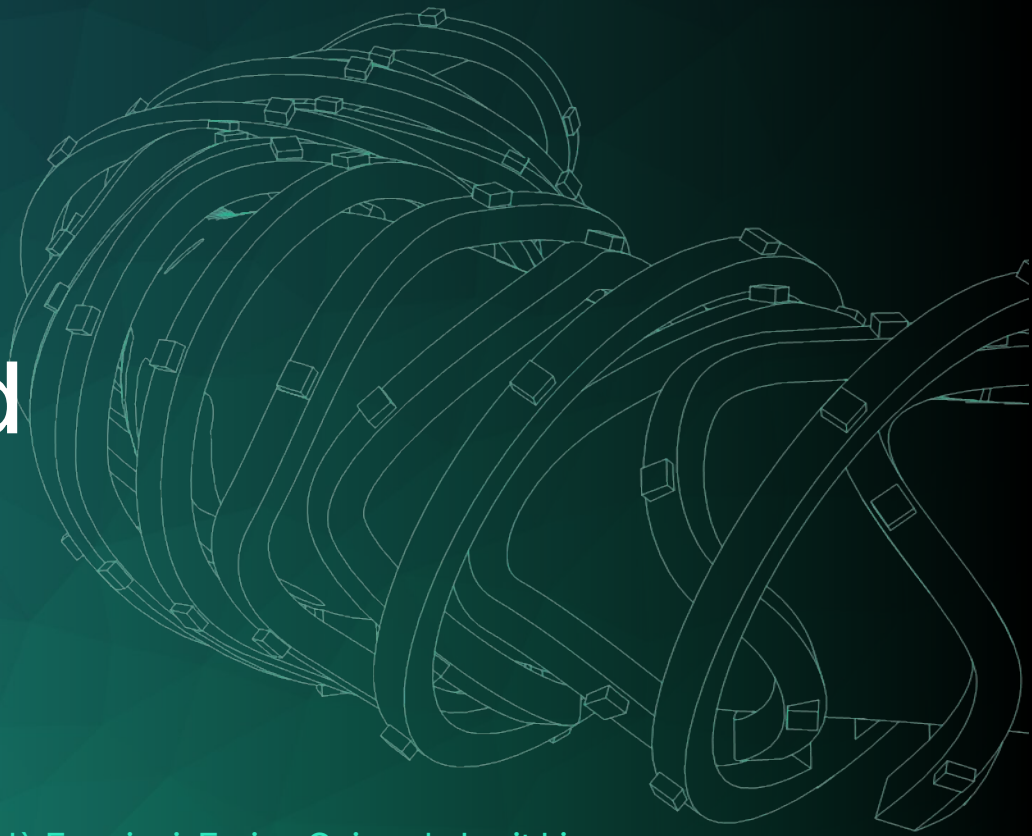
Proxima Fusion

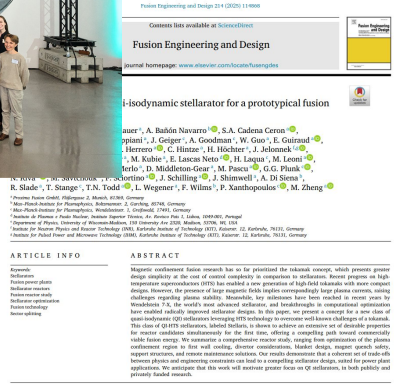
OpenMC usage and development for fusion simulations



Jon Shimwell, Rodrigo Herrero, Adam Urbanczk, Nicolò Foppiani, Enrico Guiraud, Jorrit Lion, Andrea Merlo, Jim-Felix Lobsien, Mikhail Khalizov, Victor Maurin and the Proxima Fusion team

