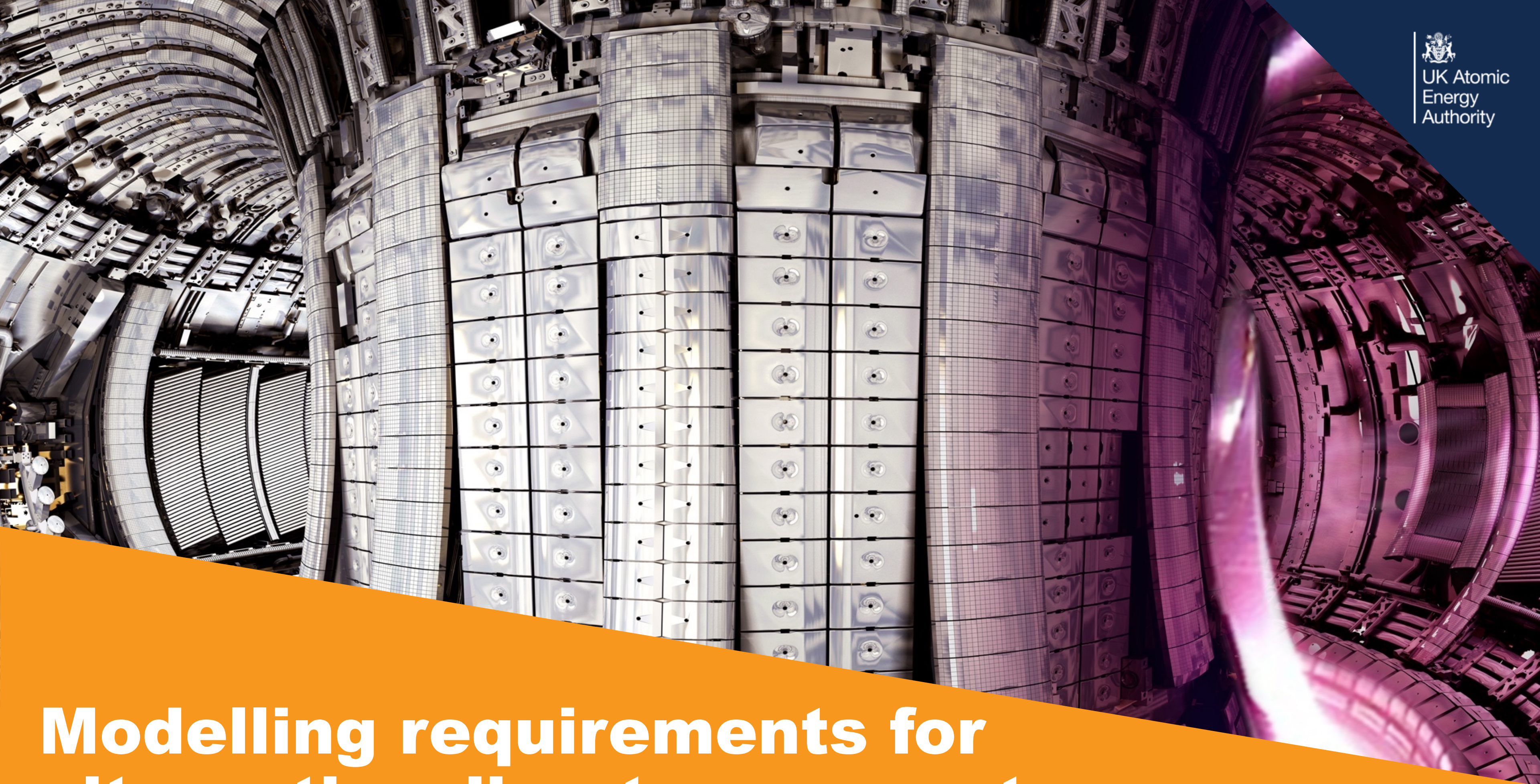

UK Atomic Energy Authority

# Modelling requirements for ~~alternative diverter concepts~~ reactors

**Fulvio Militello**

**with contributions from the WP-DTT1/ADC team, in particular D. Moulton and L. Xiang**

Energy
For a Low Carbon Future

This work was funded by the RCUK Energy Programme
[Grant number EP/P012450/1]

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# Introduction

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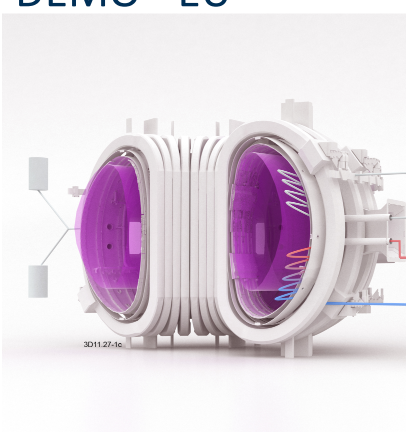
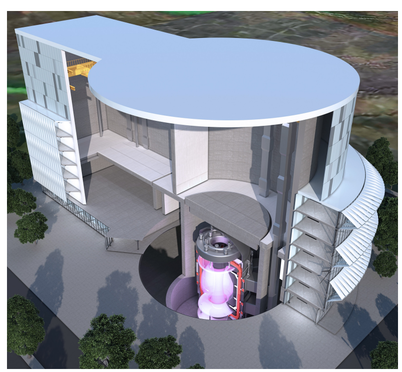
- Fusion energy entering the delivery era.
- In several places around the world we have reactor design efforts.
- In silico design: need for accurate data, models and modelling to reduce uncertainties.
- Boundary physics is one of the major concerns as it is a strong design driver.

