Innovative divertor development to solve the plasma heat-flux problem


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Outline

1. **Motivation:**

2. **Status:**

3. **Proposed plan:**
The bottom line: What you should remember

1. The GAP: solution to the excessive peak heat-flux on PFCs must be found for future fusion devices

2. Area is ripe for a Research Thrust to assess present new ideas and to generate others

3. Thrust needs to include experiments on existing devices, supporting theory/simulation and diagnostics, and device upgrades
The problem becomes very severe for future fusion reactors based on tokamaks.

The ARIES-ST reactor will have energy flux equivalent to the surface of the Sun (~ 60 MW/ m²).

At present, there are no clear solutions to the problem of handling such energy fluxes in divertors.

Novel ideas are necessary…
Various options are being considered

- **Snowflake divertor (Ryutov et al., this talk)**
- **Super X-divertor (Kotschenreuther et al., Wed.)**
- **Liquid metal divertor (Majeski et al., Thurs.)**
- **Boron-tungsten mesh (Wong et al., Thurs.)**
- **...**
Simplest Snowflake configuration just requires splitting of divertor poloidal coil into 2 coils

Poloidal plane

Currents

Poloidal flux surfaces

Near snowflake X-point, $B_{pol} \sim (r - r_x)^2$

Compare standard X-point, $B_{pol} \sim (r - r_x)$
Existence proof: Snowflake configuration tests in two tokamaks

Piras et al. PPCF ‘09 in TCV

Flux surfaces

(a) SF+

(b) SF

(c) SF-

Visible light

DIII-D shot 135564
Makowski, Osborne et al.
Snowflake configuration has several potentially important features

- Larger flux expansion in vicinity of X-point/divertor; increased wetted area, radiation volume (UEDGE modeling done)
- Long B-field-line length; lower $T_{ed}$, higher $n_{ed}$ for increased radiation effectiveness
- Larger Snowflake magnetic shear can increase ELM thresholds (Snyder, prelim.), and likely impact turbulence

Questions
- sufficient wetted-area increase
- stability of radiating zone
- net effect on ELMs/turbulence
- combine with other
- …
How should an Innovative Divertor Thrust be structured?

- 0-5 years: ideas are relatively young; evaluate multiple candidates
- 3-10 years: consolidate optimized scheme(s)
- 10+ years: next-step device(s)
How should an Innovative Divertor Thrust be structured?

- **0-5 years: ideas are relatively young; evaluate multiple candidates**
  - short-term experiments where possible to identify big +/-’s
  - enhanced simulation/analysis to
    - consolidate theory consensus
    - consider variations, combinations of ideas
    - validate models (or not) using experimental data
  - enhanced diagnostic effort to measure defining characteristics
  - cultivate international collaboration through all stages

- **3-10 years: consolidate**
  - Design/test optimized divertor for existing tokamak
  - Continue supporting theory/simulation/diagnostic support

- **10+ years: next-step device(s)**
  - Implement on next-generation device
  - Continue supporting activities
Such a Thrust should meet a number of requirements

- **Requirements for divertor characterization/qualification:**
  - Sufficient power to achieve edge ELM-generating pressure gradients
  - Diagnostics to measure PWI and SOL properties, turbulent transport including 2D heat flux; radiative loss, impurity content
  - Sufficient parallel heat flux to test limits on radiative dissipation and detachment
  - Equilibrium reconstruction to verify snowflake or other geometries
  - Particle exhaust control of global particle balance and diagnostics to quantify results
  - 2D/4D transport, 3D/5D turbulence, & near-surface transport simulation to validate with data

- **Requirements for core/edge integration:**
  - Capability for high-confinement, high-beta, and steady-state modes
  - High power capability, acceptable impurity levels for candidate materials
  - Sufficient core diagnostics to quantify: confinement, plasma purity, stability…
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