ID: PP12.00041

Predictions of heat and neutron loads onto FPP first walls in FUSE

G. Dose[*,a], G. Avdeeva[a], T. Cote[a], A.G. Ghiozzi[b], J. Guterl[a], J. Harvey[a], B.C. Lyons[a], J. McClenaghan[a], K. McLaughlin[a], O. Meneghini[a], T.F. Neiser[a], N. Shi[a], T. Slendebroek[b], D. Weisberg[a] and B.A. Grierson[a]

[a]*General Atomics, San Diego, CA 92121, USA*

[b]*Oak Ridge Associated Universities, 100 ORAU Way, Oak Ridge, TN 37830, USA*

**doseg@fusion.gat.com*

GENERAL ATOMICS

Abstract

Computational modules have been implemented in the FUsion Synthesis Engine (FUSE), General Atomics' framework for reactor design, to evaluate heat and neutron loads onto the first wall of a Fusion Pilot Plant (FPP). Three modules have been developed which compute respectively: the **neutron wall loading (NWL)**, the **core radiative wall loading (CRWL)** and the **boundary plasma wall loading (PWL)**. These modules allow for a quick evaluation (< 10 s) of the NWL, the CRWL and the PWL for different FPP designs.

The FUsion Synthesis Engine (FUSE)

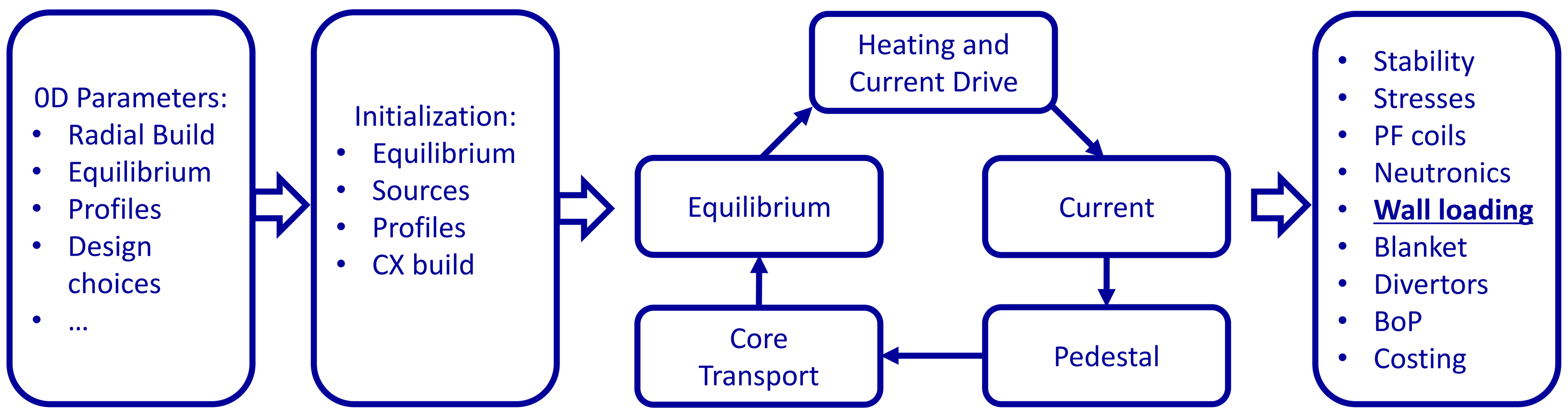
FUSE integrates first-principle models, machine learning, and reduced models into a unified framework, enabling comprehensive simulations that go beyond traditional 0D systems studies.