ITER

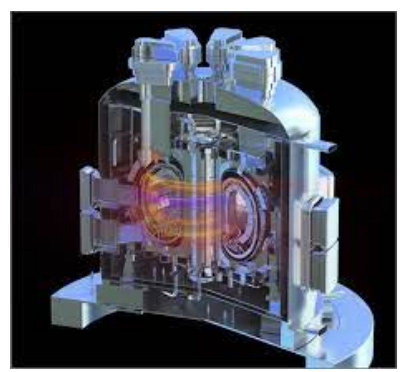
DEMO - EU



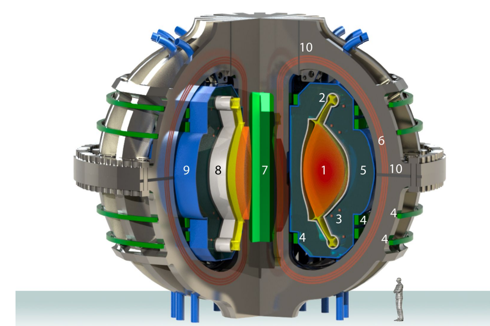
STEP - UK



CFETR - China



ARC - USA





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# Reactor exhaust physics

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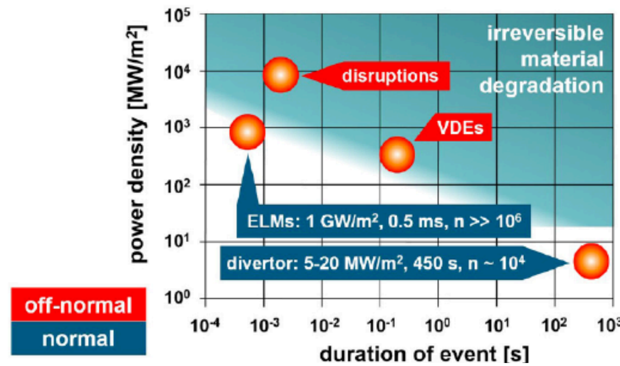
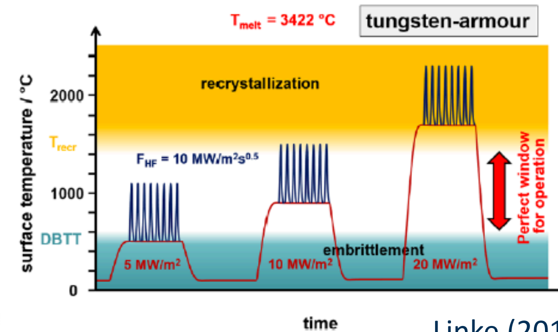
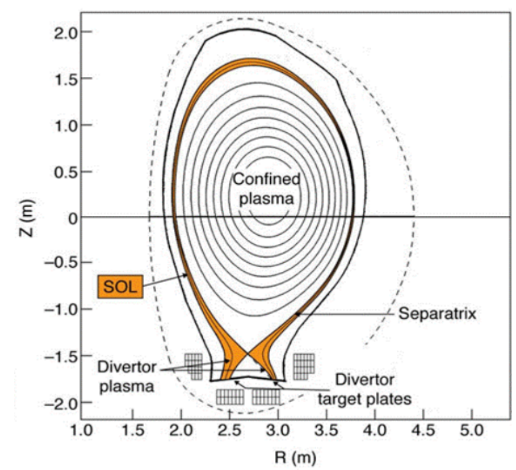
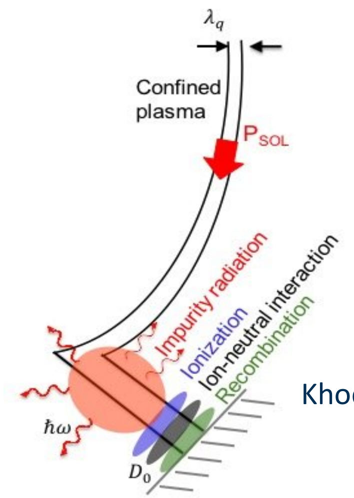
- Material limits and fusion performance constrain the plasma exhaust.
- $P/(R\lambda_q)$ is a useful parametrization of the challenge.
- But we are victims of our own success… $\lambda_q$ is very small!



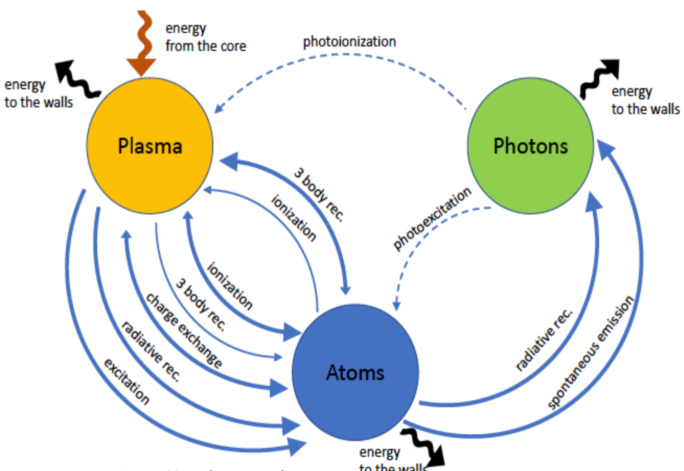




Linke (2019)




Khodunov (2018)




Militello (2021)

- Need to reduce the energy fluxes: transfer energy to particles that are not affected by the confining fields.

Atomic processes!

Excitation, spontaneous emission, ionization, charge exchange, molecular processes.

