# Atomic Data, Diagnostic Design and Plasma Performance

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# Atomic data and MCF devices

How does atomic data and plasma models *and the quality of these data and models* influence the fusion programme:

- Diagnostics — interpretation and design.
- Plasma performance.

Any predictive work must be strongly rooted in properly describing the behaviour of current devices:

- Transport — how well does this scale?.
- Plasma parameters — how realistic are the predictions.

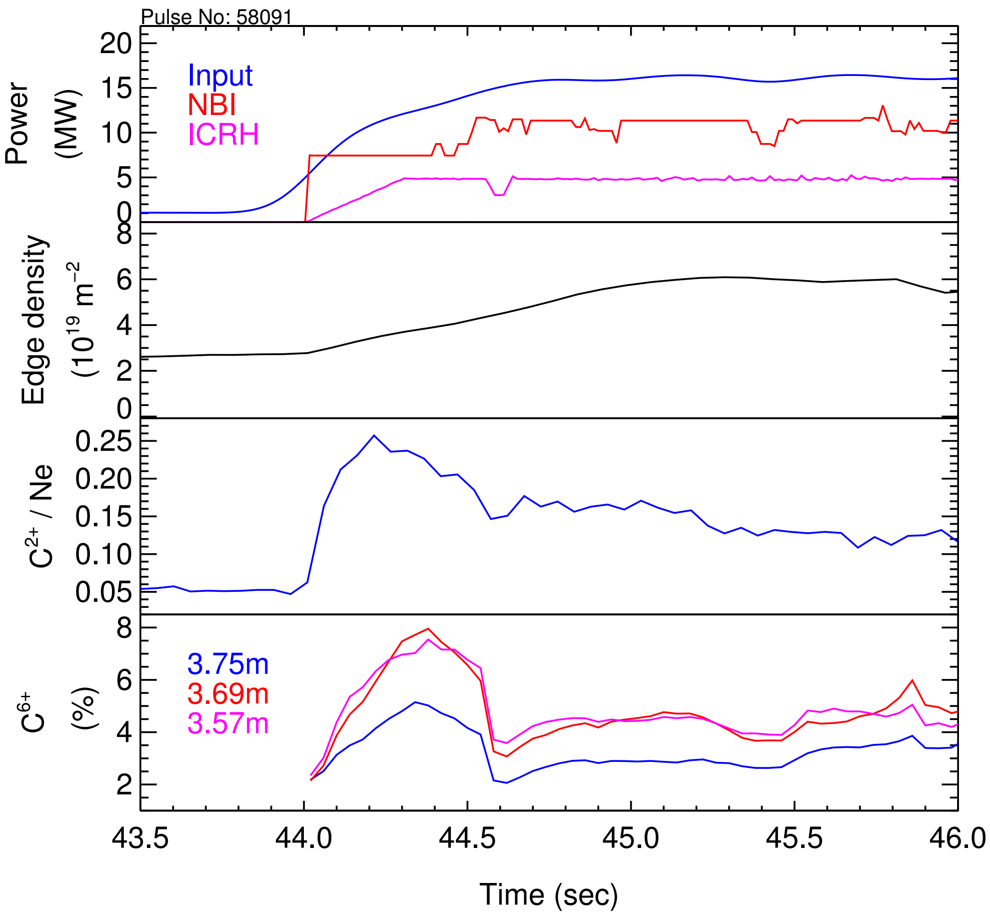
Consider a number of germane questions:

- Will beam shine-through be a problem with the ITER-like wall in JET?
- How much radiated power will 0.1% of oxygen produce in ITER?
- What crystal is best for measuring core tungsten emission in JET?
- What is the spectral emission of high-Z species in ITER divertor?

# Beam shine through question

The new ITER-like wall of JET will have a tungsten PFC beam dump.

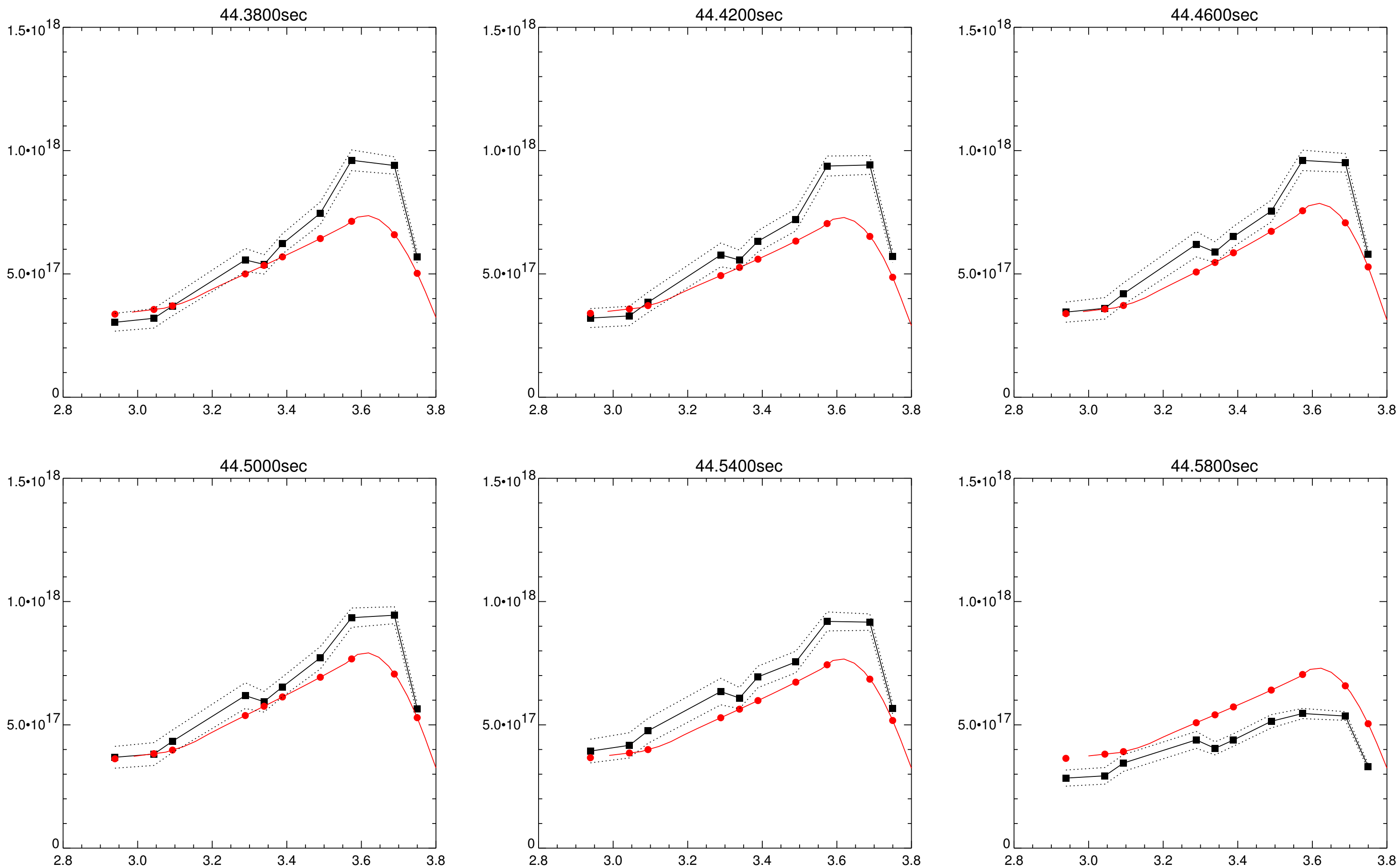
*How will this affect the radiated power and plasma resistivity?*