Introduction to Proxima Fusion

- First spin-out from Max Planck Institute for Plasma Physics
- Europe’s fastest-growing fusion energy startup.
- 80+ world-class scientists, engineers and operators
- HQ in Munich with offices near Zurich and Oxford
- Developing a high-field Stellarator Model Coil (SMC)
- Targeting QI-HTS stellarators
  - Alpha, demonstration stellarator
  - Stellaris, first-of-a-kind power plant concept
- Published cohesive Stellaris paper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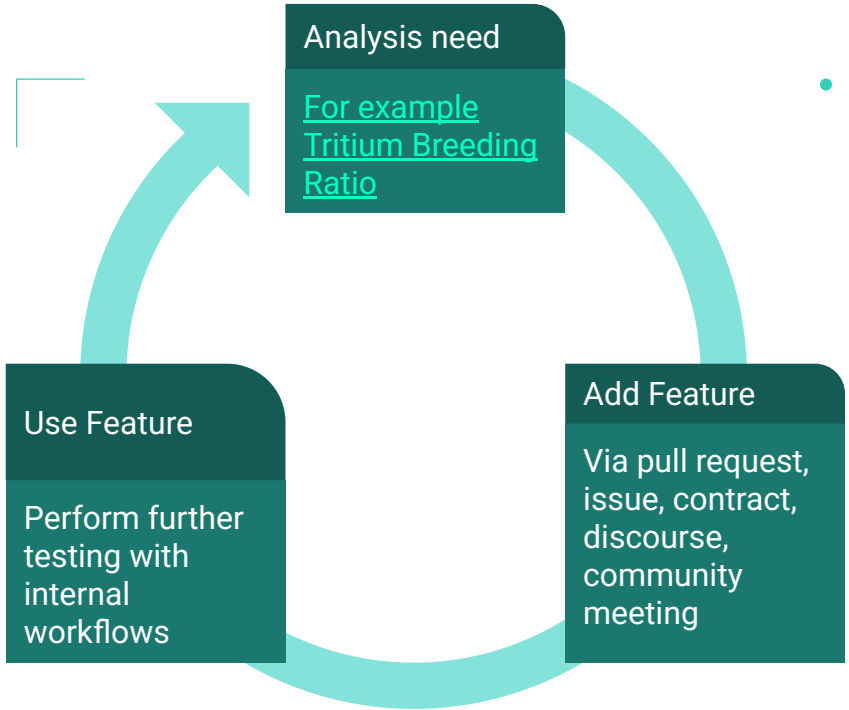
i-isodynamic stellarator for a prototypical fusion

ARTICLE INFO

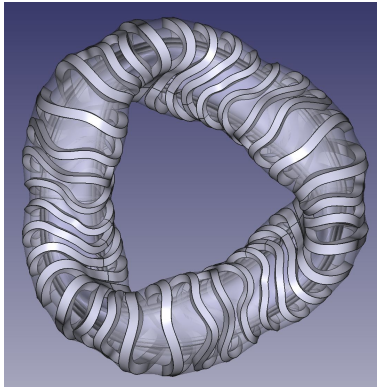
ABSTRACT

Prosumer

- Combination of code producer and code consumer.
- Useful role for accelerating application specific features into codebase.
- Provides additional level of feature testing.
- Main OpenMC contributor in Europe and 5th worldwide.
- Supporting wider neutronics tool chain (e.g. DAGMC, CadQuery)
- Contributions to code but also packaging deployment options (PIP, Conda, Docker)

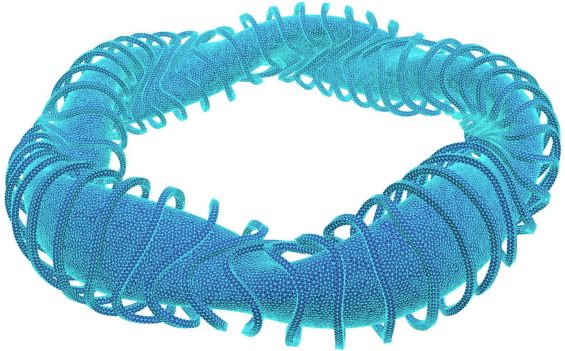


CAD to Mesh to Transport



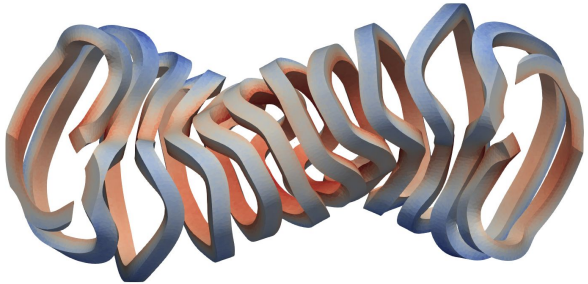
Code Parametric CAD

Using CadQuery to generate geometry from a design point in the database to a CAD model in a few minutes.



Volume and surface mesh

Cad-to-dagmc Python package allows user customisable mesh parameters and produces a DAGMC h5m geometry file.