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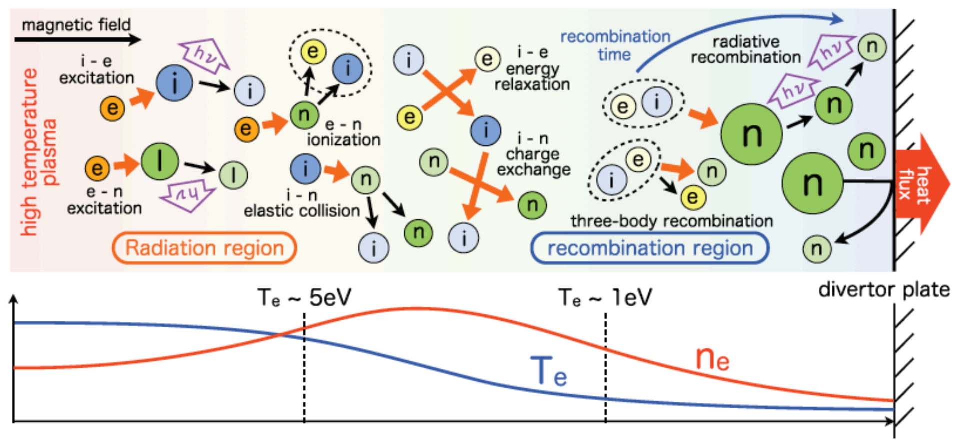
# More reactor exhaust physics



- Reducing the energy density fluxes is not enough. We need to reduce the particle fluxes as well, due to surface recombination loads.
- Also, we must have low plasma temperatures to avoid sputtering (lifetime reduction).

(ultimate) detachment

Atomic processes again! Volumetric recombination (including MAR), molecular processes.




Hayashi (2016)

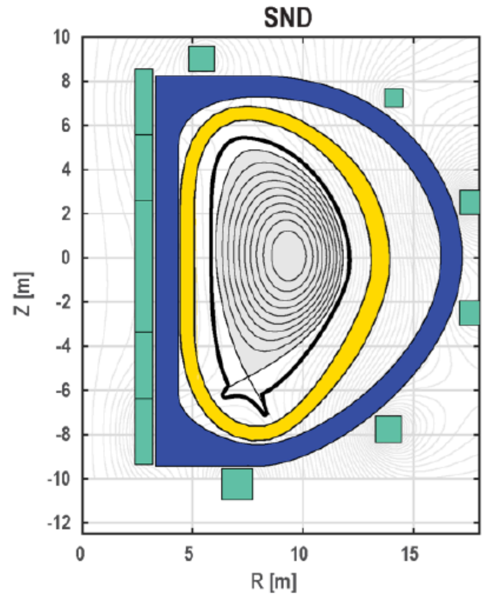
Without detachment, we have loads that are more than one order of magnitude higher than tolerable limits!

- Alternative configurations can improve detachment.

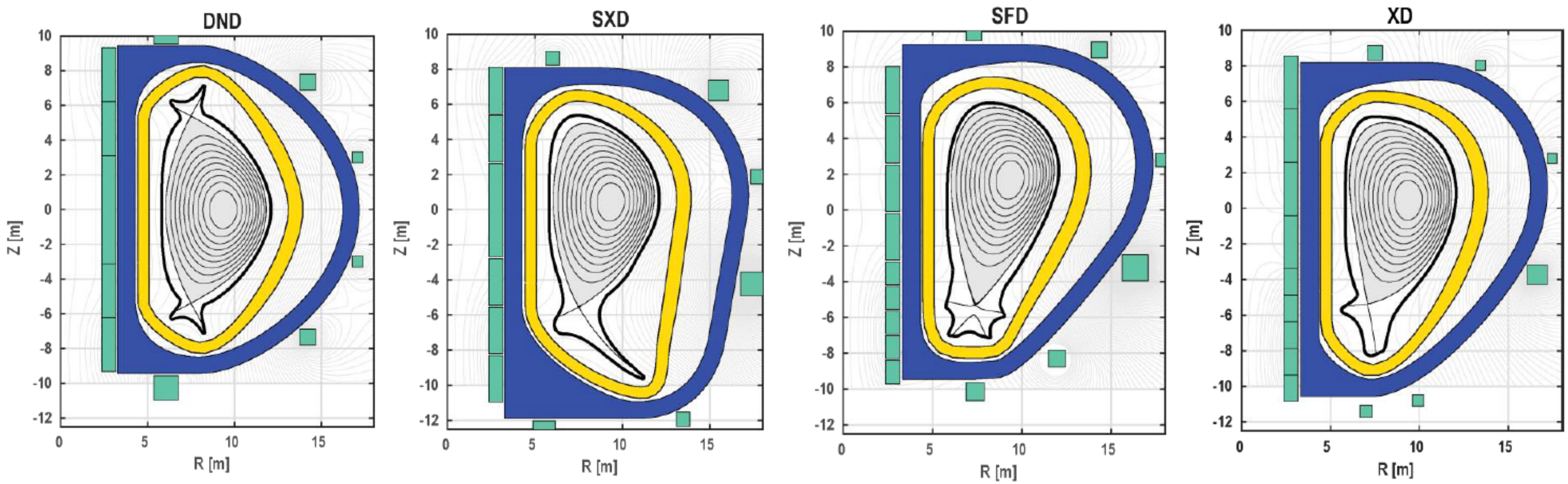
# Examples of alternative configurations

- Alternative configurations improve certain features of the exhaust system:

1. Connection length;
2. Flux expansion;
3. Multiple strike points.

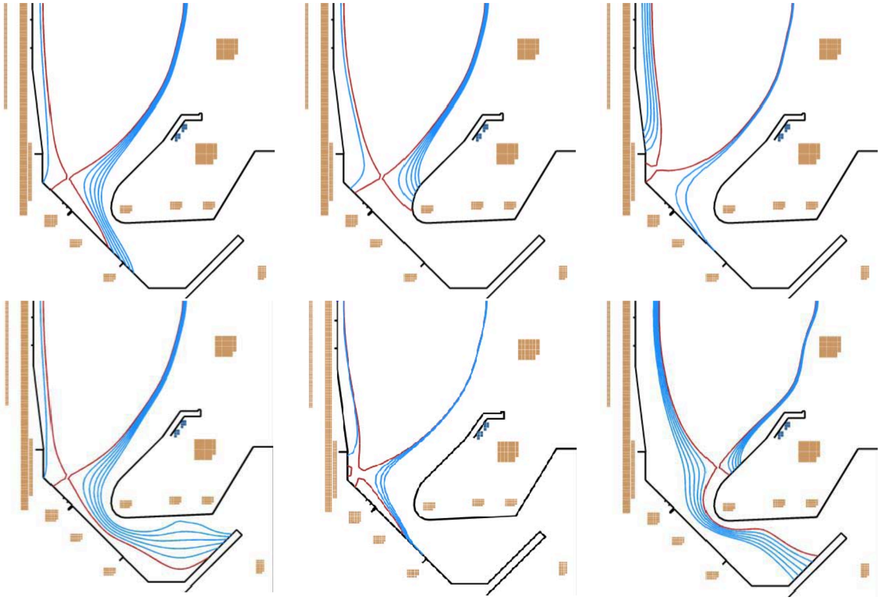


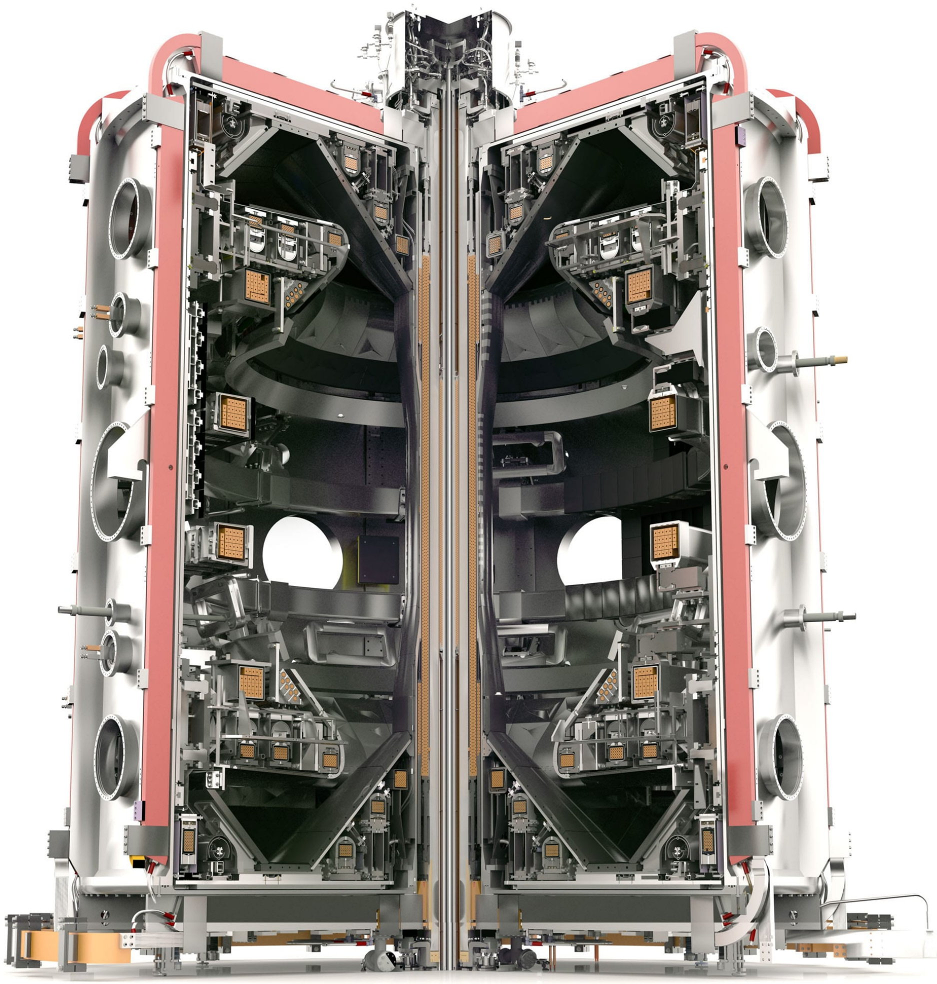

- Alternative configurations are a mean, not an end.



# MAST-U

- MAST-U started operations in October 2020.
- Its incredible flexibility in terms of magnetic geometry and excellent diagnostics will provide a good test ground for ideas.





# Reactor conditions

High core radiation to reduce the target loads. → Understand high Z impurity transport and radiation at high temperatures.

