Simulations of Boundary Plasma in X-Point Target Divertor Configuration

M.V. Umansky, M.E. Rensink, T.D. Rognlien
Lawrence, Livermore National Lab, Livermore, CA 94550, USA

B. LaBombard, D. Brunner, J.L. Terry, D.G. Whyte
MIT Plasma Science and Fusion Center, Cambridge, MA 02139, USA

Presented at 1st IAEA Technical Meeting on Divertor Concepts
Sept. 29 – Oct. 02, 2015, Vienna, Austria
1. Modeling divertors with 2 X-points in arbitrary orientation

2. Initial simulations X-point Target Divertor (XPTD)

3. Comparisons between XPTD and a standard tilted-plate divertor with 1 X-point
Configurations with a secondary X-point in divertor considered by many groups in recent years; for example:

Cusp divertor [1]

Snowflake divertor [2; Soukhanovskii]

X-divertor [3]

X-point target divertor [4]

X-point target divertor is similar to the super-X divertor, but with the second X-point in the plasma volume.

- As Super-X, exploits $1/R$ geometric reduction of divertor heat flux
- May produce stable ‘X-point MARFE’ in the divertor chamber

Analytic model of $B_{pol}$ for two nearby X-points allows a topological classification of configurations.

- $\theta =$ angle between X-point bisector and horizontal axis
- Also mirror reflections of cases b,c,d,e

Divertor simulation codes must account for such topologies.
Upgrades to UEDGE include two arbitrarily placed X-pts: computational subdomains and mesh generation.

- $0 < \theta < 30^\circ$
- $30 < \theta < 60^\circ$
- $60 < \theta < 90^\circ$

Domain mapping
Upgrades to UEDGE include two arbitrarily placed X-pts: computational subdomains and mesh generation.
UEDGE is used to model both X-points in an XPTD for the lower half of up-down symmetric configuration

Mesh constructed by combining two lower-half single-null domains

Use UEDGE fluid transport model
- Fluid neutrals (inertial)
- Fixed fraction impurity radiation
- No drifts
- Four orthogonal target plates
- 100% recycling on all walls

Use geometry & parameters from LaBombard et al., NF 2015
- MHD equilibrium provided by MIT
- Density at separatrix $\sim 1e20$ m$^{-3}$
- Power into lower-half domain 1-5 MW
UEDGE is used to model both X-points in an XPTD for the lower half of up-down symmetric configuration.

Mesh constructed by combining two lower-half single-null domains.

Use UEDGE fluid transport model:
- Fluid neutrals (inertial)
- Fixed fraction impurity radiation
- No drifts
- Four orthogonal target plates
- 100% recycling on all walls

Use geometry & parameters from LaBombard et al., NF 2015:
- MHD equilibrium provided by MIT
- Density at separatrix $\sim 1e20 \text{ m}^{-3}$
- Power into lower-half domain 1-5 MW
A comparison divertor configuration (STPD) is used to assess effectiveness of the XPTD

- Same magnetic equilibrium as in the two-X-point XPTD case
- Vertical (tilted) divertor plates are added to reduce heat flux
- Simulation model the same
  - physics equations
  - boundary conditions
  - radial transport
Radial transport parameters are set to yield upstream SOL profiles projected from C-Mod

- Unity recycling on surfaces
- Using radially growing diffusing coefficient to match the expected density profile width ~5 mm
- Spatially constant $\chi_{e,i}$ is sufficient to achieve ~3 mm width of mid-plane $T_{e,i}$

### Mid-plane profiles

\[
D = \alpha \exp((r-r_{sep})/\lambda)
\]

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>0.25 [m$^2$/s]</th>
<th>$\lambda$</th>
<th>2 [mm]</th>
</tr>
</thead>
</table>

![Density profile graph]
XPTD: input power $P_{1/2} = 3$ MW, 1% neon impurity

- 3 of 4 legs attached
XPTD: input power $P_{1/2} = 2$ MW, 1% neon impurity

- Onset of widespread detachment
XPTD: input power $P_{1/2} = 1$ MW, 1% neon impurity

- Full detachment
Same 3 input-power sequence for the STPD
Comparison geometry, STPD: input power $P_{1/2} = 3$ MW, 1% neon impurity

- At 3 MW, both legs attached
Comparison geometry, STPD: input power $P_{1/2} = 2$ MW, 1% neon impurity

- At 2 MW, inner leg detached, outer leg attached
Comparison geometry, STPD:
input power $P_{1/2} = 1$ MW, 1% neon impurity

- At 1 MW most radiation above X-point => MARFE & disruption
The 2 X-point, long-leg XPTD provides lower peak heat flux and better divertor/core isolation than the STPD

- Reducing peak heat-flux to <10 MW/m² requires lower impurity concentration for XPTD, even without tilting plates
- XPTD provides a larger operating window in input power free from a core MARFE; radiation spread
- Multiple impurity species may optimize radiated power
Summary and conclusions

1. UEDGE upgraded to model divertors having 2 X-points in arbitrary orientation

2. Initial simulations performed for the X-point Target divertor (XPTD) using geometry and parameters from LaBombard et al., NF (2015)

3. Comparison of peak divertor heat-flux and detachment onset between XPTD and a standard tilted-plate divertor (STPD) shows:
   - XPTD orthogonal plate can operate at higher input power than STPD
   - Easier to achieve detachment than for short leg divertor
   - XPTD detachment front stays far away from the main X-point

Further studies will include

- tilting XPTD plates
- comparison to Super-X
- multiple impurity species, puff/pump scenarios
- density and transport variations, ...
X-point target divertor study is motivated by the ADX tokamak concept discussed at MIT PSFC

- ADX = Advanced Divertor and RF tokamak eXperiment*
- Designed to address critical gaps on pathway to next-step devices
- Advanced divertors
- Advanced RF actuators
- Reactor-prototypical core plasma conditions

*B. LaBombard et al., Nucl. Fusion 55, 053020, 2015.