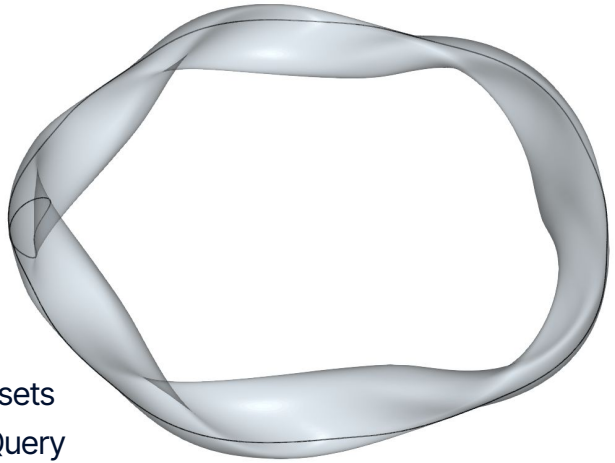


Neutron heating on the magnets

These particular magnets have a casing and core cells. Simulation outputs for optimisation include peak and total heat

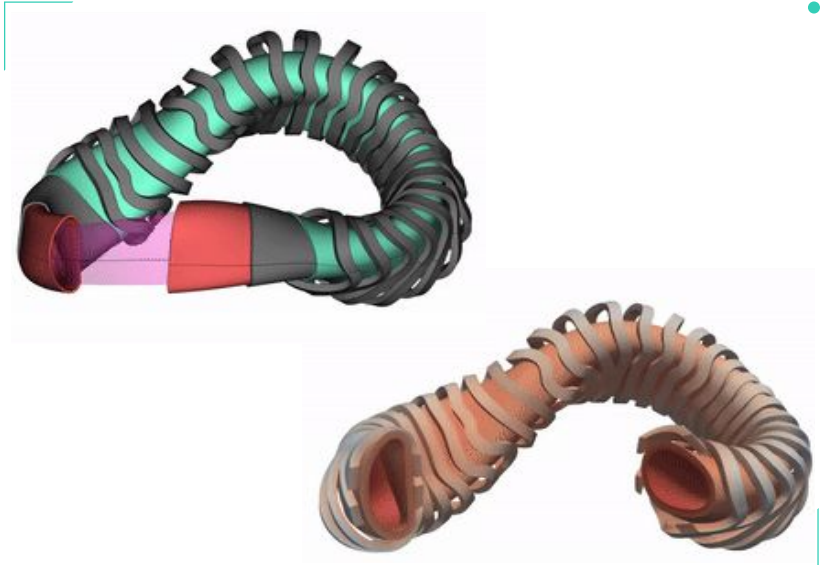
Example CAD Parameters

- Automated production of CAD
- Tested analysis ready CAD
- Single stellarator plasma
- Parameters varied:
  - Number of layers
  - Magnet width
  - Magnet depth
  - Magnitude of uniform offsets
- Created with open source CadQuery
- Imprinted or non imprinted faces



Parameter Study Example

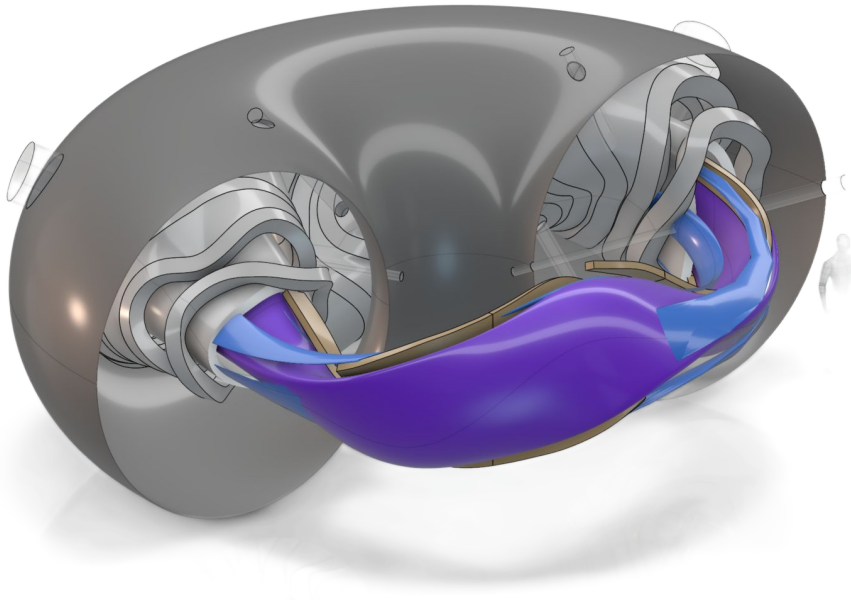
- Sweep of different uniform offsets between the first wall and the plasma.
- Outer layer kept at a constant position.
- Neutron heating recorded.
- Images generated with CadQuery and Paraview.
- All performed within a single Python script.