- The recipe for ITB formation starts with a low density plasma.
- Beams are not fully attenuated by the plasma.
- Influx of carbon is seen at beam switch-on.

# Model of carbon behaviour

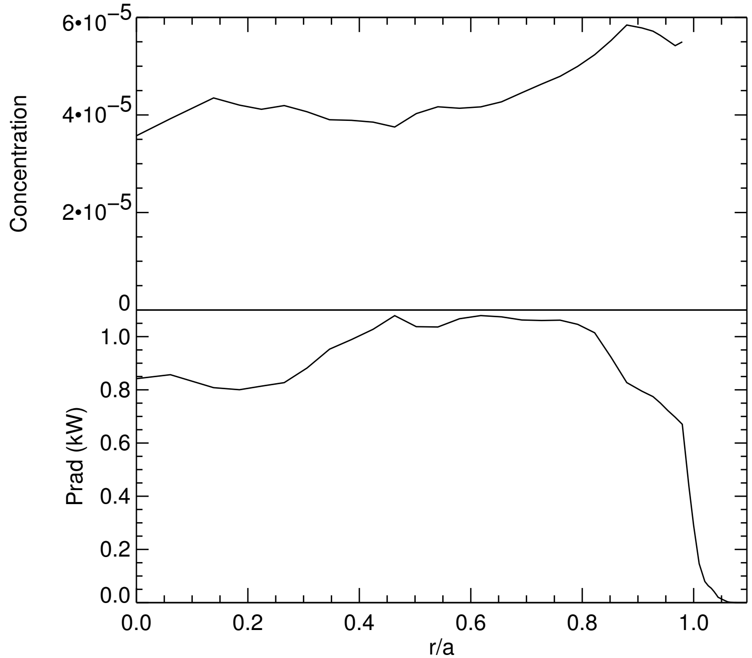
We can get reasonable agreement between a simple model and measured concentrations:

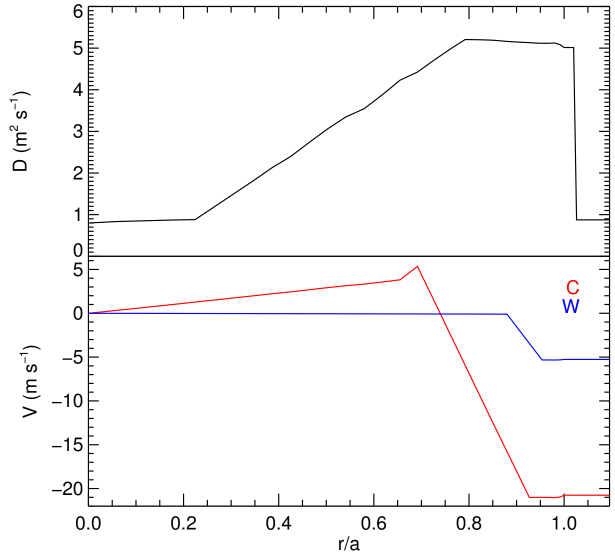


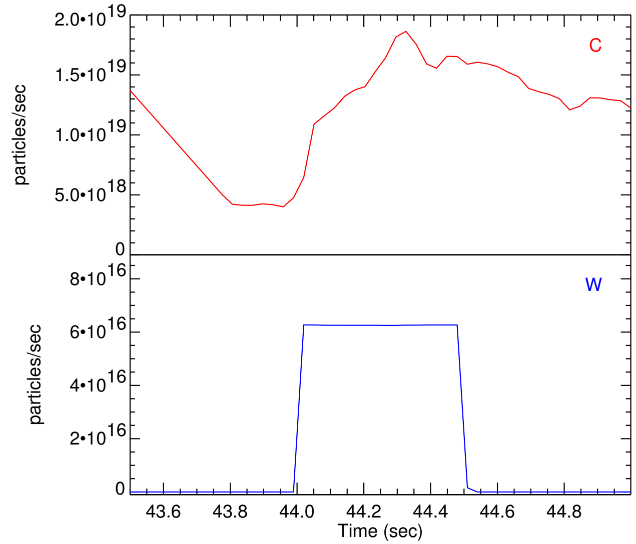

However modelling the large increase on $6^{6+}$ immediately following the beam switch-on is still a challenge.

