profile is peaked in both RS and high β_p H.
- Radiation from Cu largely contributes in RS.
- Central radiation is ascribed to Ar in high β_p H.
- In RS, no confinement degradation is observed even with high radiation loss in the main plasma.

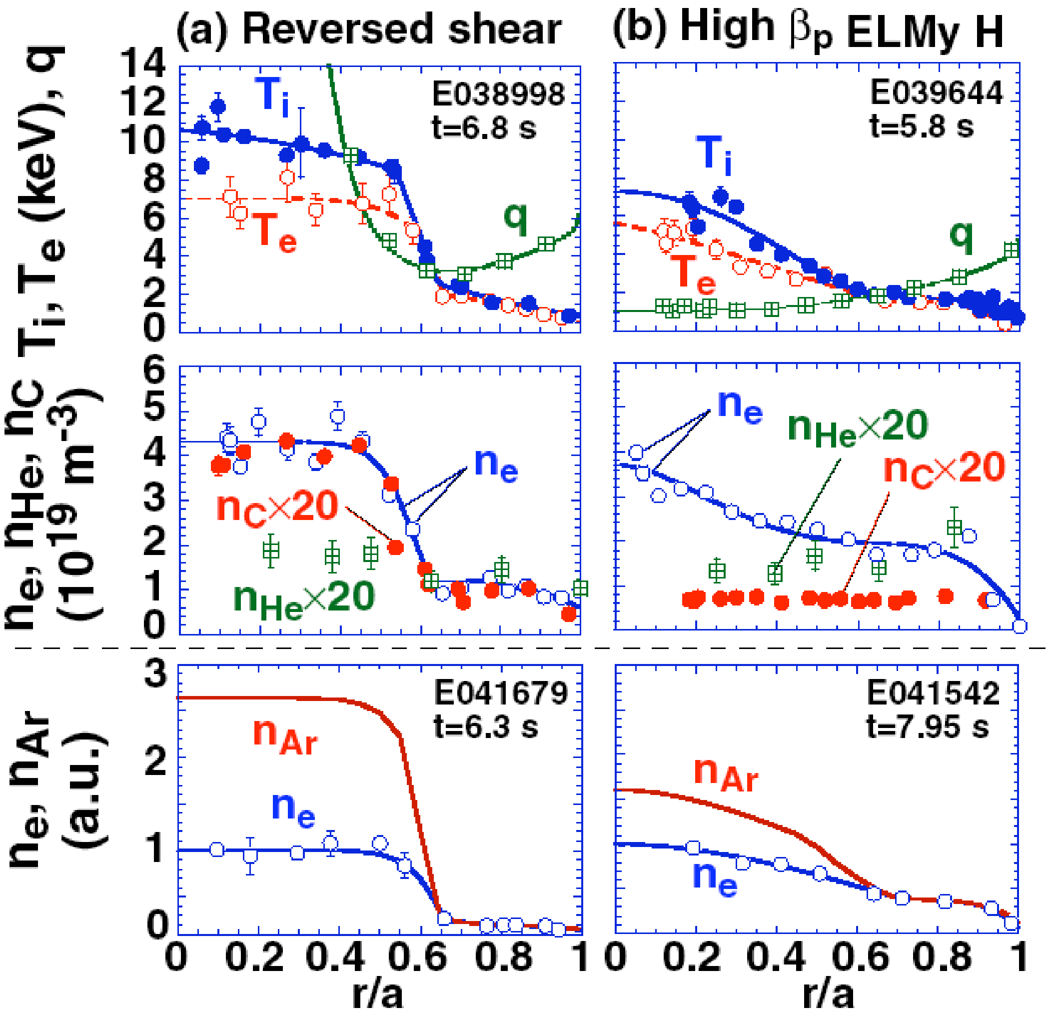




Impurity transport in JT-60U

JT-60U

Neoclassical transport $v_Z = D_{neo}\frac{Z}{Z_i}\left(\frac{1}{n_i}\frac{dn_i}{dr} - H\frac{1}{T_i}\frac{dT_i}{dr}\right)$



- No He and C accumulation inside the ITB
- Ar accumulation inside the ITB
  - weaker than the neoclassical prediction. (D_{Ar}~2-5xD_{Ar}^{NC})
  - stronger in RS than in high β_p H.

Impurity injection scenario

Flat density profile (<=low central fuelling)

- ● Small impurity accumulation
- ▲ Operation with high edge density above Greenwald density (n_{GW}) may be necessary for high fusion output.