Reference:

Use cases:

- Integrated design of a FPP
- Pulse design (future)
- Plant flight simulator (future)

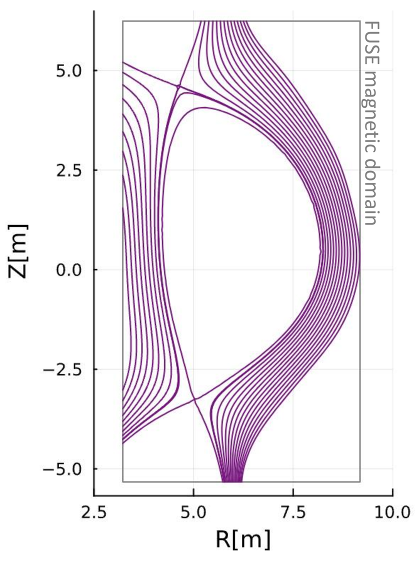
Example of a FPP design workflow



Become a (F)USER!

Methods: Mapping of the heat flux for the PWL

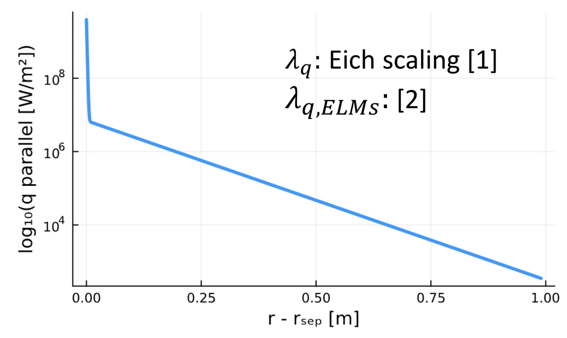
Magnetic equilibrium



+

Assumption of the parallel heat flux decay at the OMP

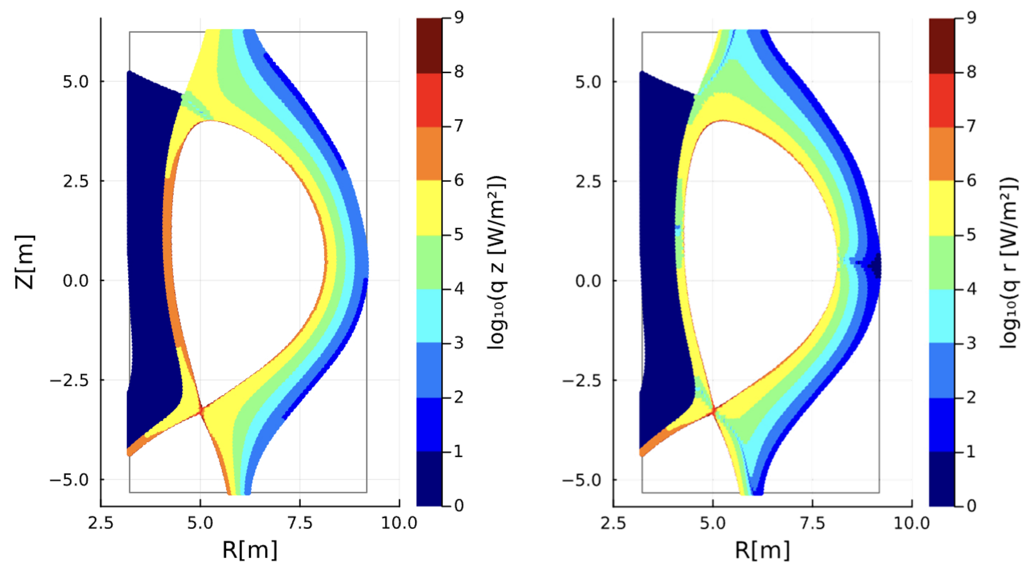
$$q_{OMP}(r) = \frac{P_{sep}}{4\pi R_{OMP}\lambda_q \sin\left(\frac{B_{pol}}{B}\right)} \exp\left(-\frac{r}{\lambda_q}\right) + \frac{P_{sep}\, f_{ELMs}}{4\pi R_{OMP}\lambda_{q,ELMs} \sin\left(\frac{B_{pol}}{B}\right)} \exp\left(-\frac{r}{\lambda_{q,ELMs}}\right)$$



Generally, a user-defined function. In this case, one uses a double exponential accounting for the heat flux decay in both near-SOL and far-SOL

