3D machine descriptions meeting June 4 2009

RECENT EXPERIENCES WITH CAD TO NEUTRONICS AND PHYSICS CODE CONVERSION

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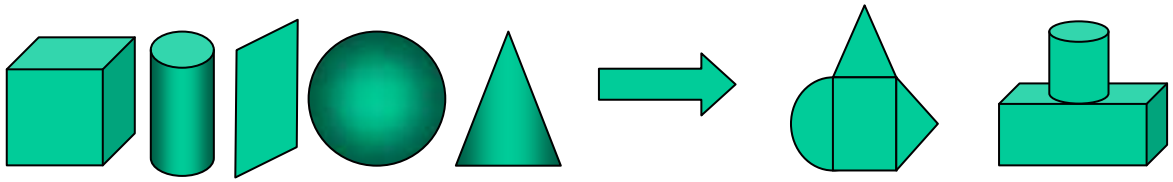
Overview of presentation

- Brief Introduction to CAD concepts (CSG, BREP, NURBS, repair, defeature)
- CAD to Neutronics software input
- CAD to Physics code input
- Example1: Complicated ITER duct model
- Example 2: Simple ITER duct model

Conversion: geometry types

Constructive
Solid
Geometry



$$ax^2+by^2+cz^2+2fyz+2gzx+2hxy+2px+2qy+2rz+d=0.$$

3D MC codes use combinatorial geometry of first- and second-order surfaces e.g. plane, cone, sphere, ellipse, cylinder etc (and fourth-degree elliptical tori). These are then used to develop 'cells' using Boolean operations which can be used to develop a more complex geometric cell.

No explicit definition of a solid surface boundary

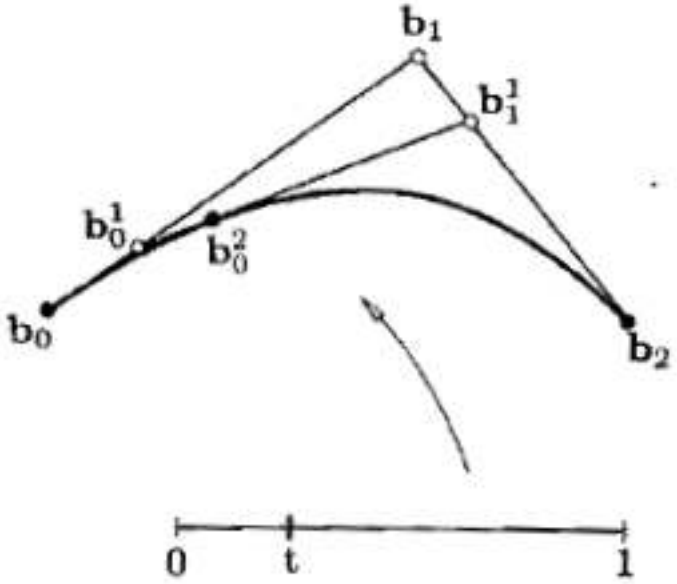
Boundary
REPresentation

Boundary representation (B-REP) solids are represented in terms of individual surfaces, edges, and vertices (and their relationship). Can be thought of as an entity made up of one or more surfaces that can be joined along shared edges.

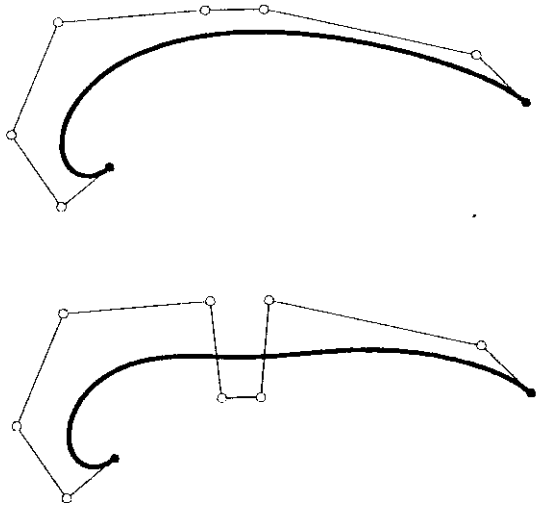
CAD kernels such as Parasolid (e.g. Solidworks) and ACIS (e.g. Autocad) use this representation.