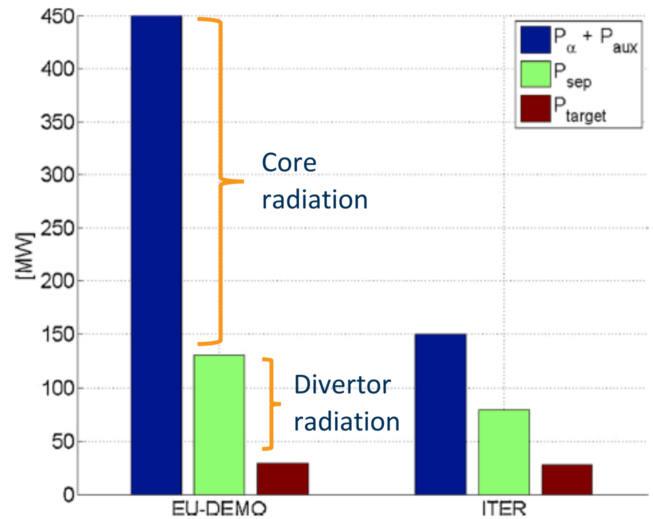
Low target temperature due to erosion (lifetime issue).

Metallic machine.

Significant seeded impurity population.

Deep detached state?

Tritium and plasma chemistry for inventory purposes.




Siccinio (2020)

# Reactor conditions

High core radiation to reduce the target loads. → Understand high Z impurity transport and radiation at high temperatures.

Low target temperature due to erosion (lifetime issue). → Detailed understanding of low temperature (<1eV) behavior of impurities.

Metallic machine.

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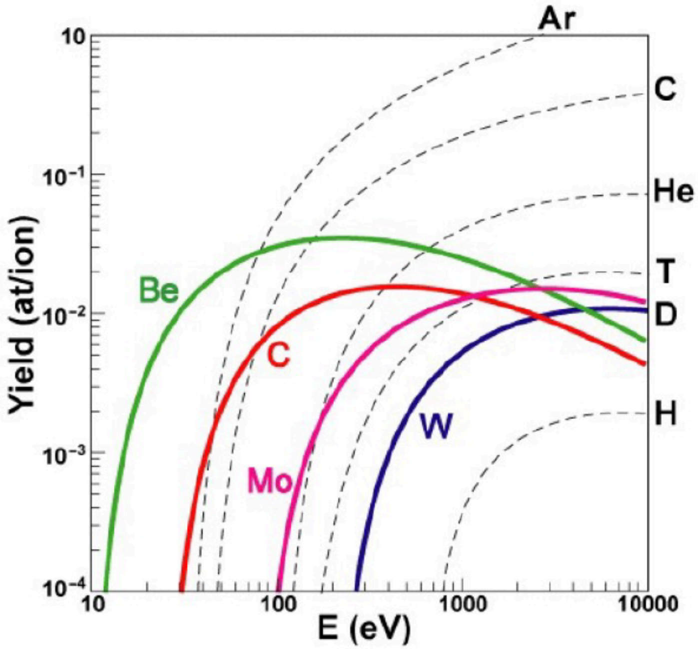

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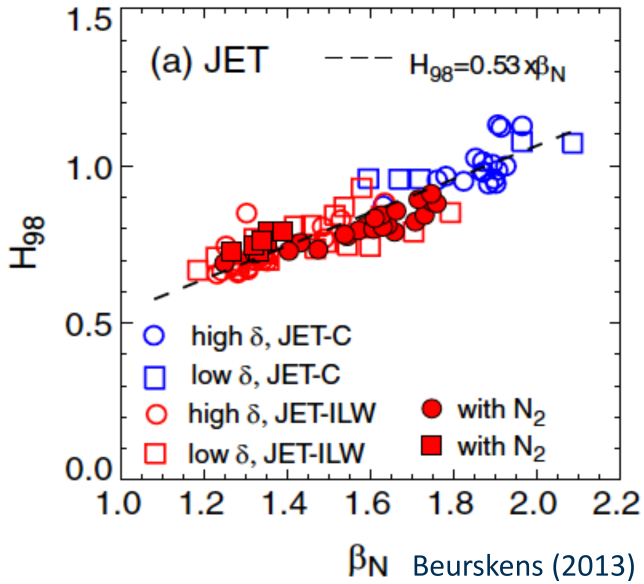


Beurskens (2013)

# Reactor conditions

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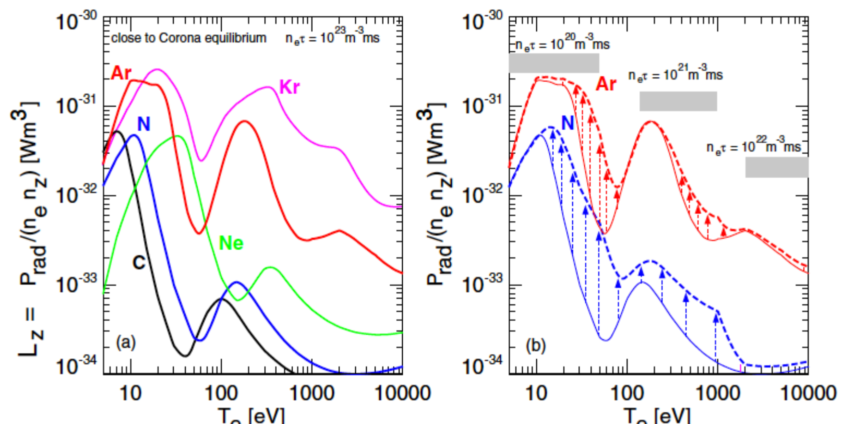
- High core radiation to reduce the target loads. → Understand high Z impurity transport and radiation at high temperatures.
- Low target temperature due to erosion (lifetime issue). → Detailed understanding of low temperature (<1eV) behavior of impurities.
- Metallic machine. → Tungsten is likely to be the “star”!
- Significant seeded impurity population. → Metallic machines requires large concentrations of impurity species. (but don’t forget He).
- Deep detached state?
- Tritium and plasma chemistry for inventory purposes.




