UEDGE modeling of detached divertor operation for long-leg divertor geometries in ARC

M. Wigram[1], B. LaBombard[2], M.V. Umansky[3]
A. Q. Kuang[2], D. Brunner[2], J.L. Terry[2], T. Golfinopoulos[2], M.E. Rensink[3], D.G. Whyte[2]

[1]York Plasma Institute, Department of Physics, University of York, Heslington, York, YO10 5DD, UK
[2]MIT PSFC, Cambridge, MA 02139, USA
[3]LLNL, Livermore, CA 94550, USA

ARC (Affordable, Robust, Compact) Reactor

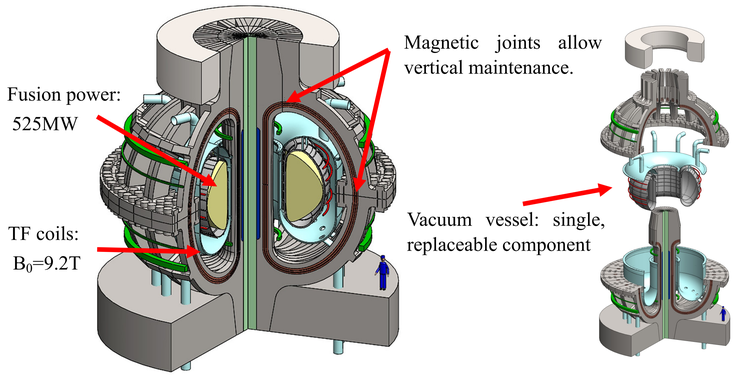

Figure 1: ARC reactor CAD model cross-section.[1]

- Compact demonstration MCF fusion power plant, ITER levels of fusion power at JET size. Possible through high magnetic fields, $P_{fus}/S_{wall} \propto RB^4$.[1]
- Employs REBCO superconducting TF coils, supporting resistive joints/ demountable coils.[2,3]
- Reduced size and cost with aim of realising fusion power in a much shorter time frame.

ARC Divertor

ARC divertor challenge: reactor-scale power in compact machine.

- ARC divertor has to exhaust 105 MW of power (assuming ~30% core radiation).
- Eich scaling: λ_q= 0.4mm - High, intense divertor power loading.[4]
- Advanced divertor geometry: double-null, long-legged, secondary X-point target.
- ADX divertor studies show improved performance of long-legged geometries, in particular X-point target.[5]
- Goal to model the X-point target divertor for ARC, determine power loading/detached regime.

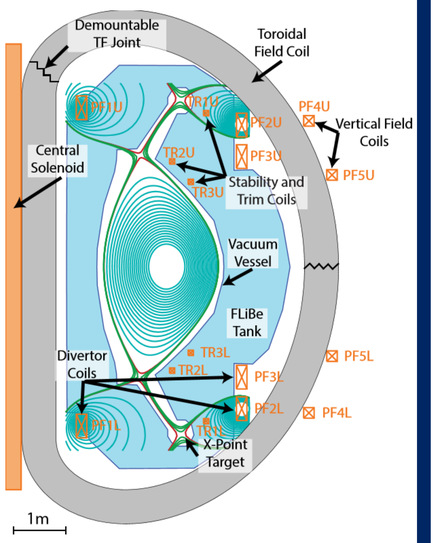

Figure 2: Proposed ARC X-point target divertor geometry, showing closed (blue) and open SOL (green) magnetic flux surfaces.[3]

UEDGE - SXD SOL model

Transport model:

- Parallel transport: flux-limited Braginskii fluid equations.
- Radial transport: diffusive thermal transport, particle transport given by:

$$\Gamma_\perp = -D\nabla n + v_{conv} n$$

- Values of D, v_{conv} and $\chi_{i,e}$ (Fig. 3) tuned to produce expected ARC I-mode midplane profiles (Figs. 4).

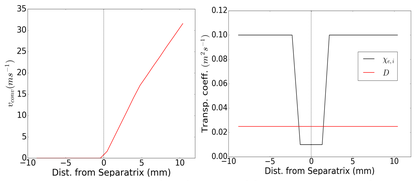

Figure 3: v_{conv} and $D/\chi_{i,e}$ profiles. Transport barrier implemented by drop in $\chi_{i,e}$ around separatrix.

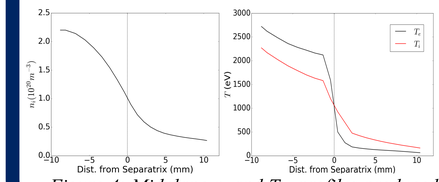

Figure 4: Midplane n_i and $T_{e,i}$ profiles produced for ARC I-mode model. λ_n~ 5.5mm, λ_q~ 0.6mm.

SXD grid:

- Modelled Super-X Divertor (SXD) geometry in UEDGE, study long-legged ARC performance.
- Double-null configuration, modelling half-domain.