More complete CAD

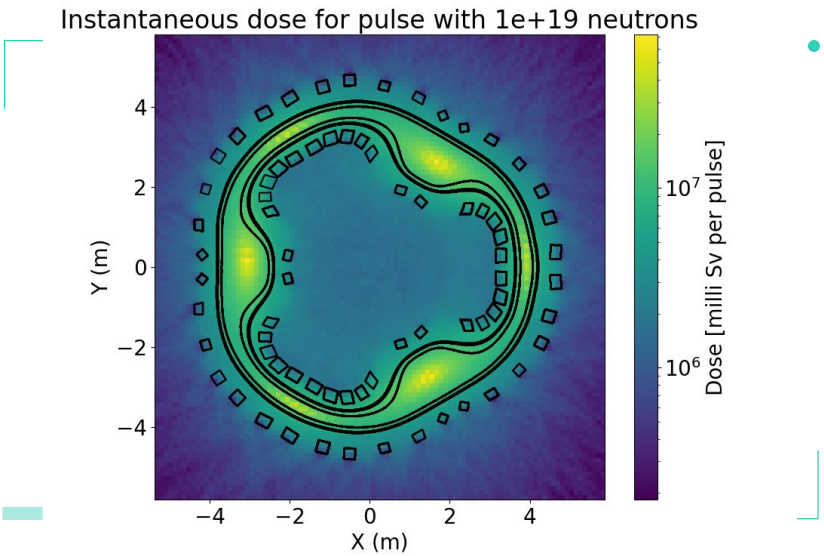
The parametric CAD models currently includes:

- Plasma and islands
- Radial build layers
- Magnets with casing
- Cryostat
- Ports
- Divertors
- Inter coil support structure



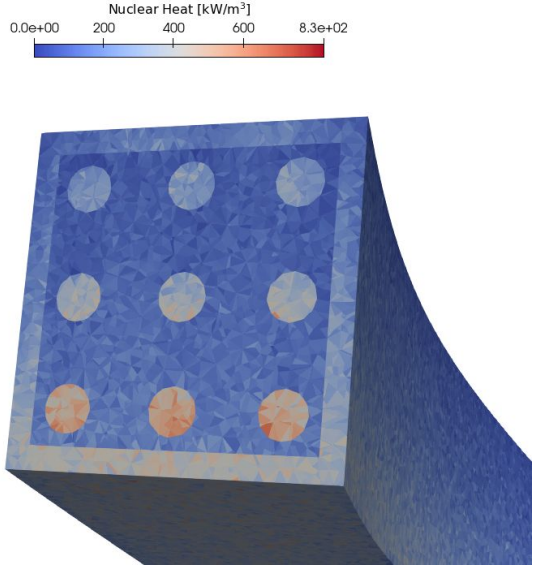
Instantaneous dose simulations

- Instantaneous dose simulations being performed for input into bioshield requirements.
- Combined neutron and photon dose.
- Hybrid model using CSG containing cell with DAGMC Universe for stellarator.
- Embree enabled
- Aiming for FW-CADIS based workflow