Complete description of a solid surface boundary

How CAD is produced - lines



- Bezier spline curve defined by control points b*i*



- Move control points to adjust shape of curve, which remains smooth

NURBS

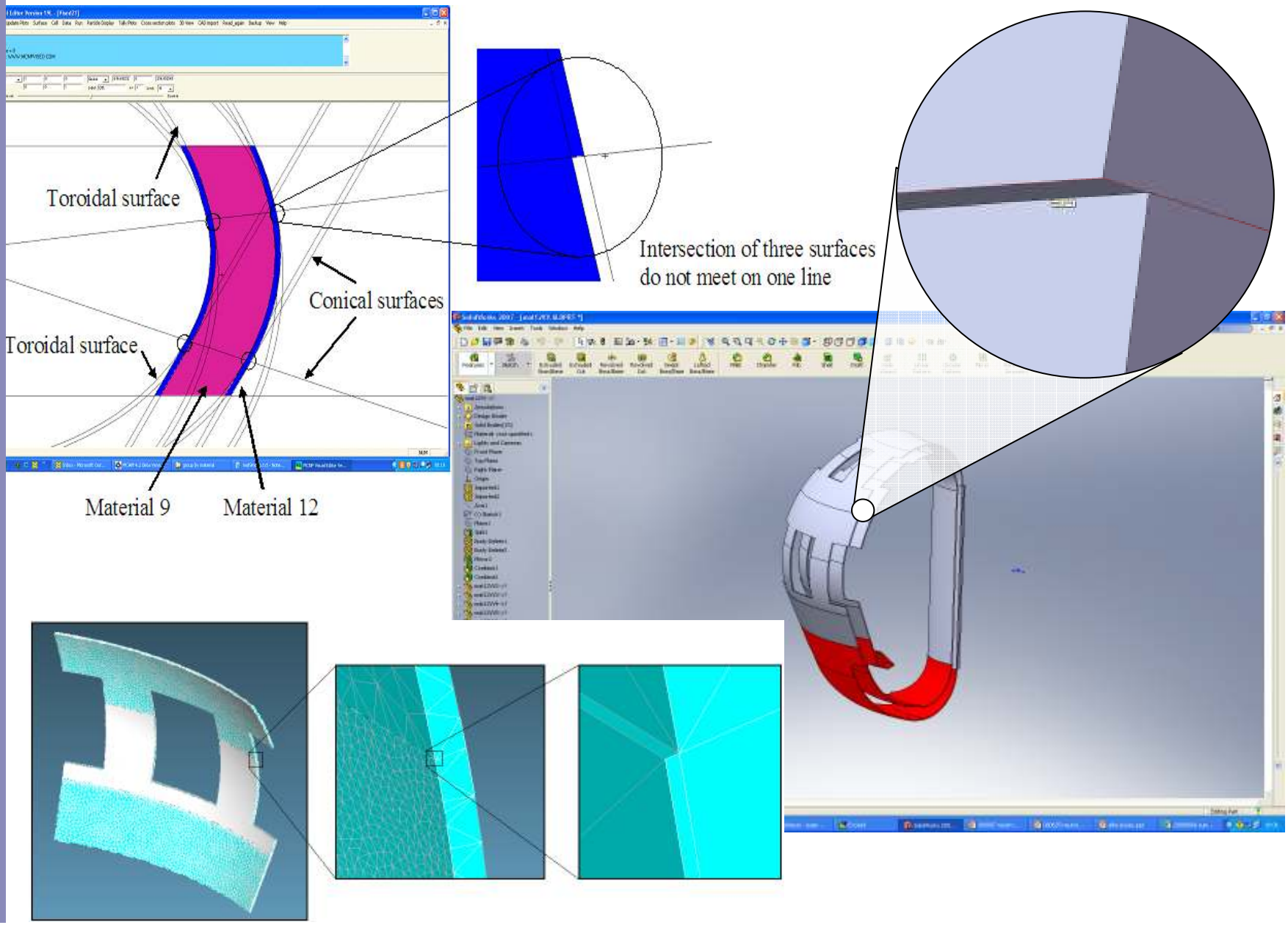
NURBS stands for non-uniform rational B-splines.
The ‘non-uniform’ and ‘B’ aspects are technicalities.
Spline property ensures curves are smooth.
‘Rational’ means that the representation uses rational polynomials.
Quadratic NURBS represent the conic sections (e.g. ellipses) exactly.