# What about Tungsten?

- Take carbon as a starting point...
- Note that low Z has an outward convection



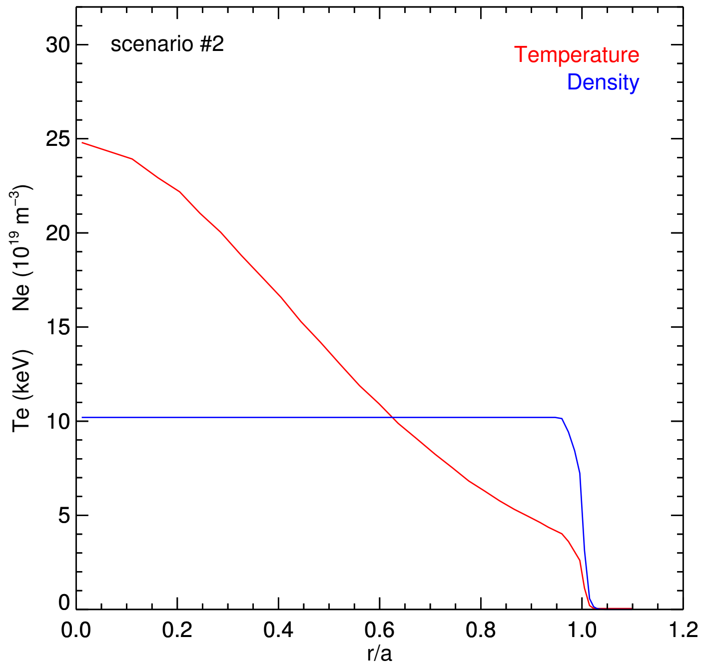



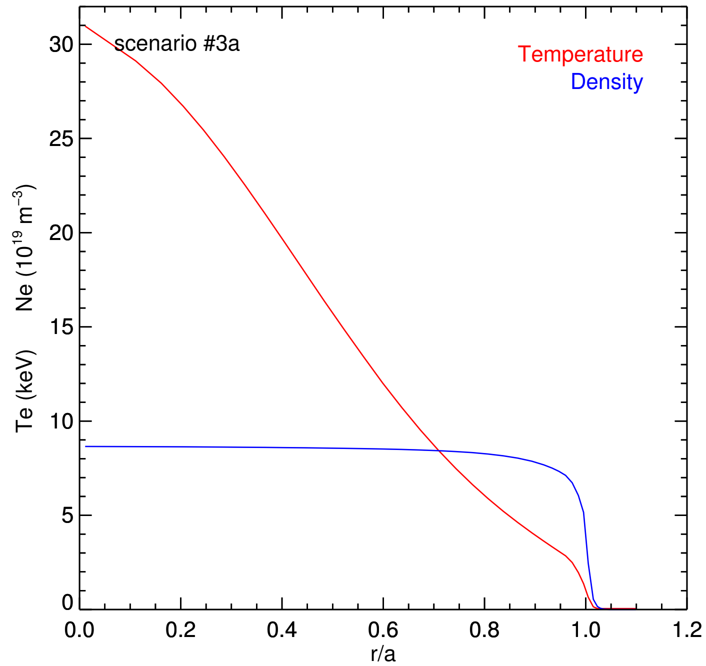

Launch $10^{19}$ particles/sec gives
$\langle N_W \rangle \sim 5 \times 10^{-5}$ and
$\langle P_W \rangle \sim 75$kW.

# Radiated power contribution from oxygen

Oxygen radiation is a measure of the vessel leak rate.

*What power is radiated from a reasonable concentration in various operating scenarios?*