DAGMC surface and volume meshes

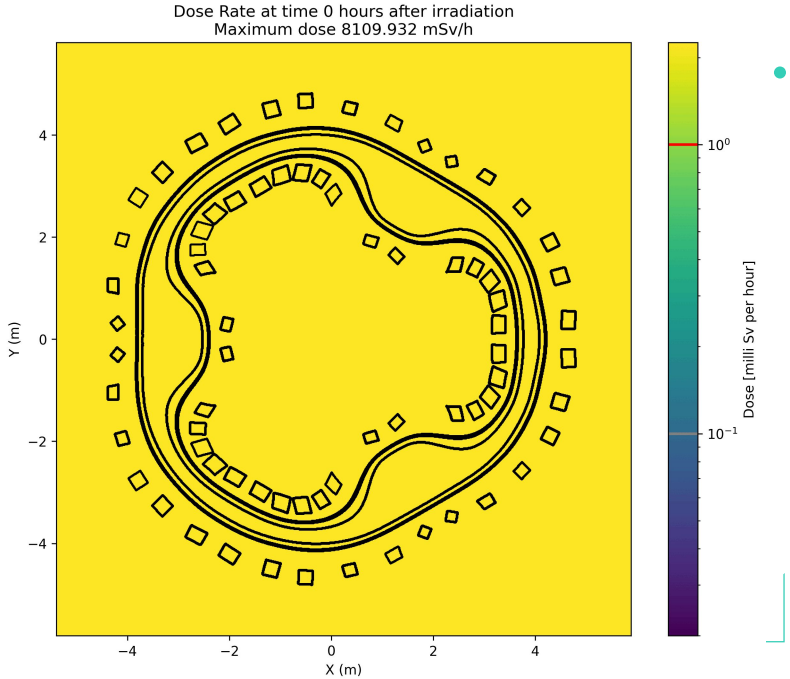
- Use of DAGMCUniverse for triangular surface mesh
- Use of UnstructuredMesh with MOAB for tetrahedral volume mesh
- Cad-to-dagmc able to produce volume meshes that matches the surface mesh
- Allows detailed simulation of magnet heat deposition (combined neutron and photon)



Note, this is geometry made to demonstrate the capability and not the actual magnet geometry.

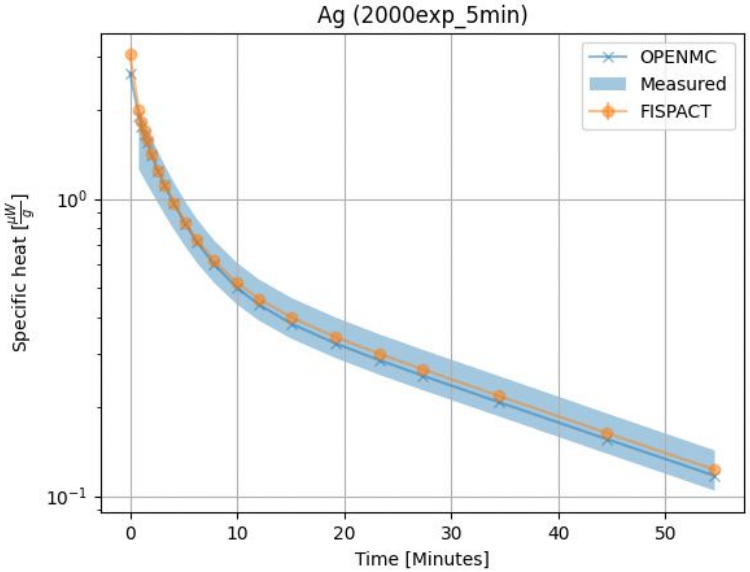
Shutdown dose rate simulations

- Dose from decay photons
- D1S method
- Hybrid DAGMC and CSG geometry
  - DAGMC for stellarator
  - CSG for bioshield and building
- Combining with FW-CADIS for bioshield simulation.