To illustrate this feature of quadratic NURBS, recall that the unit circle

$$x^2 + y^2 = 1 \quad \text{parameterises as} \quad x = \frac{(1-t^2)}{(1+t^2)}; \qquad y = \frac{2t}{(1+t^2)}$$

It may be shown that cubic NURBS allow exact representation
of all the quadric surfaces (e.g. ellipsoids and cones).

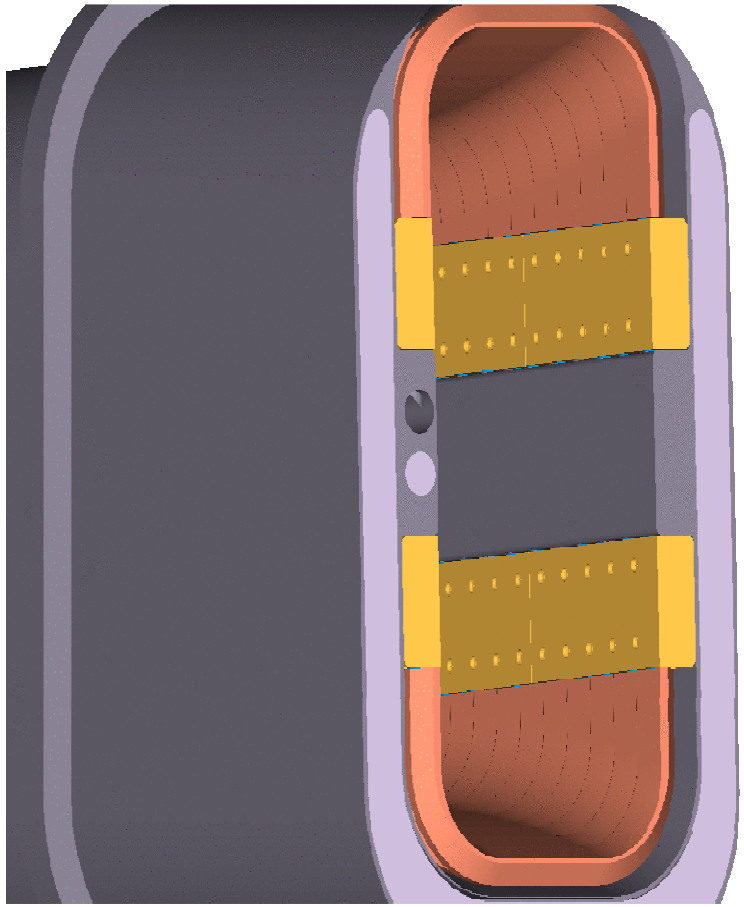
CAD repair operations: problem with vacuum vessel component