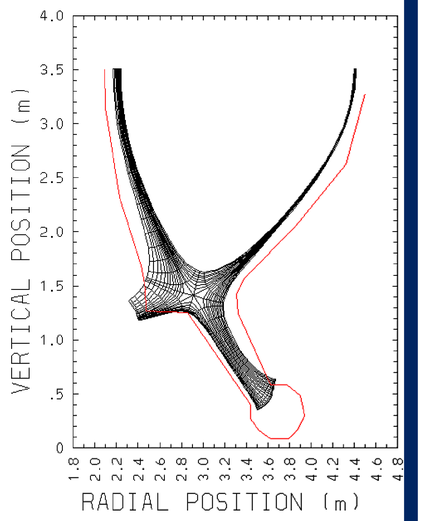

Figure 5: ARC SXD grid in UEDGE.

SXD produces stable detachment up to 92MW

No impurity

Detachment window P = 32-38 MW. Far too low for ARC operation.

0.5% Ne fixed-fraction impurity

Bifurcation of solutions:

- Cold branch - only accessible from a previously detached solution, detachment window P = 72-92 MW.
- Hot branch - accessible approaching from a high plate T_e, attached solution. No detachment.

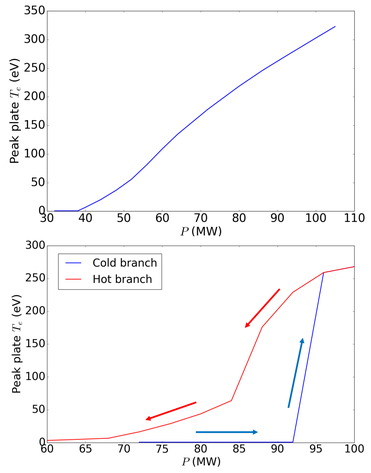

Figure 6: Peak outer target T_e vs input power P.

Power loading - Detached case

***P* = 88 MW, 0.5% Ne impurity, Cold branch**

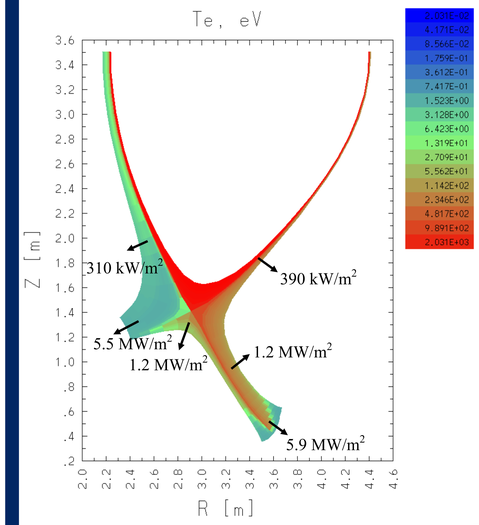

Figure 7: Te plot for detached P=44MW case, with combined plasma/radiation peak power flux densities to boundaries.

- Peak power flux density to target plates =5.9 MW/m^2
- Peak Ne impurity radiation emissivity = 600MW/m^3.

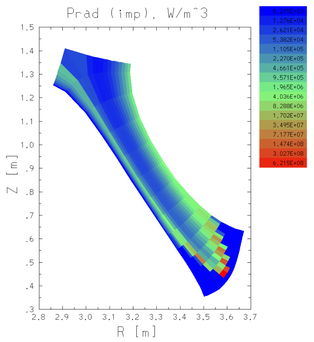

Figure 8: Neon impurity radiation emissivity.

Ongoing and future work

- Explore sensitivity to input parameters: impurity concentration, upstream density, cross-field transport models.
- Model various/multiple impurity species, track impurity transport.
- Model full ARC domain, with up-down asymmetries.
- Advance studies to full X-point target grid, for expected improved performance.

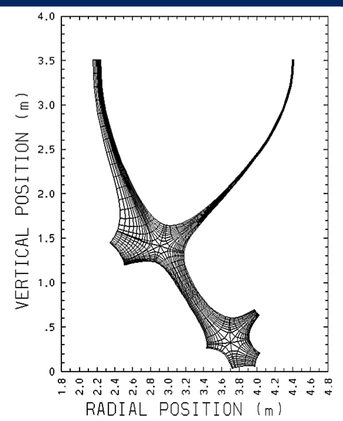

Figure 9: ARC X-point target grid in UEDGE.

References

[1] Sorbom, B. *et al*, *Fusion Engineering and Design*, **100**, 2015, pp378-405.
[2] Hartwig, Z. *et al*, *Fusion Engineering and Design*, **87** (3), 2012, p201.
[3] Barnard, H. *et al*, *Fusion Engineering and Design*, **87** (3), 2012, pp248-262.
[4] Eich, T. *et al*, *Nuclear Fusion*, **53**(9), 2013, 093031.
[5] Umansky, M. *et al*, *Physics of Plasmas*, **24**, 2017, 056112.

Massachusetts Institute of Technology
Lawrence Livermore National Laboratory
EPSRC Engineering and Physical Sciences Research Council