=

Mapping of the poloidal heat flux over the volume



$$q_R(R,Z) = \frac{q_{OMP}(\psi(R,Z))}{F(R,Z)} \sin\left(\frac{B_{pol}(R,Z)}{B(R,Z)}\right)\left(\frac{B_R(R,Z)}{B_{pol}(R,Z)}\right)$$

$$q_Z(R,Z) = \frac{q_{OMP}(\psi(R,Z))}{F(R,Z)} \sin\left(\frac{B_{pol}(R,Z)}{B(R,Z)}\right)\left(\frac{B_Z(R,Z)}{B_{pol}(R,Z)}\right)$$

Where:

$$F(R,Z) = \frac{B(R,Z)}{B_{OMP}(\psi(R,Z))}$$

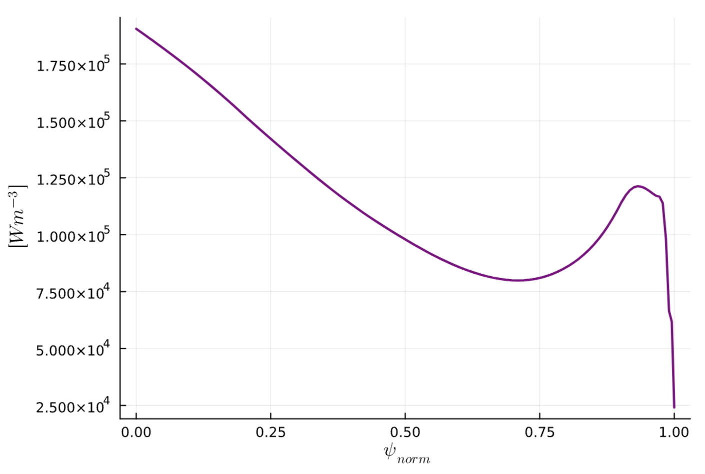
Total flux expansion (Alfven Theorem)

The heat flux on a wall segment with normal vector n_{wall} is computed as:

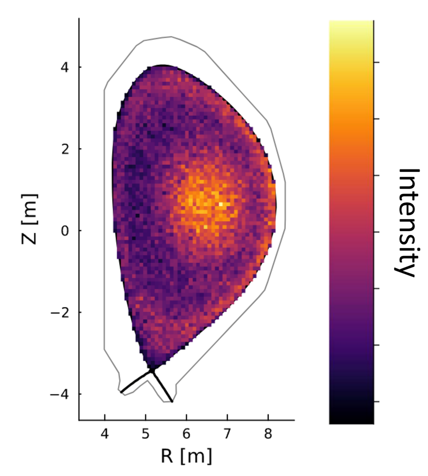
$$\boxed{\begin{aligned} q_{wall}(R,Z) &= q_{pol}(R,Z) \cdot n_{wall} \\ q_{wall}(R,Z) &= -q_R(R,Z)dz + q_Z(R,Z)dr \end{aligned}}$$