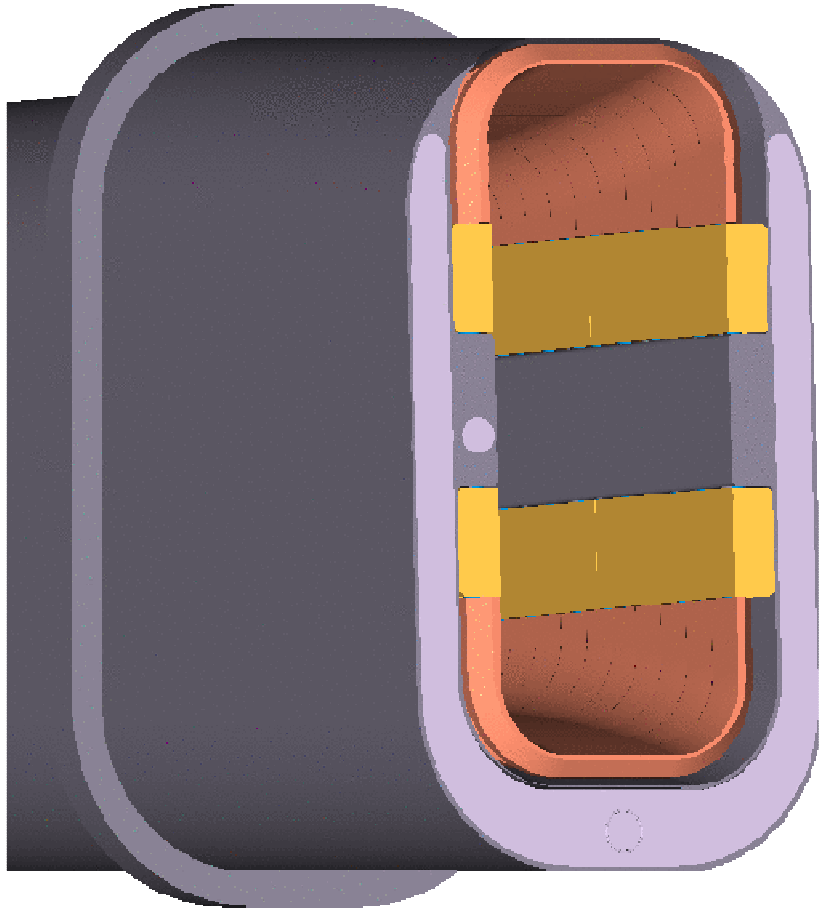
CAD defeaturing – unwanted small holes in CAD

UKAEA Fusion

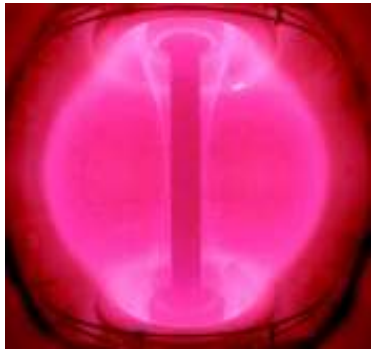
Before – small holes

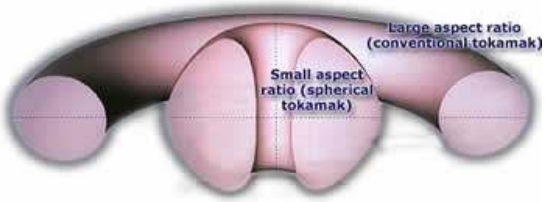


After - removed

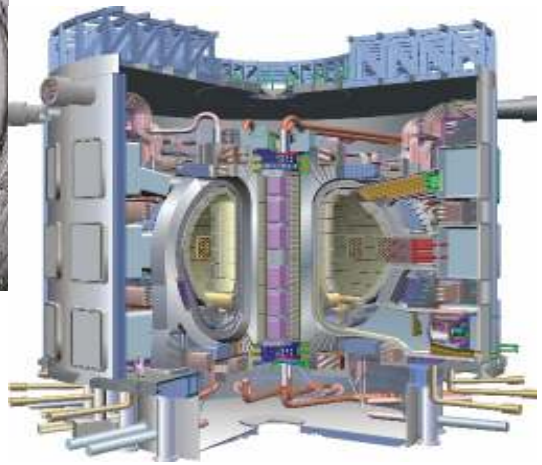


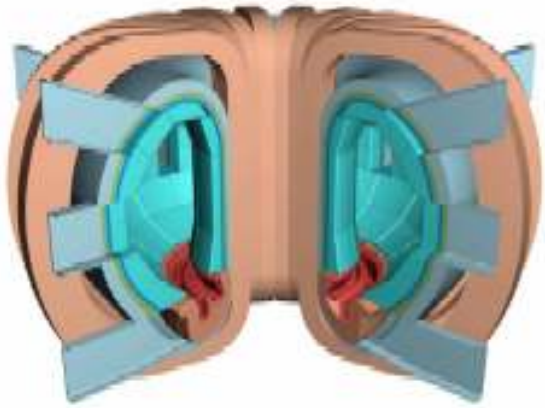
Neutronics analysis carried out at UKAEA in support of:





- MAST: Mega Amp Spherical Tokamak – UK domestic facility
- JET: Joint European Torus – currently holds record for D-T power production
- ITER: Scheduled to be built in Caderache, France
- DEMO: Conceptual power plant to demonstrate feasibility of fusion power production and tritium generation



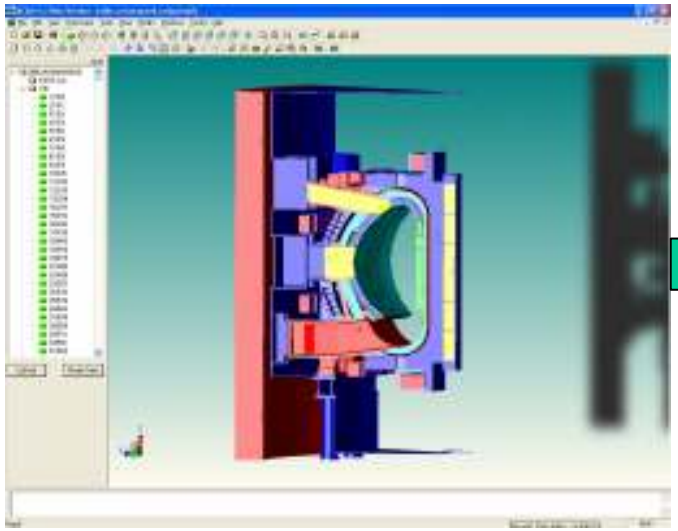


Requirements for neutronic analysis in fusion

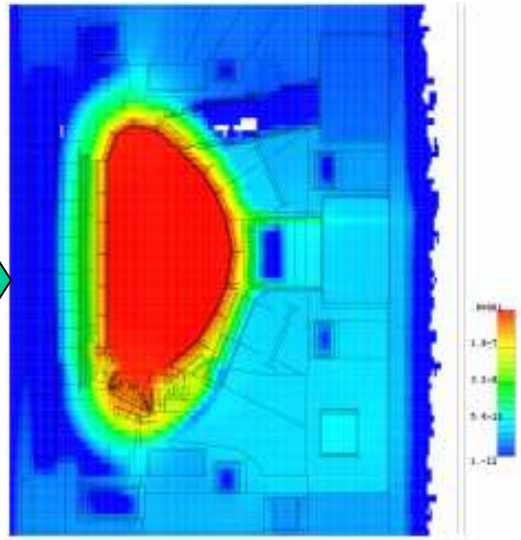
UKAEA Fusion

- Radiation transport codes - Mainly use MCNP5, MCNPX and Attila.
- Transmutation/decay code – FISPACT.
- Fusion evaluated nuclear cross section data e.g. FENDL 2.1 and EAF data.
- Complex geometries encountered often involving many design iterations and the need for delivery of neutronic analysis within a short time frame mean that CAD conversion software is highly desirable (and methods to speed up the transport calculations).

CAD drawings



CAD to MC format conversion



Neutronic deliverables

Some geometry conversion approaches

UKAEA Fusion

- Develop geometry within a CAD environment and export as CSG for input to MCNP using conversion software.
- Develop model within a CAD environment and save as BREP for input to Attila calculation (Attila has bundled tet-mesher)
- Develop model within a CAD environment and 'voxelize'/tet-mesh geometry for MCNP5/X calculation.
- Use modified MCNPX source code with CAD engine (e.g. DAG-MCNPX) – approach taken by University of Wisconsin.