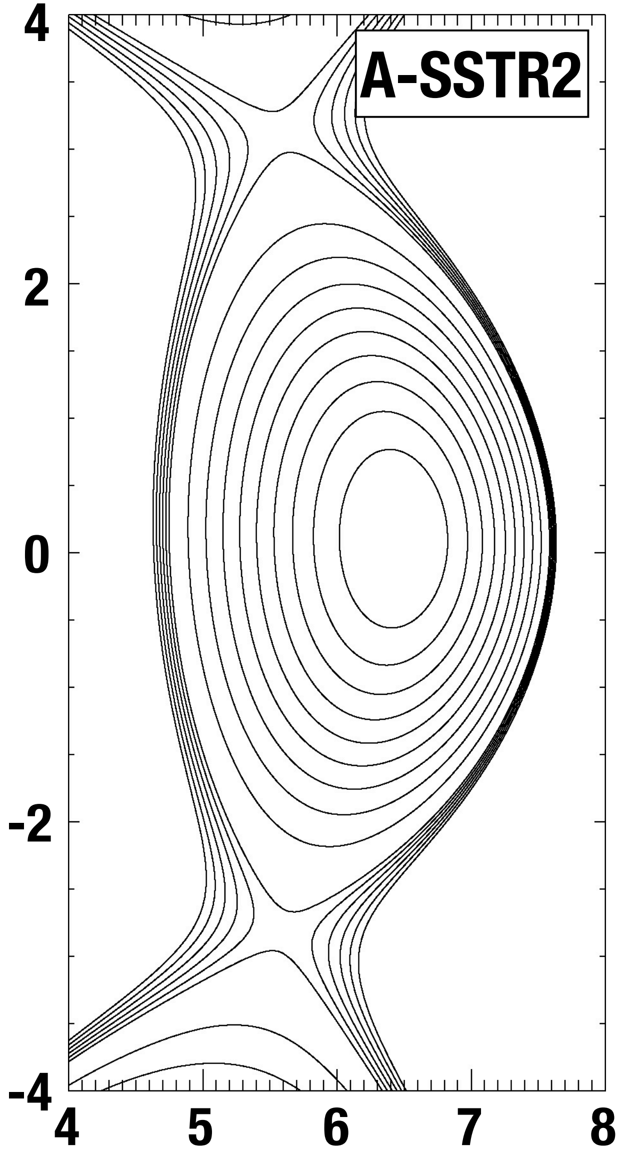
Peaked density profile (<=inward pinch)

- ● It is possible to achieve high fusion output with relatively low edge density ($<n_{GW}$).
- ▲ Impurity accumulation is one of the largest concerns.

Establishment of impurity injection secnario in a burning plasma

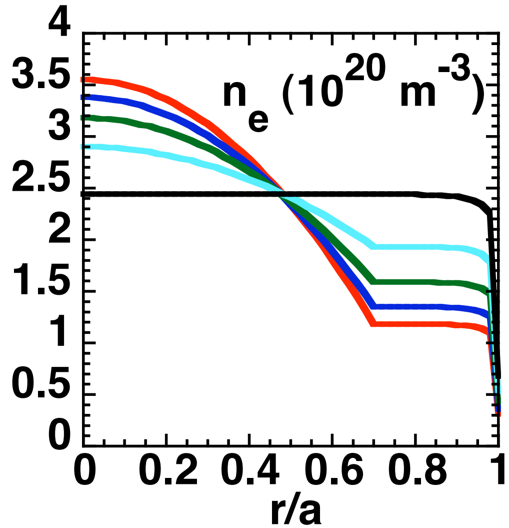
➔ It is necessary to clarify dependence of required confinement and edge density on the impurity accumulation level and density profile.