OpenMC Depletion verification and validation

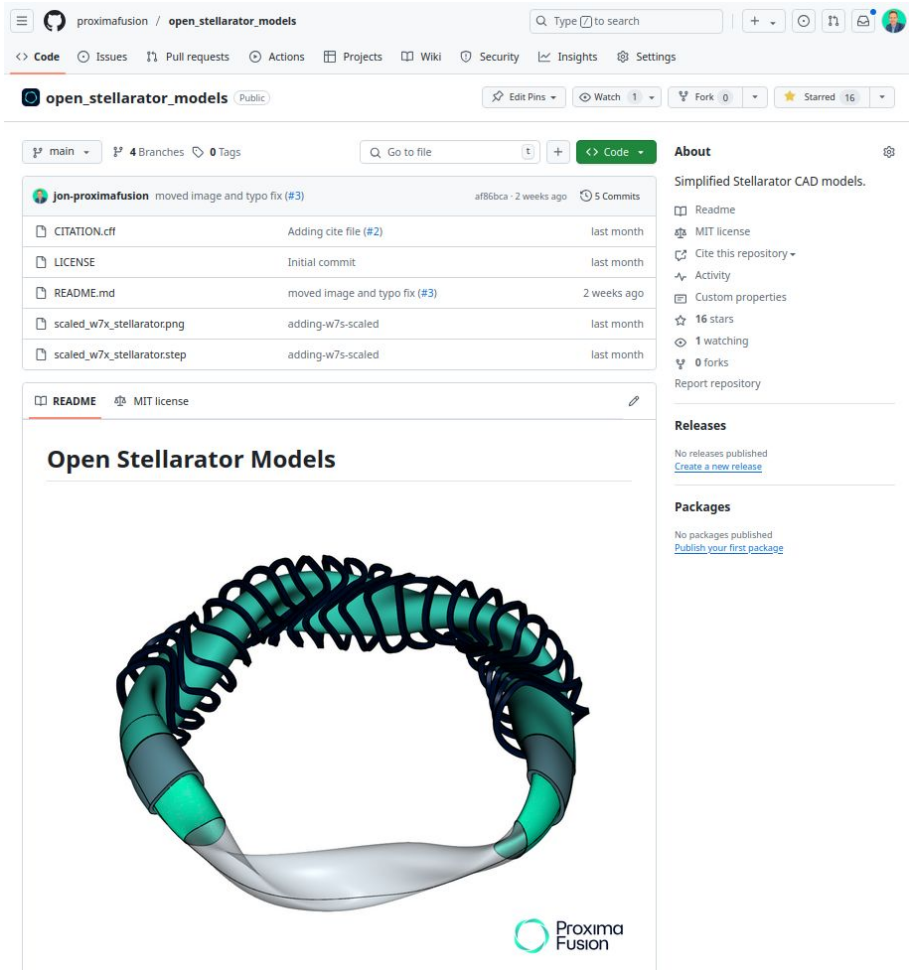
- OpenMC depletion function
- IAEA CoNDERC FNS Fusion Decay-Heat Benchmarks.
- Comparison with experimental result and inventory code (FISPACT)
- Neutron spectra combined with material definition for individual elements and materials.
- OpenMC-Activator OpenMC Activator by Jin Whan Bae
- PyPact by Thomas Stainer
- PR made to OpenMC



Images made with OpenMC-Activator

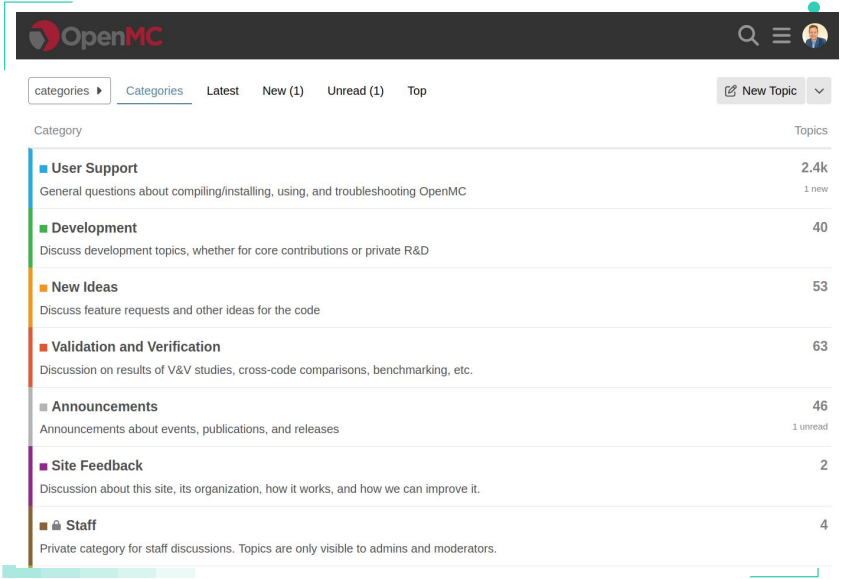
Open benchmarks

- Generic Stellarator model CAD geometry.
- MIT Licensed.
- On GitHub github.com/proximafusion/open_stellarator_models
- Useful for benchmarking and testing CAD based workflows.
- Large surface area relatively low number of surfaces.
- Ring source fits inside conveniently
- Planning to add more details and different stellarator types.