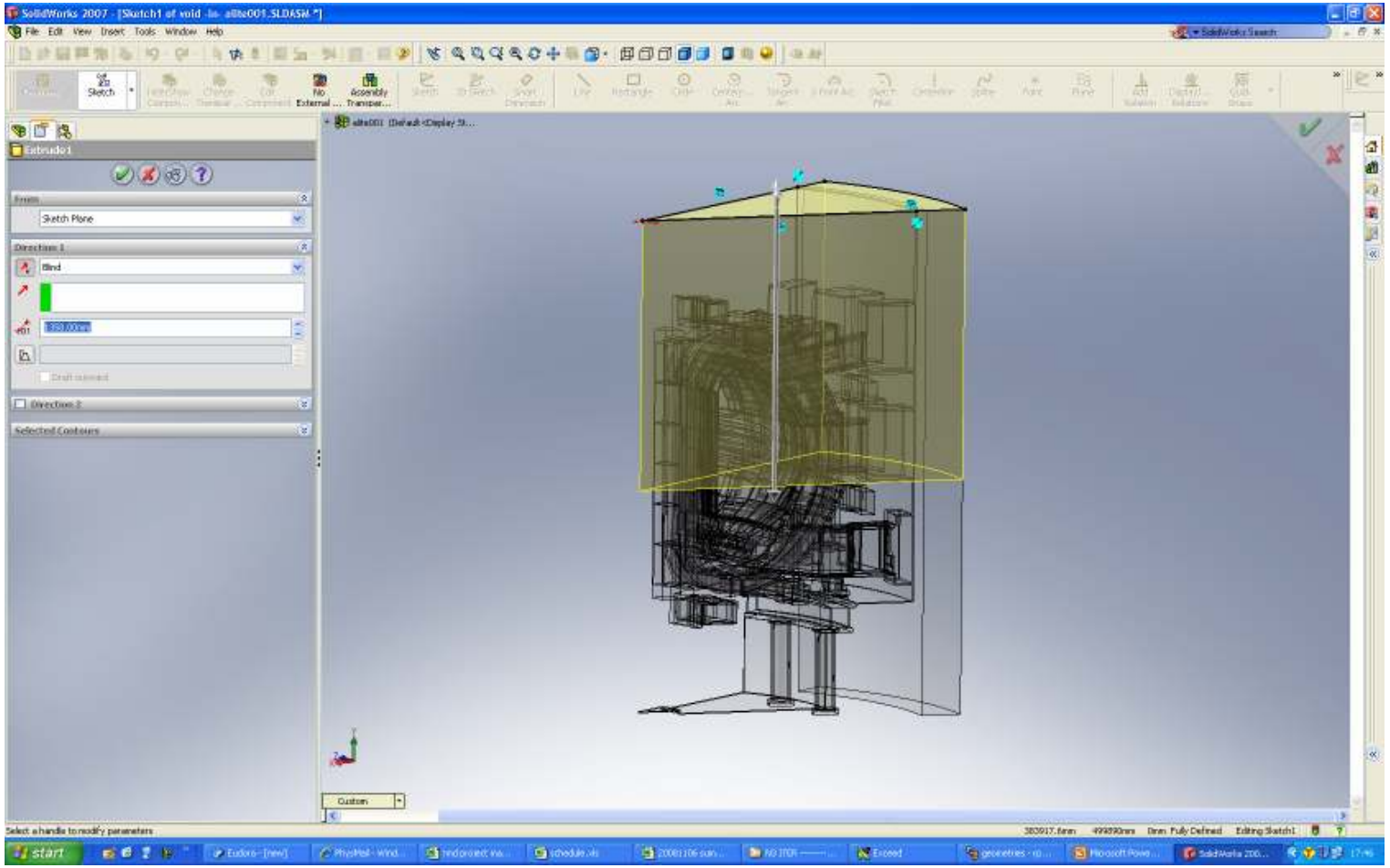
It is also desirable to compare calculations using different transport codes and models, so we need to

- Convert geometry suitable for Attila (BREP) into CSG for MCNP – may require defeaturing and/or simplification.
- Convert CSG geometry model into BREP suitable for meshing and Attila calculation.