Kallenbach (2013)

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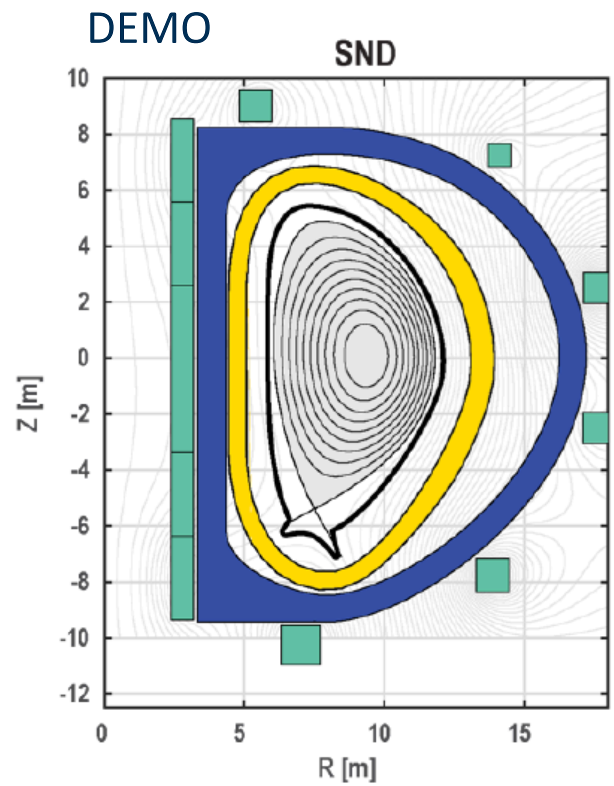
# Reactor conditions

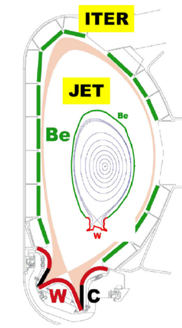
| | |
|---|---|
| High core radiation to reduce the target loads. | Understand high Z impurity transport and radiation at high temperatures. |
| Low target temperature due to erosion (lifetime issue). | Detailed understanding of low temperature (<1eV) behavior of impurities. |
| Metallic machine. | Tungsten is likely to be the “star”! |
| Significant seeded impurity population. | Metallic machines requires large concentrations of impurity species. (but don’t forget He). |
| Deep detached state? | Role of molecules (e.g. MAR). |
| Tritium and plasma chemistry for inventory purposes. | Chemical reactivity with T needs to be properly accounted for. |

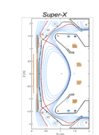
# Size matters

- Many properties of the SOL are related with ratios of length scales.
- Collisionality: $L_{//}/\lambda_{ei}$.
- Ionization mean free path with respect to machine size and divertor leg length.
- Position of the ionization front with respect to the length of the divertor leg.
- Mean free path with respect to the distance between inner and outer target.

- Closure induced by size (better segregation of impurities, better neutral compression)!
- Opacity induced by size (like a hot blanket, it can change detachment)!