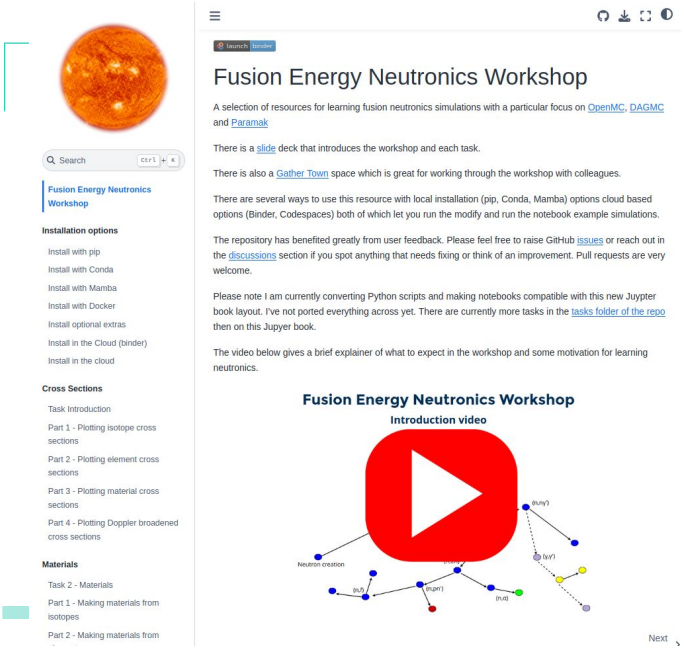
OpenMC Discussion Group

- Contributing to the OpenMC discourse group.
- Growing resource with answers to many common questions.
- Supports marking answers as solutions.
- Index by topic and searchable.
- People outside of ANL group with Admin responsibilities.



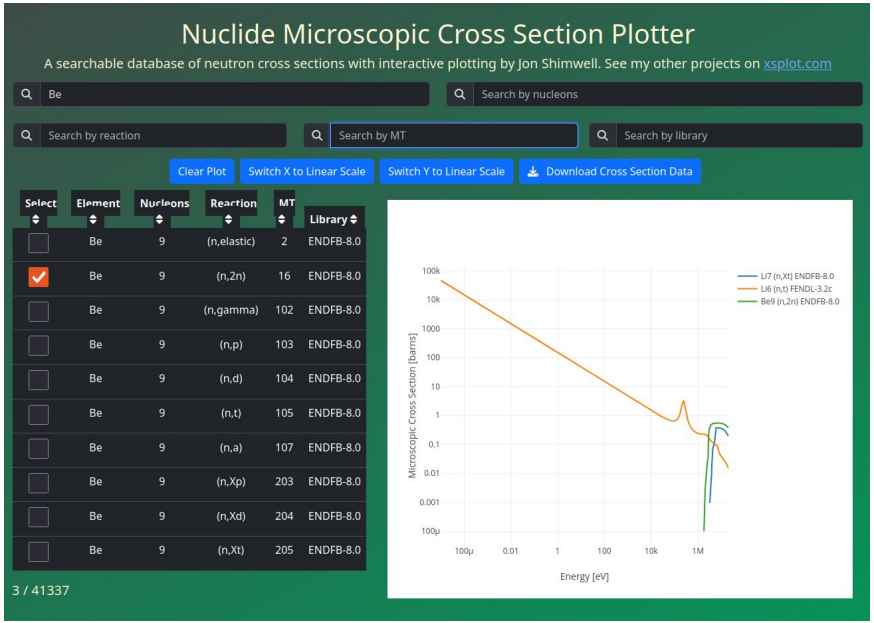
Training resources for OpenMC usage in fusion

- Reproducible minimal examples for many routine fusion analysis tasks
- Continuously developed since 2019
- Jupyter book https://fusion-energy.github.io/neutronics-workshop
- GitHub https://github.com/fusion-energy/neutronics-workshop/
- Popularity community resource with 15 contributors and 144 stars