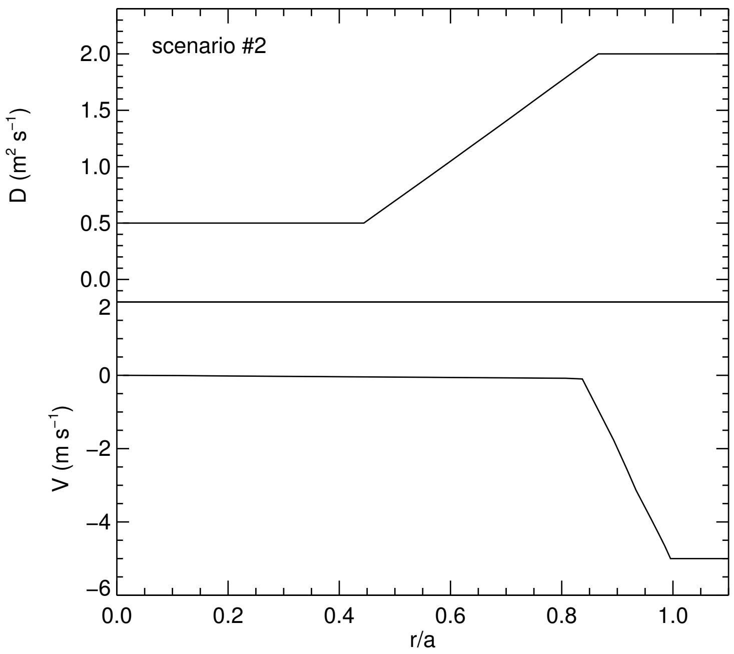



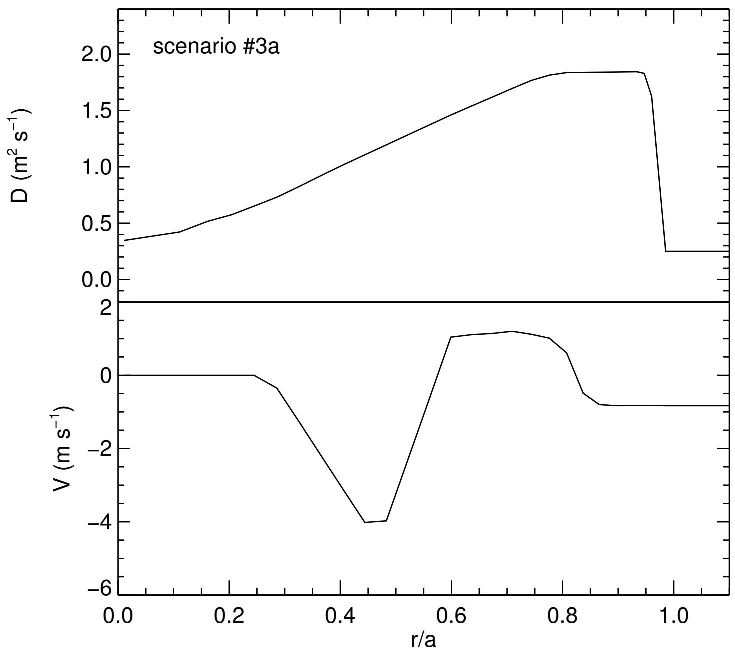

Scenario #2 is a full bore plasma with an inductive current of 15MA in the flat top producing 400MW of fusion power at Q=10 for approximately 400s. It is an ELMy H-mode plasma with 40MW of additional heating. Radiated power during burn is predicted to be 47MW.

Scenario #3a is similar in size and produces a similar amount of fusion power. It is a hybrid regime with 13.8MA current and 73MW of additional heating. Predicted radiated power during burn is 55MW.

# What transport to use?

Transport determines the impurity distribution in the plasma which directly affects where the radiation is emitted. There are no robust empirical rules to predict the impurity transport coefficients. However, extrapolating from existing machines, the possible range of values can be confidently chosen.

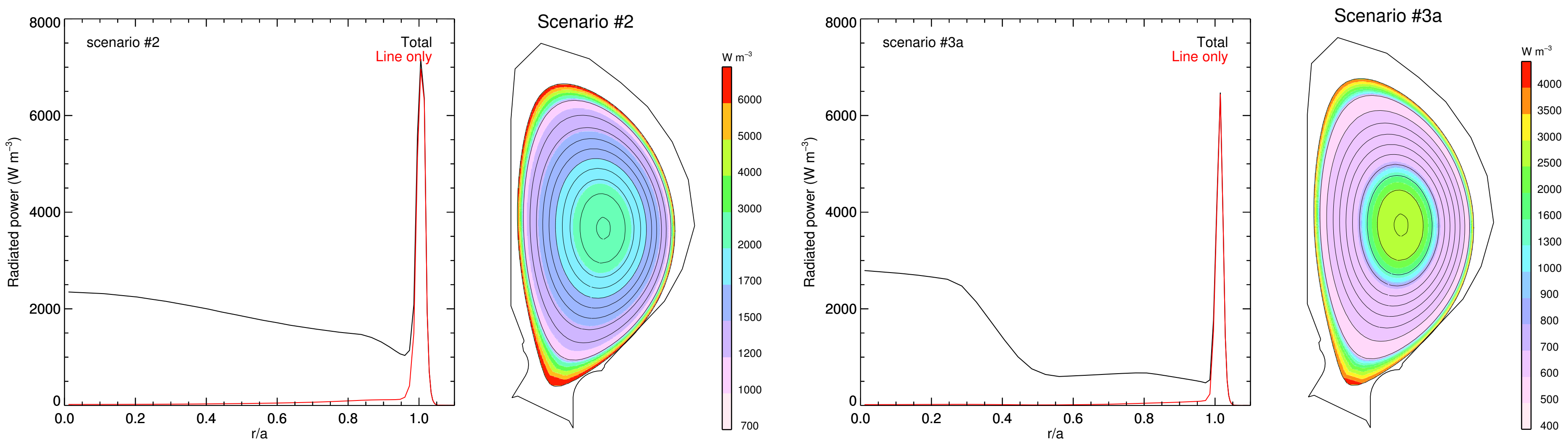



The hybrid transport is less well known due to the internal transport barrier. For this study the transport coefficients deduced for JET hybrid discharges [Giroud04] are used directly *without* any scaling.

# Radiated power profiles

For a 0.1% oxygen concentration:



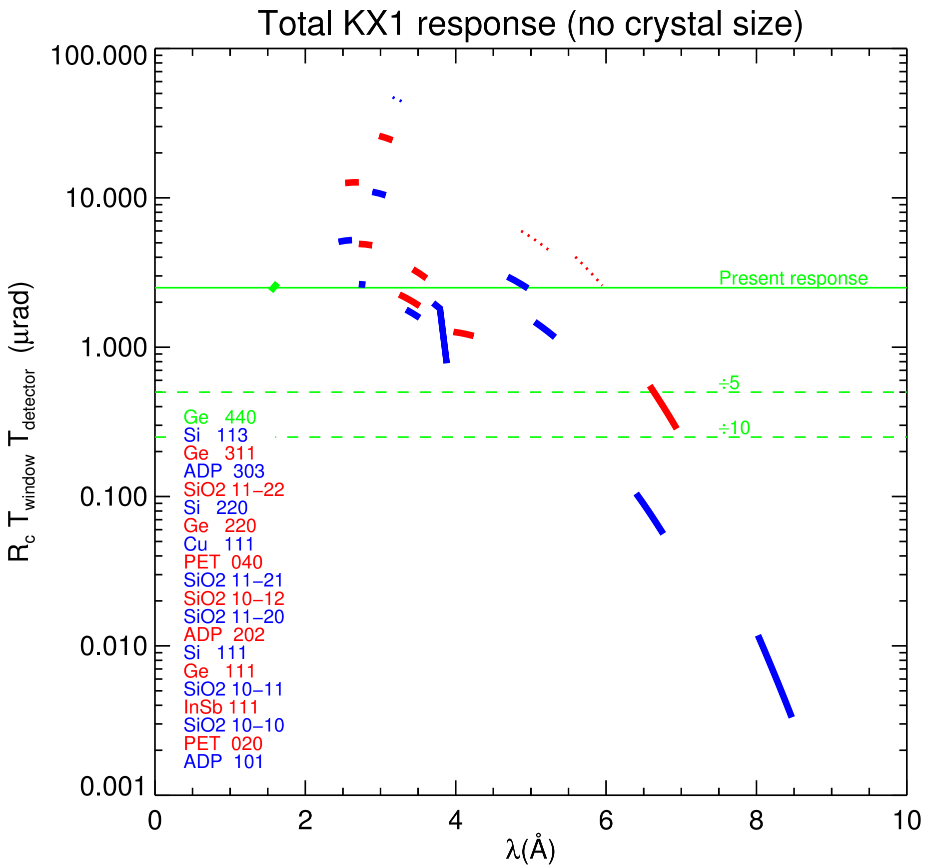

| $P_{rad}$/MW (V /m$^3$) | Scenario #2 | | Scenario #3a | |
|---|---|---|---|---|
| Total | 1.72 | (1050) | 1.07 | (1052) |
| Core | 1.49 | ( 794) | 0.79 | ( 791) |
| SOL | 0.39 | ( 279) | 0.38 | ( 284) |
| $r/a > 0.95$ | 0.64 | ( 385) | 0.47 | ( 394) |

Compared to the expected total radiated power of 40–60MW, the modelled radiated powers of 1–2MW are not serious, but neither are they quite negligible.

# Core tungsten radiation in JET?

With probable core contamination of tungsten in JET the X-ray spectrometer will be upgraded to view W line emission for concentration and ion temperature measurements.

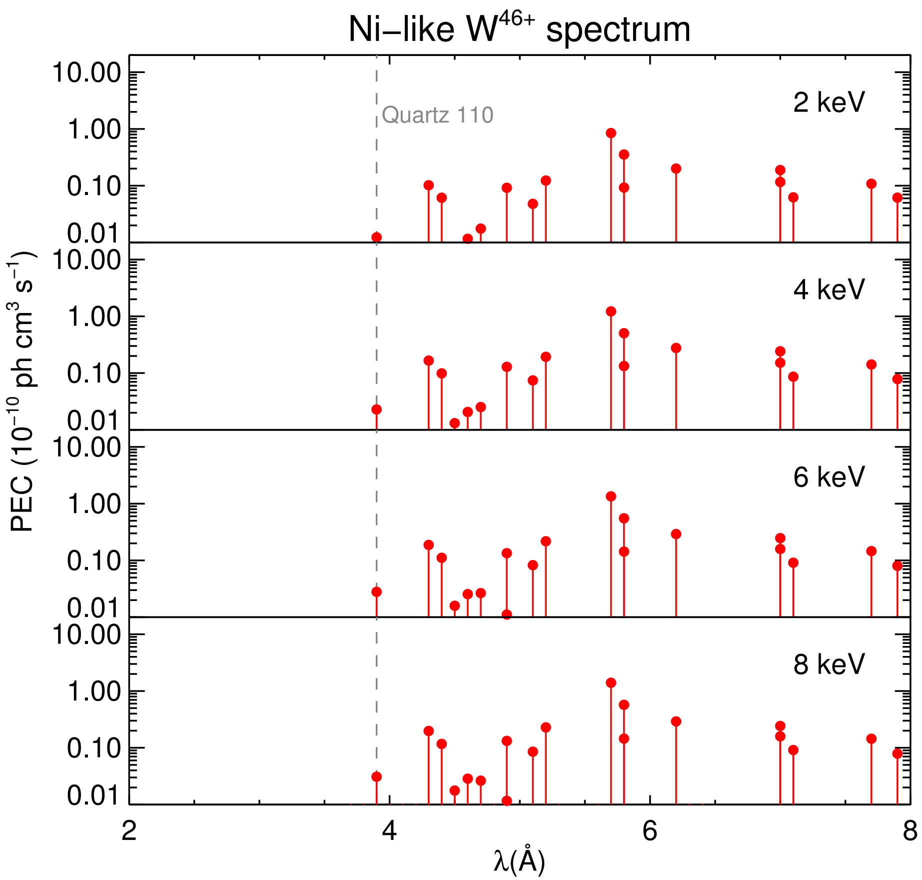
*Which is the most suitable crystal to use?*




- Current crystal for $Ni^{26+}$
- Reflectivity of crystals can compensate for reduced detector efficiency.
- Can see detector (Ar) edge with $SiO_2$ $11\bar{2}0$.
- $\lambda > 6$Å with PET within factor 10 of current response.

# Consider Ni-like Tungsten : $W^{46+}$

This ionisation stage should have a wide radial profiles for ‘typical’ electron temperatures.