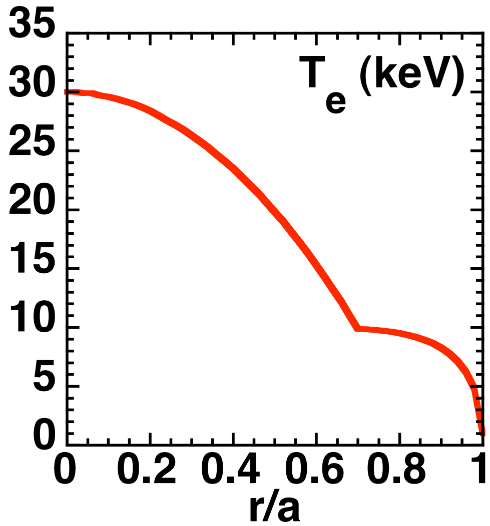
Calculation conditions



Impurity transport : IMPACT
Fusion output : TOPICS

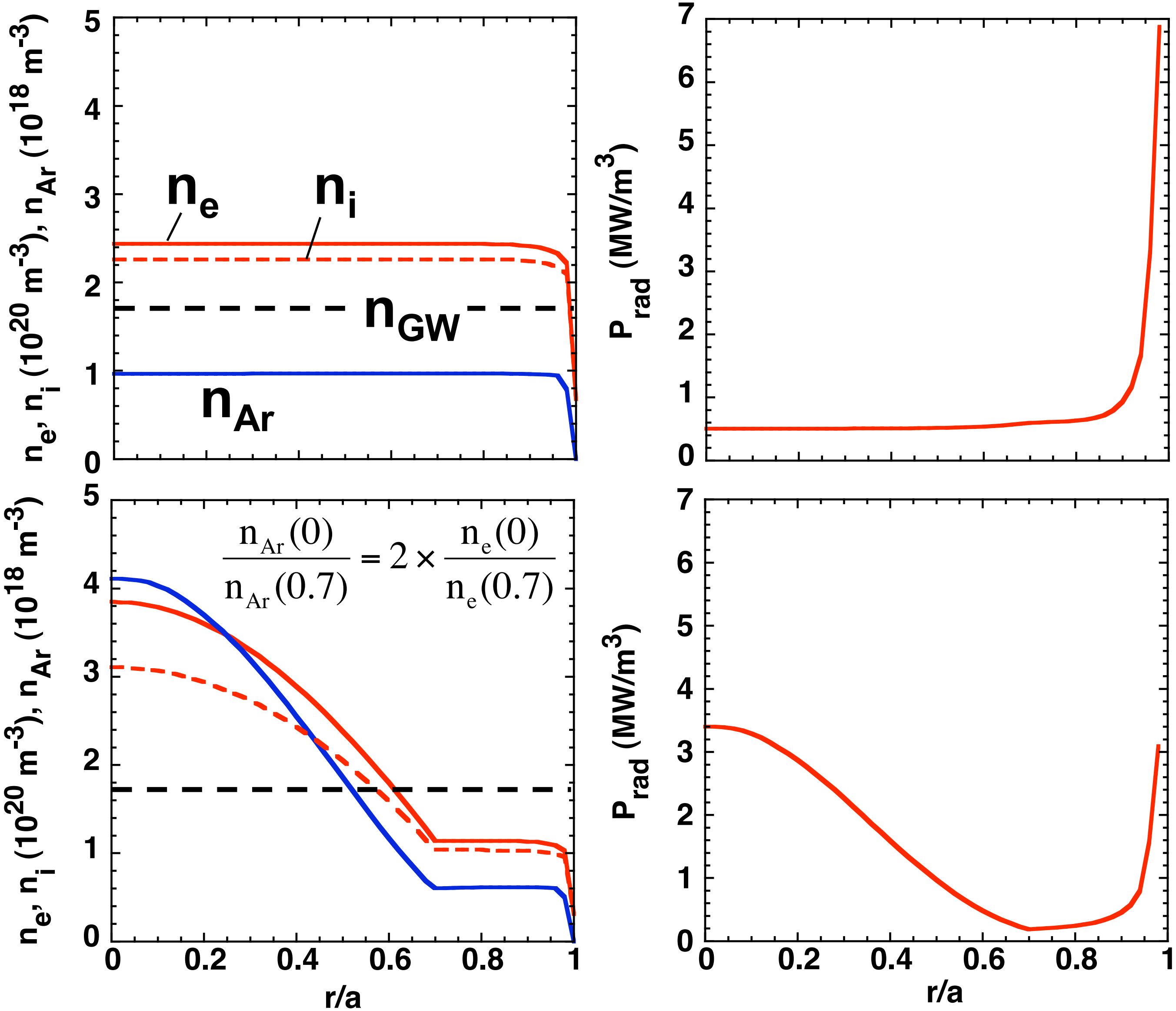
I_p=12MA, B_T=11T, R_p=6.2m, a=1.5m,
Fusion output ~4GW, P_{rad}^{main}~400MW,
Aux. heating=60MW
Impurity : Ar