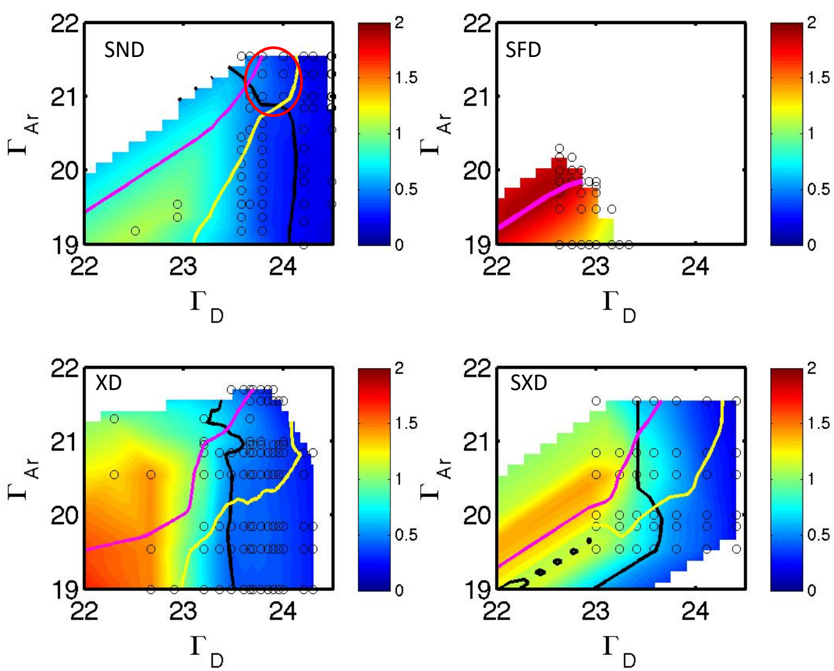



# Examples of Reactor Modelling

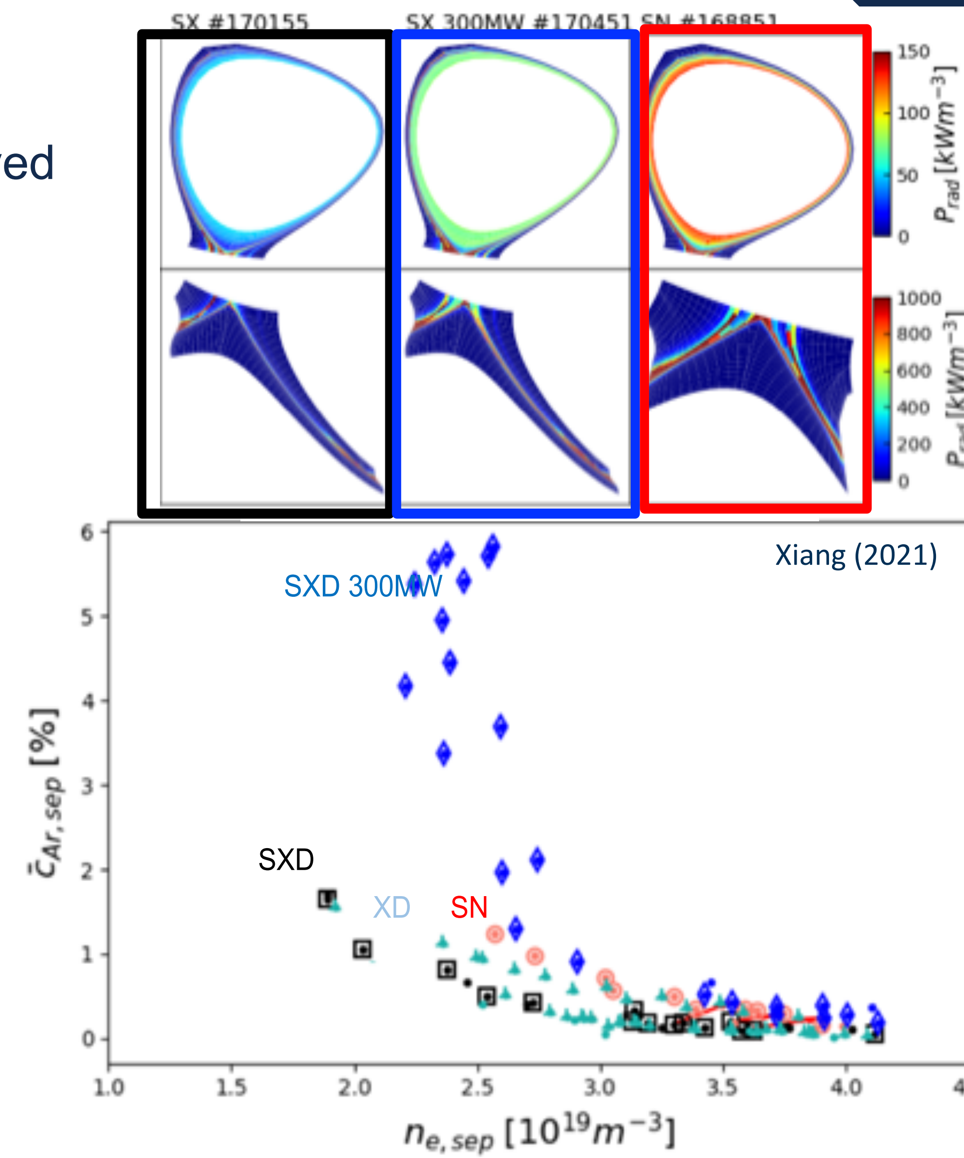
This is an example of a SOLPS DEMO calculation with alternative configurations.

Acceptable operations can only be achieved at high Ar seeding.

Radiation physics plays a major role in determining the operating regime.

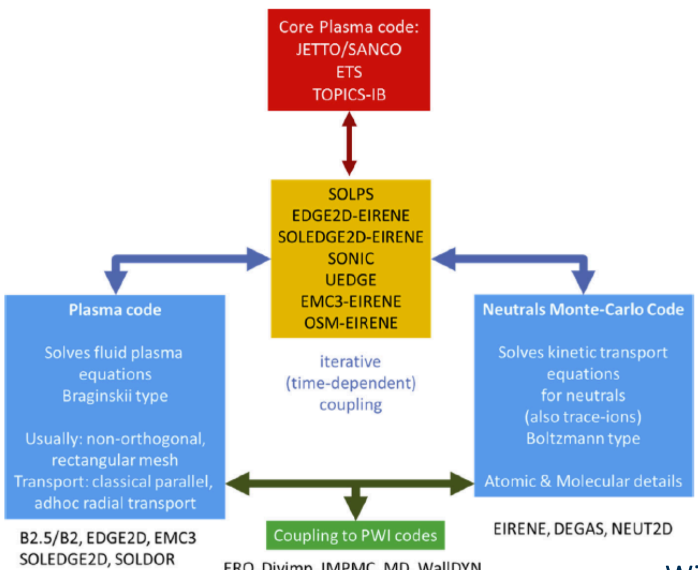



Militello (2021)