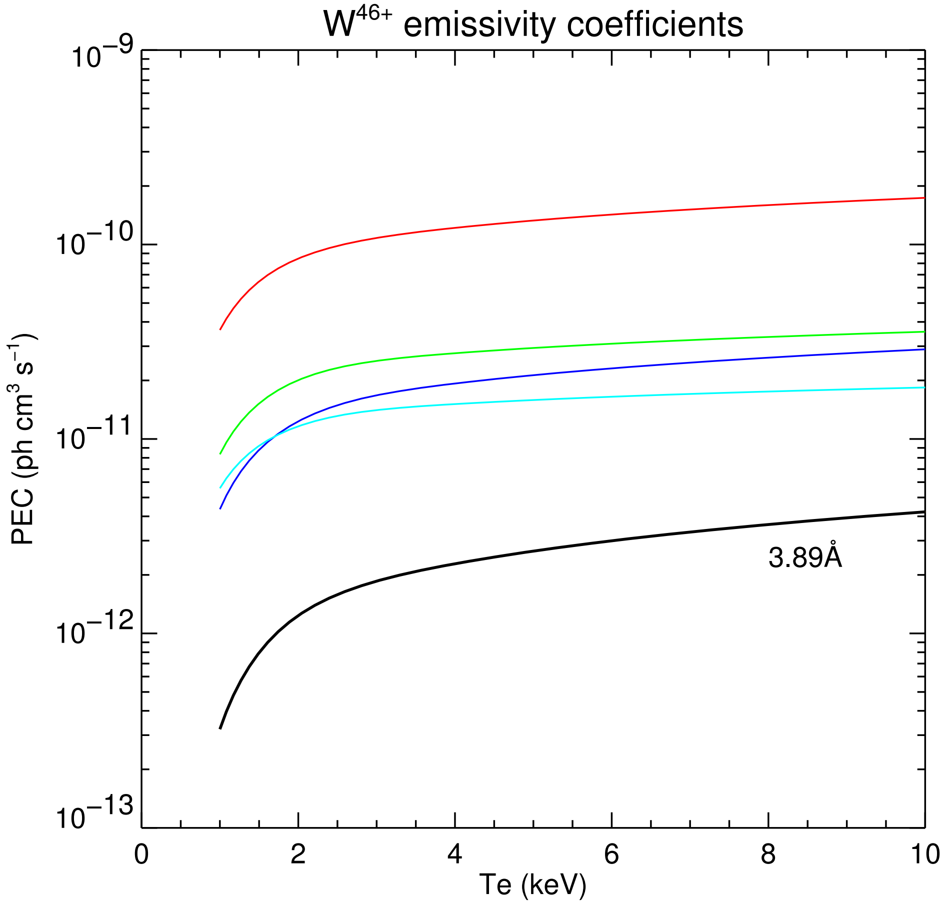

- Relatively simple structure.
- At the $3d^{10}$ shell boundary.
- ADAS801 predictions.
- Configurations considered:

| Even | | | | Odd | | | |
|---|---|---|---|---|---|---|---|
| 3s2 | 3p6 | 3d10 | | 3s2 | 3p6 | 3d9 | 4p1 |
| 3s2 | 3p6 | 3d9 | 4s1 | 3s2 | 3p6 | 3d9 | 4f1 |
| 3s2 | 3p6 | 3d9 | 4d1 | 3s2 | 3p6 | 3d9 | 5p1 |
| 3s2 | 3p6 | 3d9 | 5s1 | 3s2 | 3p6 | 3d9 | 5f1 |
| 3s2 | 3p6 | 3d9 | 5d1 | 3s2 | 3p5 | 3d10 | 4s1 |
| 3s2 | 3p6 | 3d9 | 5g1 | 3s2 | 3p5 | 3d10 | 4d1 |
| 3s2 | 3p5 | 3d10 | 4p1 | 3s2 | 3p5 | 3d10 | 5s1 |
| 3s2 | 3p5 | 3d10 | 5p1 | 3s2 | 3p5 | 3d10 | 5d1 |
| 3s2 | 3p5 | 3d10 | 4f1 | 3s1 | 3p6 | 3d10 | 4p1 |
| 3s2 | 3p5 | 3d10 | 5f1 | 3s1 | 3p6 | 3d10 | 4f1 |
| 3s1 | 3p6 | 3d10 | 4s1 | | | | |
| 3s1 | 3p6 | 3d10 | 4d1 | | | | |

Note that the line at $\lambda \simeq 3.89$Å ($3s^2 3d^{10}\ ^1S - 3s^2 3p^5 3d^{10} 5d^1\ ^1P$) fits within the 0.8% spectral range for the current Bragg angle for a Quartz 110 crystal.

# The $W^{46+}$ 3.89Å line

This line is a little 'exotic' in that a deep 3p electron is promoted to an *n* = 5 level.




All strong dipole $3s^2 3p^6 3d^{10}$ $^1S$ – $^1P$ transitions:

$3s^2 3p^6 3d^9 4f^1$ : 5.687Å

$3s^2 3p^5 3d^{10} 4s^1$ : 6.150Å

$3s^2 3p^5 3d^{10} 4d^1$ : 5.200Å

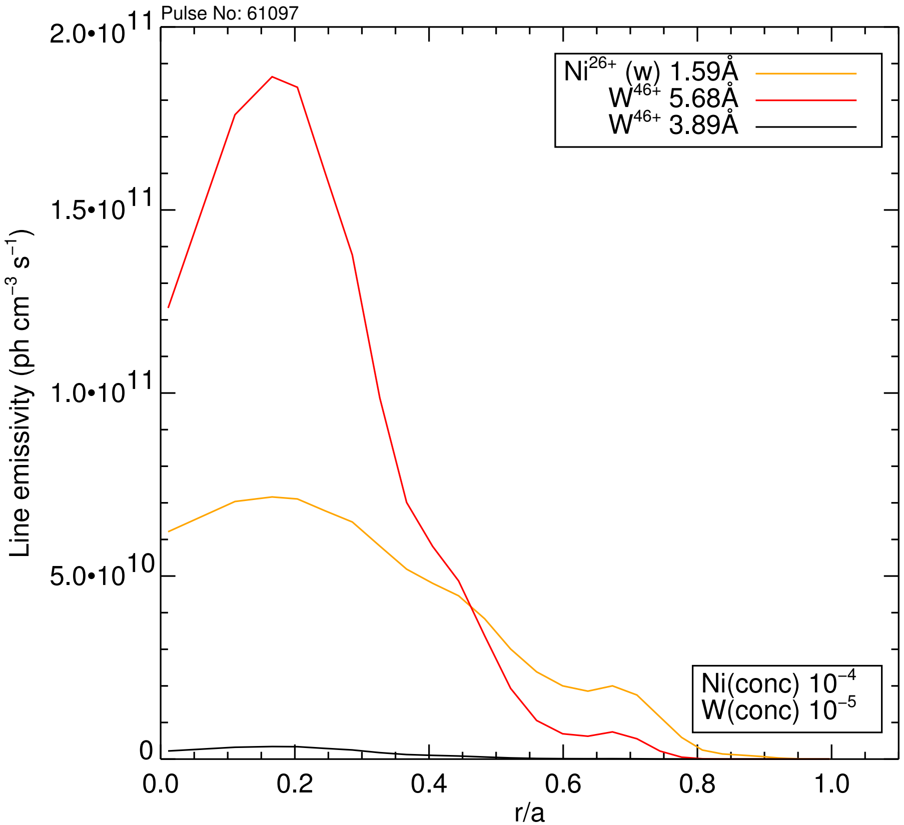
$3s^2 3p^6 3d^9 4p^1$ : 7.011Å

$3s^2 3p^5 3d^{10} 5d^1$ : 3.894Å

Transitions with a promoted 3p electron will not be as strong the principal lines but may be measurable. The *n* = 5 upper level does not help!

# Can the $W^{46+}$ 3.89Å line be seen?

The intensity of any Tungsten line depends on the concentration in the core plasma.



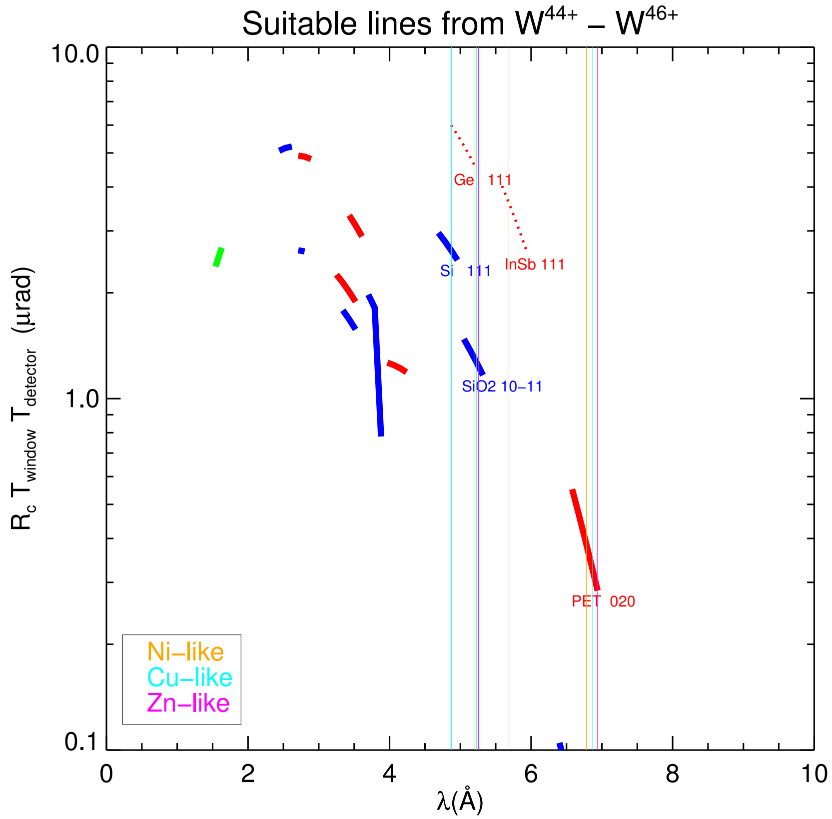

Take #61097 as a typical/favoured shot:

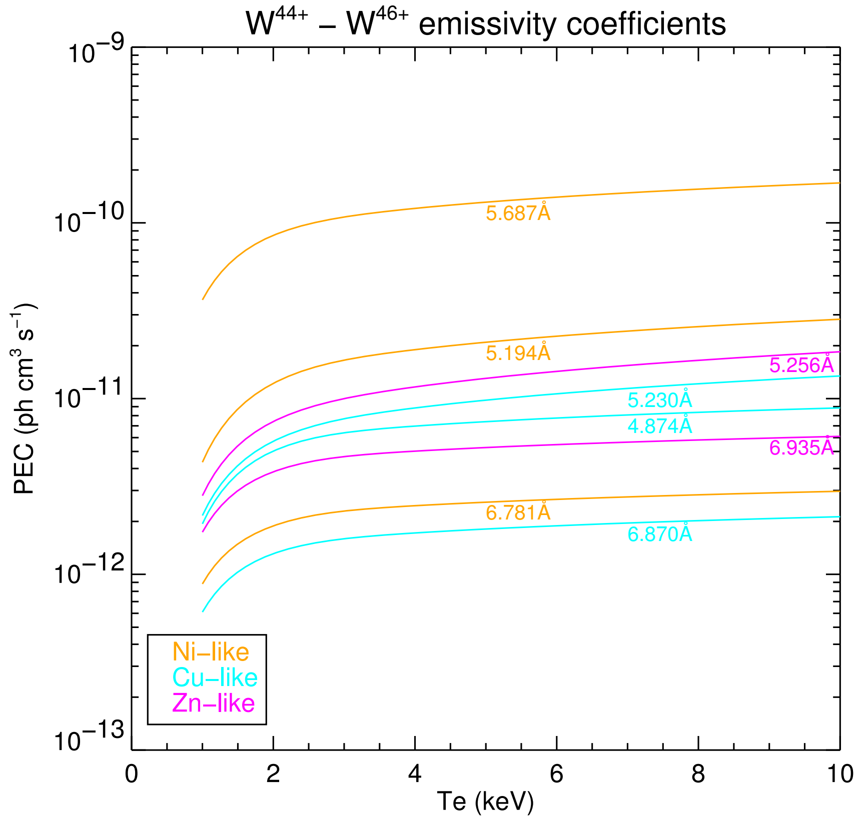
- 3.5keV and $5 \times 10^{13}$cm$^{-3}$.
- XCS Ni concentration of $\sim 10^{-4}$.
- Assume W concentration of $\sim 10^{-5}$.
- Assume steady state W and Ni conditions.