$$\tau_E = W/(P_{aux.} + P_\alpha - P_{rad}(r/a<0.9))$$

Case with n_{Ar} profile more peaked by a factor of 2 than n_e profile



Flat density profile

W=850MJ

P_{rad}(r/a<0.9) =218MW

HH=1.39

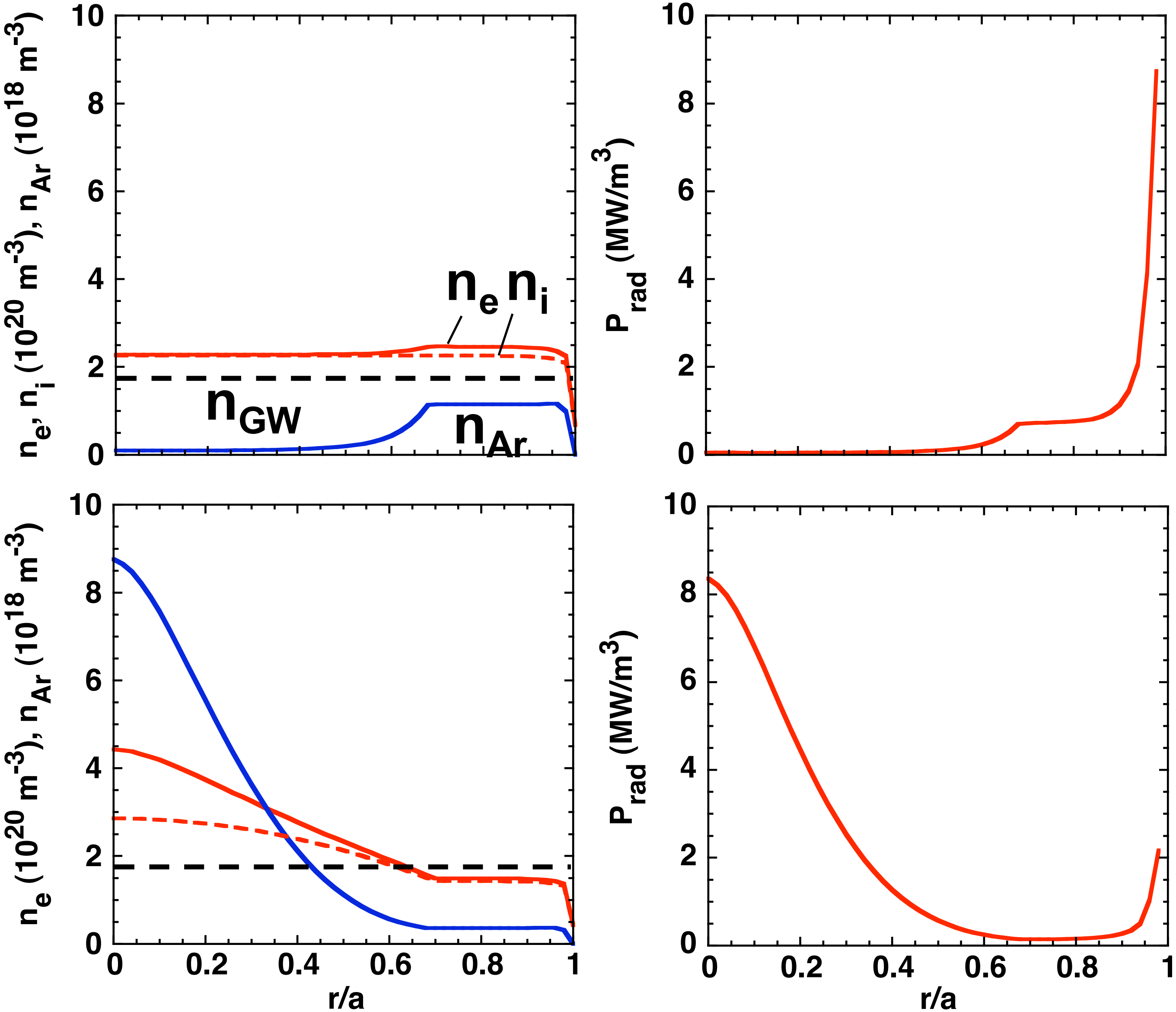
Peaked density profile

W=767MJ

P_{rad}(r/a<0.9) =342MW

HH=1.48

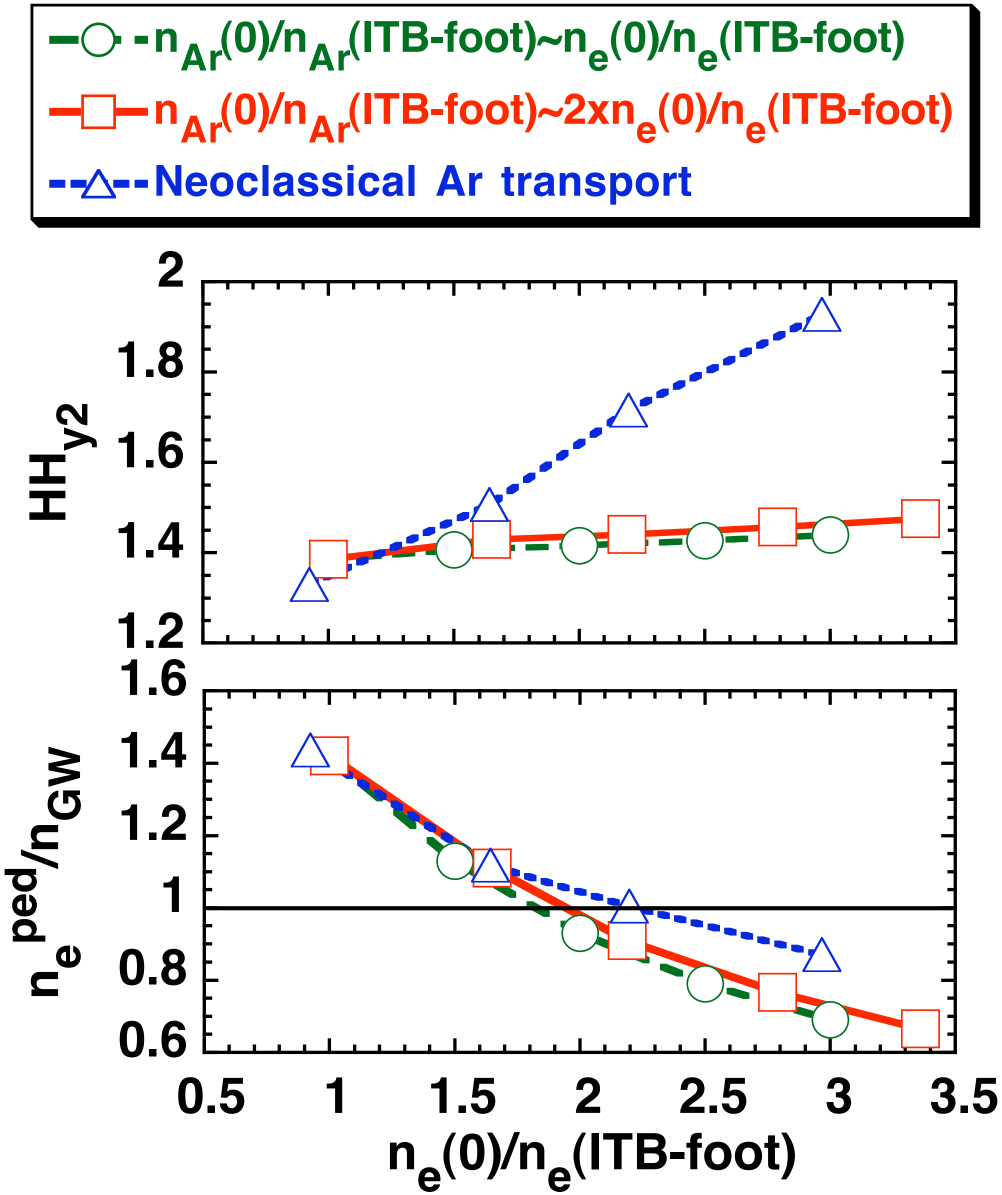
Case with n_{Ar} profile determined by Neoclassical transport



Flat density profile
W=830MJ
P_{rad}(r/a<0.9) =160MW
HH=1.33

Peaked density profile
W=1025MJ
P_{rad}(r/a<0.9) =361MW
HH=1.93

Dependence on electron density profile



- Increase in core radiation loss from accumulated Ar by a factor of 2 can be compensated with slightly enhanced confinement.
- Higher confinement is required with peaked density profile in the neoclassical case.
- Edge density can be reduced below Greenwald density by density peaking.

Summary

- **Required confinement and edge density are estimated with 1-D transport code TOPICS/IMPACT for various impurity accumulation levels and density profiles.**
- **In the case with Ar profile more accumulated by a factor of 2 than electron density, increase in required confinement is small even with peaked density profile. At the same time, required edge density can be reduced below Greenwald density.**
- **The analysis indicates that Ar accumulation by a factor of 2, as observed in the high β_p H-mode plasma, is acceptable in a fusion reactor for impurity seeding.**