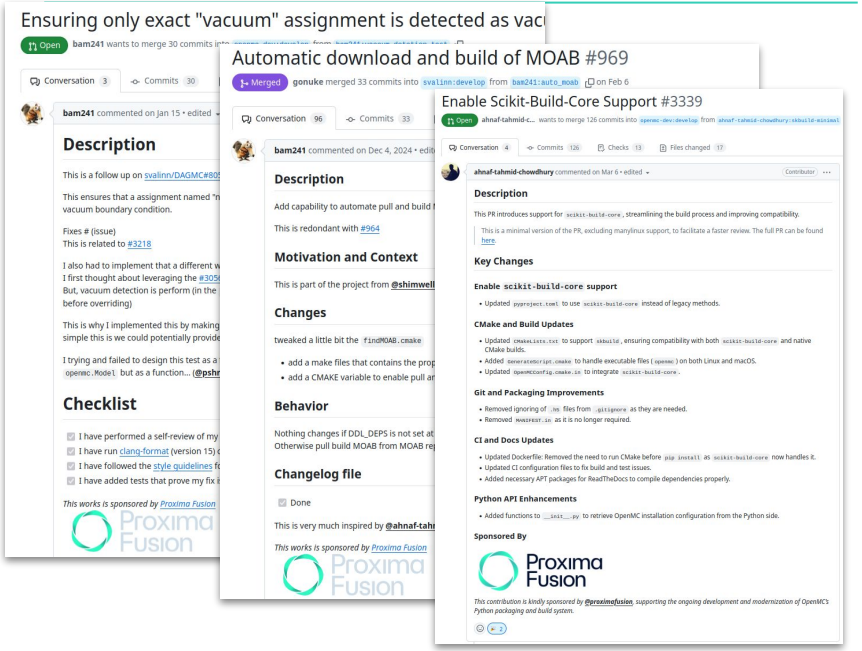
Application of OpenMC nuclear data

- OpenMC nuclear data format is particularly accessible compared to ENDF and ACE files.
- Processing OpenMC nuclear data to extract all reactions for multiple libraries.
- 40,000 plus nuclear data cross sections readily available from ENDF and FENDL.
- Online nuclear data explore using Rust WASM backend which runs in local browser.
- Allows mixed reactions and mixed isotopes plots.
- Raw data for the plot is downloadable.



Contributions to the Neutronics Community

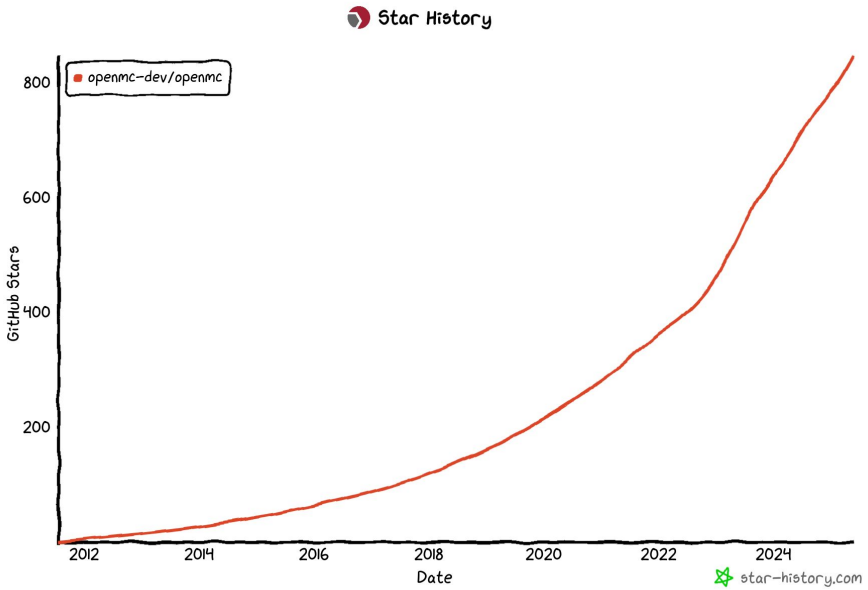
- Processing Nuclear Data (e.g. FENDL 3.2c)
- Processing decay data with full reaction channels
- Funding contractors for DAGMC and OpenMC development
- Contributing directly OpenMC
- OSSFE helping organise and sponsoring 2025 conference, hosting 2026 conference.
- Funding two core CadQuery developers for improvements, features and maintenance.
- Continuous development of the fusion energy neutronics workshop with example simulations



Example pull requests by sponsored developers Ahnaf-tahmid Chowdhury and Baptiste Mouginot

Discussion points for consideration

- JSON serialisable OpenMC classes. Eases integration of OpenMC into workflows.
- Accurate metastable state production by accounting for incident energy.
- Openmc.org revamp with more nuclear data libraries and chain files available as downloads. Open repo that accepts PRs?
- PIP install with the optional packages such as DAGMC.
- Conda install for develop branch.
- Review backlog ideas. Hackathons. OSSFE



Summary

- Automated CAD core to large scale concept exploration strategy.
- Neutronics simulations well integrated into the reactor workflow.
- Using and developing the latest software tools to carry out modern neutronics analysis.
- Neutronics simulations run automatically as part of design analysis.
- Proxima is contributing to the neutronics ecosystem.
- Team is able to avoid common neutronics issues such as working on models that are out of date.