The 'strong' Tungsten line at 5.68Å is competitive with the Ni w-line but the exotic W line at 3.89Å may be too weak.

# The suitability of the other crystals

If the constraint of not moving the KX1 arm is relaxed then lines from Ni-like, Cu-like and Zn-like transitions can be viewed on two crystals.

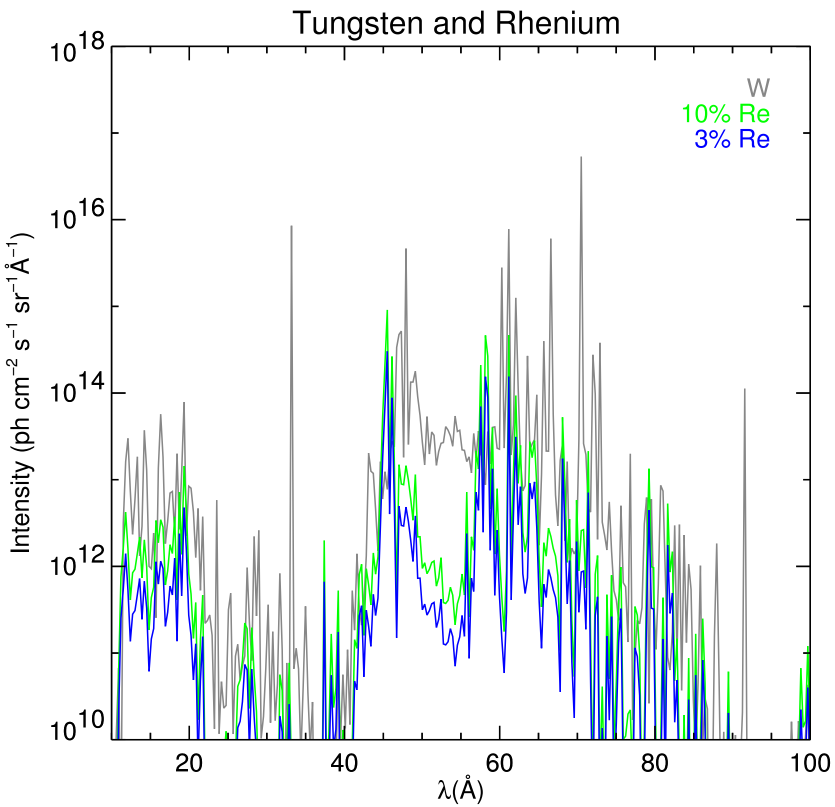


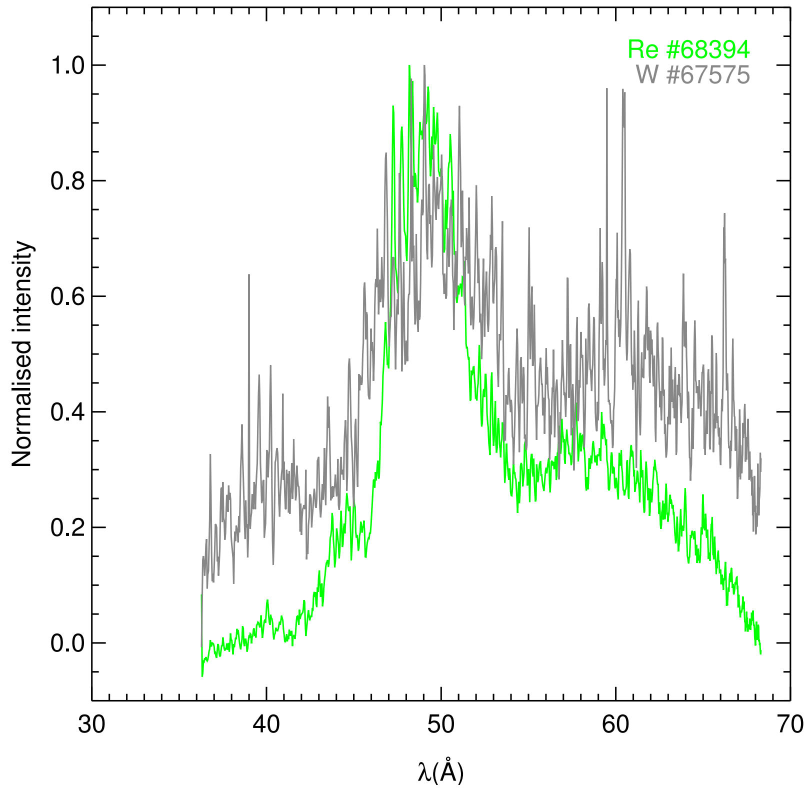

- The Si10$\bar{1}$1 crystal appears to be the most useful.
- PET possible but has a lower sensitivity.

# Is Tungsten the only high Z element likely in ITER (or JET)?

Last year's workshop prediction: there would be a detectable spectroscopic signature between W (Z=74) and Re (Z=75).




ADAS prediction




Recent measurements

*More analysis and experimental data is required.*