Modelling of global impurity migration in tokamaks

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This talk is about...

1. How global impurity migration can be studied experimentally

2. Why modelling of the experiments is needed and what we can learn about it
Plasma-surface interaction leads to the generation of impurity particles

- Tokamaks usually large, complex machines $\rightarrow$ how can we study the migration of eroded impurities?

Plasma-surface interaction $\rightarrow$ erosion $\rightarrow$ impurities

ASDEX Upgrade tokamak in Garching, Germany
Trace-element injection experiments for studying global impurity migration

- Tokamaks usually large, complex machines $\rightarrow$ **how can we study the migration of eroded impurities?**
- **Solution:**
  1. Inject a tracer into the plasma
     - Example: $^{13}$C in the form of $^{13}$CH$_4$ (methane)
  2. Study deposition of the injected tracer on wall tiles
  3. Make conclusions
How does this happen in practice?
Inject the tracer from the region of interest

1. Injection of methane
What happens to injected methane in the plasma?

- For example:
  \[ ^{13}\text{CH}_4 \rightarrow ^{13}\text{CH}_3 \rightarrow \ldots \rightarrow ^{13}\text{C}^+ \]
- From molecules to ions

2. Dissociation of molecules
Released ions are transported in the magnetic field and plasma

- Interaction with the background plasma (hydrogen/deuterium)
Tracer is deposited on surfaces around the torus

4. Deposition at the wall
Prevent any disturbances
→ tokamak shutdown
Remove selected wall tiles for analysis (not all of them!)
Surface analysis on removed tiles results in a deposition profile

- So, we have done a controlled experiment that shows where injected impurities migrate
- Why do we need any complicated simulations then?

Modelling is needed to **understand** the experiment

- Why does the injected tracer migrate as observed?
  - What are the important physical mechanisms?

- Experimental results based on a few samples → do the samples represent deposition on all plasma-facing surfaces?

- What would happen in different experimental conditions?
Global $^{13}\text{CH}_4$ injection experiment on ASDEX Upgrade in 2011: lessons learned from modelling
Modelling is a large, joint effort

- Multiple specialised codes needed to include all relevant physics
  - Properties of the background plasma: temperature, density, flow velocity (*SOLPS code package*)
  - Dissociation of methane in the plasma: where are the carbon ions released? (*ERO code*)
  - Global transport of the released ions: how are the ions deposited on surfaces around the tokamak? (*ASCOT code*)
ERO predicts methane dissociation closer to the wall with increasing density

- Experiment of 2011 in a high-density plasma: dissociation likely occurred close to wall
Deposition of $^{13}\text{C}$ shifted from the divertor towards the main chamber with increasing density
ASCOT shows toroidally asymmetric $^{13}$C deposition near the injection location.

Toroidally symmetric → Toroidally asymmetric

Toroidally symmetric →

Typical experimental assumption:
Full toroidal symmetry!
Summary

- Trace-element injection experiment can provide insight into global impurity migration in tokamaks
- However, formation of a complete physical picture requires combining experimental observations with numerical simulations
- Modelling at Aalto & VTT has shown that
  - Impurity deposition pattern can exhibit toroidal asymmetry
  - Density dependence of molecule dissociation and global transport can shift deposition: divertor → main chamber
Thank you!