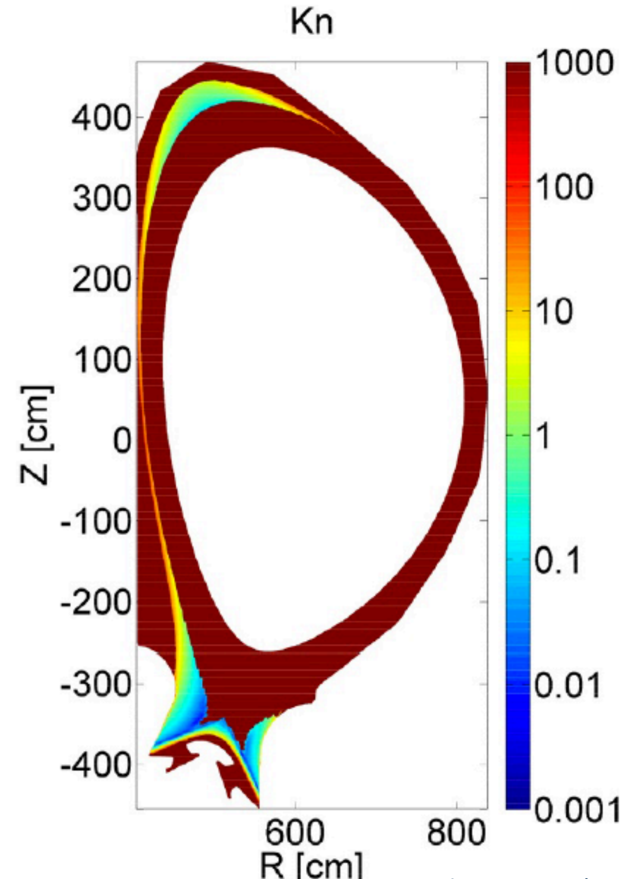


# Modelling challenges for reactors

- Integration for predictive modelling;
- Need for fast codes and a multi fidelity approach;
- Development of kinetic/fluid models;
- Error bars and uncertainty quantification;
- Filling the gaps in atomic and molecular data.



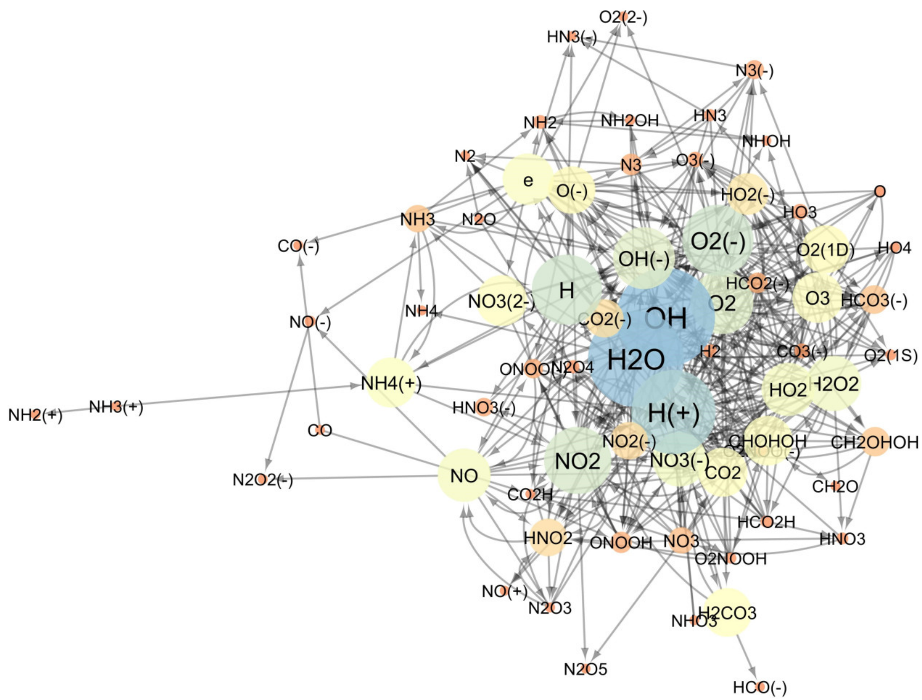

Wiesen (2017)




Valentinuzzi (2019)

# How can the Atomic and Molecular physics community help

- Improved data for:
  - Optically thick plasmas;
  - Kinetic collision operators;
  - Vibrational states;
  - Isotopes (T in particular);
- Data accessibility;
- Better wall models (reflection, absorption and adsorption; population re-injected);
- Help developing efficient codes.



# Summary and conclusions

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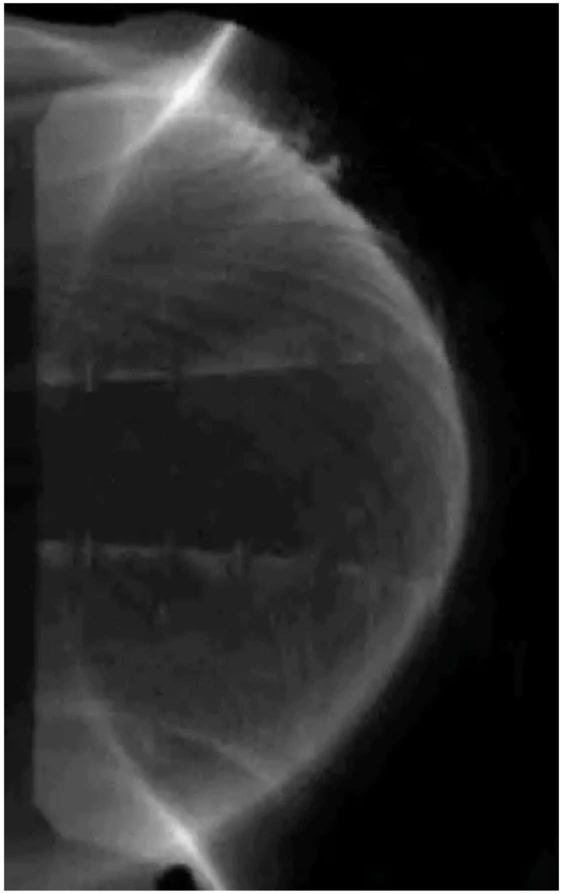
- Plasma exhaust faces new challenges as we move towards reactor physics.
- Boundary physics is a key factor in reactor design.
- Atomic and molecular processes determine many (most?) of the dominant boundary plasma mechanisms.
- The integration of atomic and molecular processes in reactor design needs to be efficient and requires accessible tools (appropriate fits, databases, etc.).
- There is (will be) a lot of effort on developing new tools in boundary physics and the atomic and molecular physics community can give an essential input.



Plasma filaments in MAST, showing the interaction between the plasma and the neutrals



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