Methods: Particle tracker for the CRWL and NWL

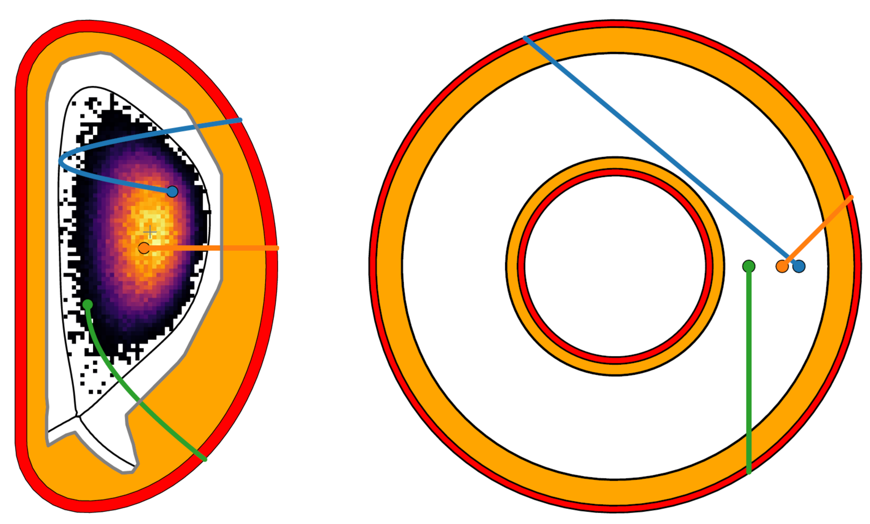
1D source profile from core solution



2D source in axisymmetric geometry



Particles are generated in all directions and tracked in the toroidal space up to the FW



Ballistic trajectories for:

- Neutrons
- Photons

Each particle deposits the same power. The flux is obtained dividing by the wall surface.

Caveats:

- NWL depends only on streaming neutrons
- No surface reflection

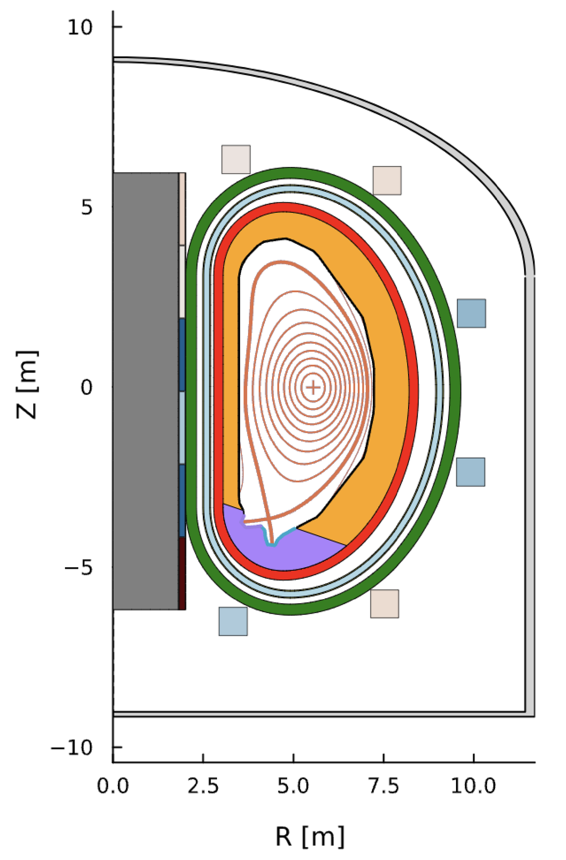
Results: Application for FPP design

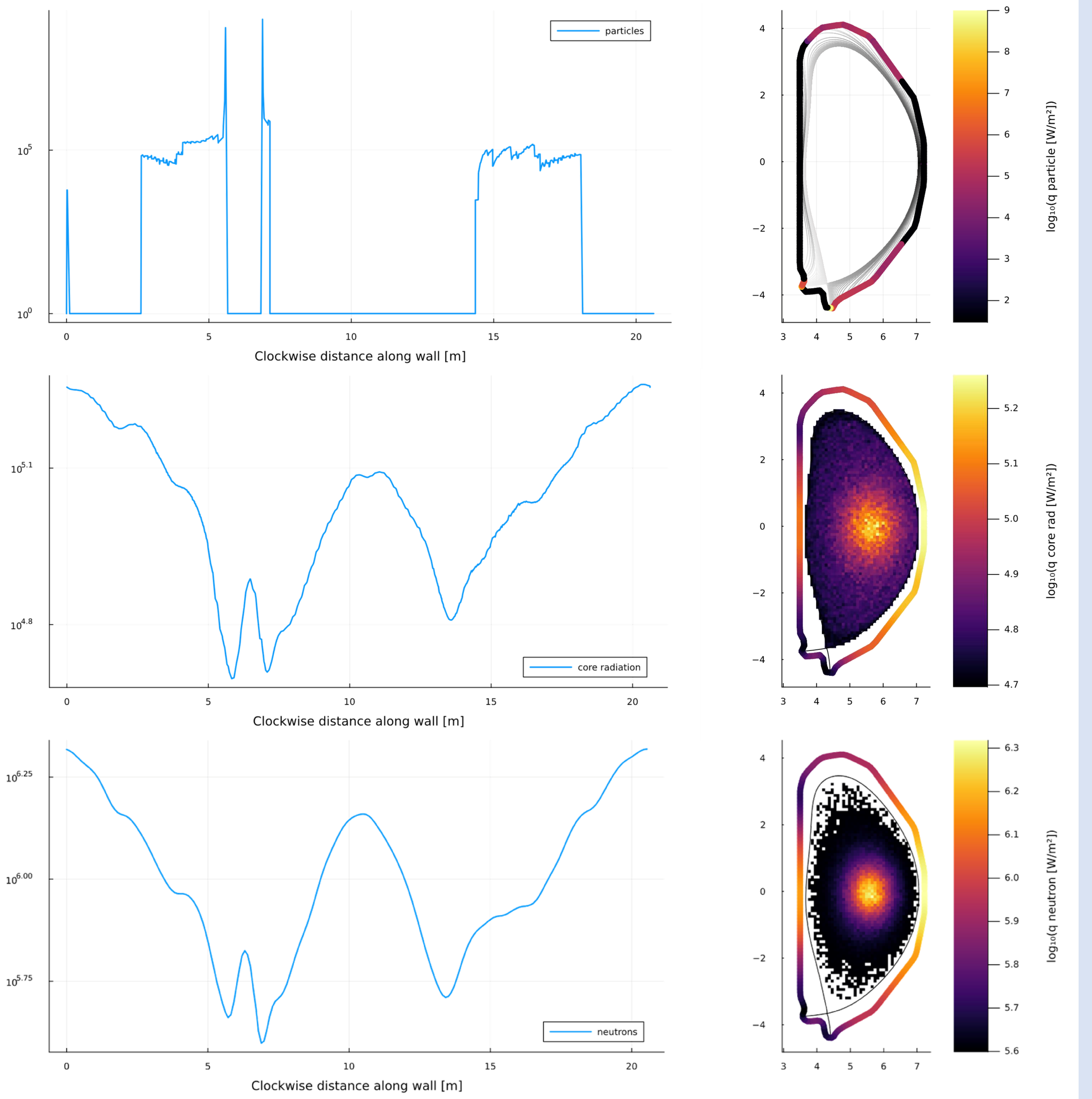
As a result of the FUSE workflow, one gets an integrated solution, such the one reported here

The Wall Loading is computed both in the 2D cross-section and along the curvilinear abscissa.

Example of a FPP design

B_0 [T]	6.19
I_p [MA]	16.5
R_0, a [m]	5.36, 1.65
κ,δ	2.04, 0.41
q_{95}	3.39
β_n	1.8
f_{GW}	0.95
Z_{eff}	2.0
Q	18.9
P_{fus}, P_{el} [MW]	969, 308
P_{SOL}, P_{aux} [MW]	165, 51.3
TBR	1.17





Conclusions and next steps

- The FUSE code has modules for the computation of the wall loading due to: neutrons, core radiation and plasma.
- Roughest approximation is for the divertor loads, due to the lack of neutral particles. For the same reason, radiation in the SOL is not computed.
- Next steps: 1. Fluid 1D SOL (onion skin); 2. Neutrals 2D; 3. Engineering: Does the wall survive due to this loads?

Acknowledgments and references

Work supported by General Atomics corporate funding.

[1] T. Eich et al., 2013 Nucl. Fusion 53 093031
[2] A. Loarte et al., IAEA FEC 2008
[3] O. Meneghini et al., arXiv:2409.05894v1 [physics.plasm-ph]