CAD to MCNP (BREP to CSG) geometry conversion software

- **MCAM**, CAD-MCNP interface (Chinese Institute of Plasma Physics, Fusion Driven Subcritical (FDS) system team).
- **VISUAL EDITOR** (VISED), CAD format conversion to MCNP (Visual Editor Consultants, R. Schwarz).
- **GEOMIT**, based on an SQL database (JAEA).
- **ANSYS** FEM software (mainly used for structural, thermohydraulic and elecromagnetic analysis).
- **MCCAD** CAD-MCNP interface. GUI under development. (FZK-Euratom, Forschungszentrum Karlsruhe, Institut für Reaktorsicherheit, Germany)
- **DAG-MCNPX**, Direct Advanced Geometry Monte Carlo (DAGMC - not a CAD to MCNP conversion approach) requires CUBIT (SNL) and modified version of MCNPX. Version not released widely. (University of Wisconsin).

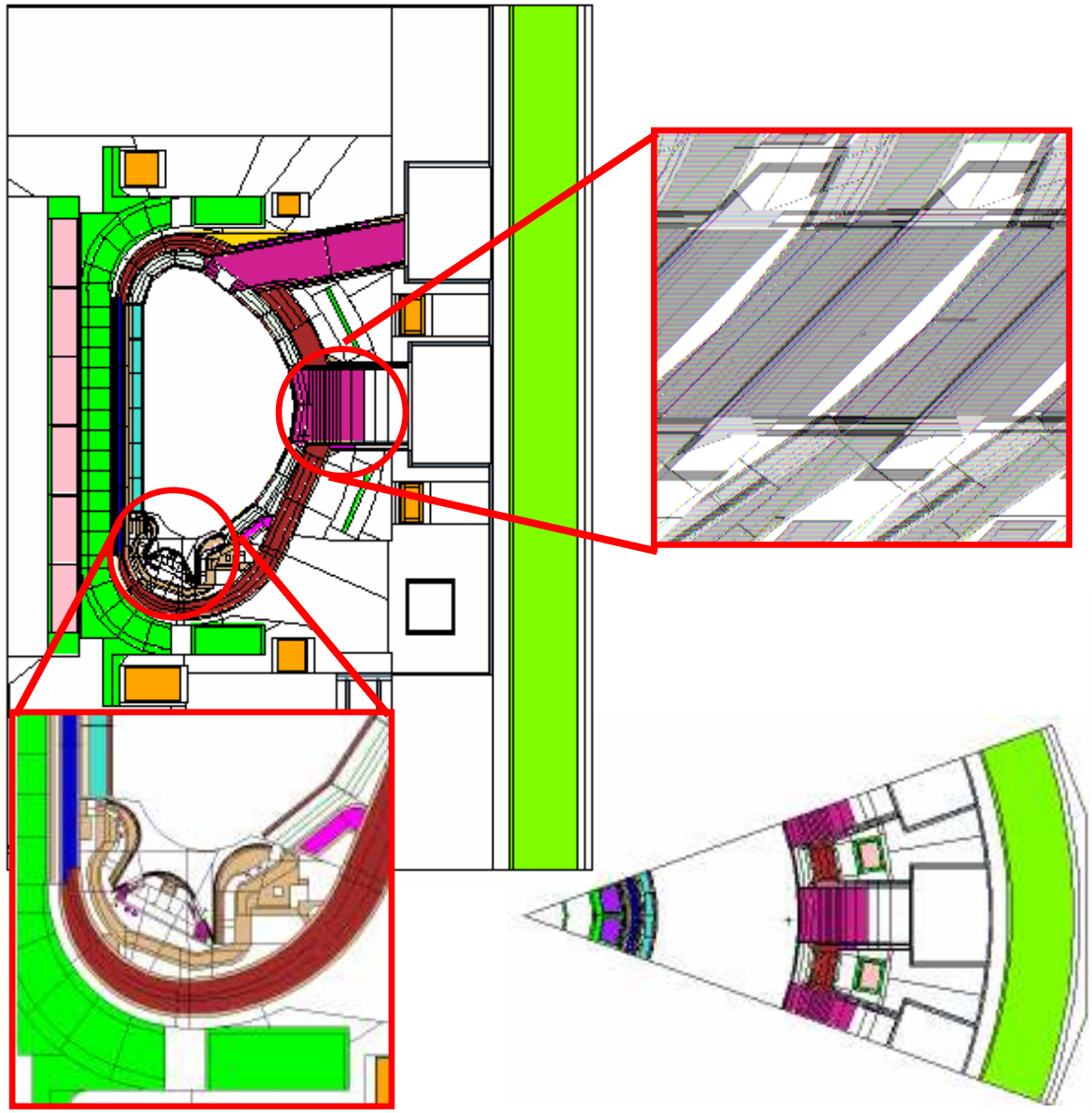
Geometry generation using SolidWorks



- Usually have to re-create CAD from scratch for neutronics, because of special accuracy requirements
- Special accuracy to prevent loss of particles, applies also to rays.

MCNP5 ‘A-lite’ ITER reference geometry and plasma source subroutine

UKAEA Fusion



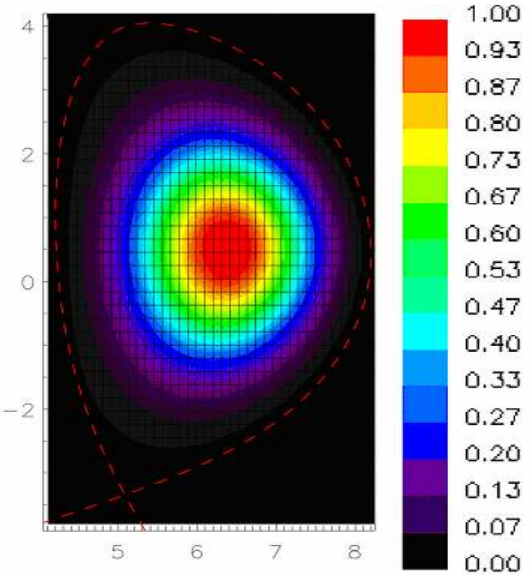
Main geometry:

~ 8,000 surfaces
~ 4,000 cells
24 materials

Divertor geometry:

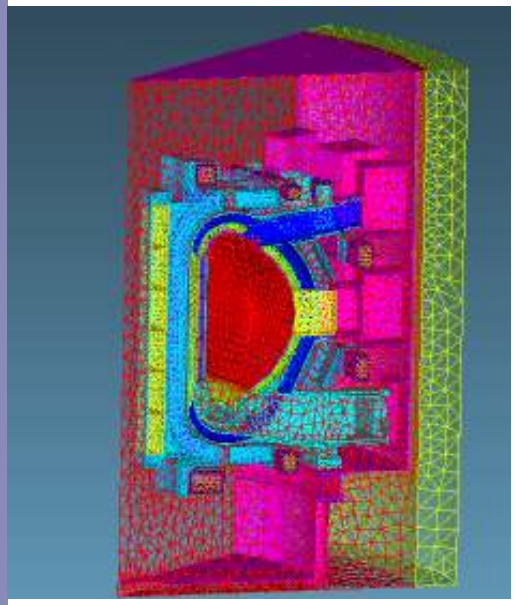
~ 1,000 surfaces
450 cells
11 materials

Source:
40 x 40 grid

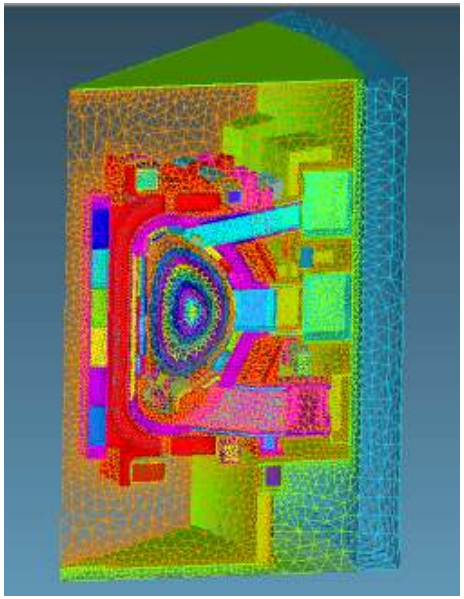


Final model: Alite003v0.x_t

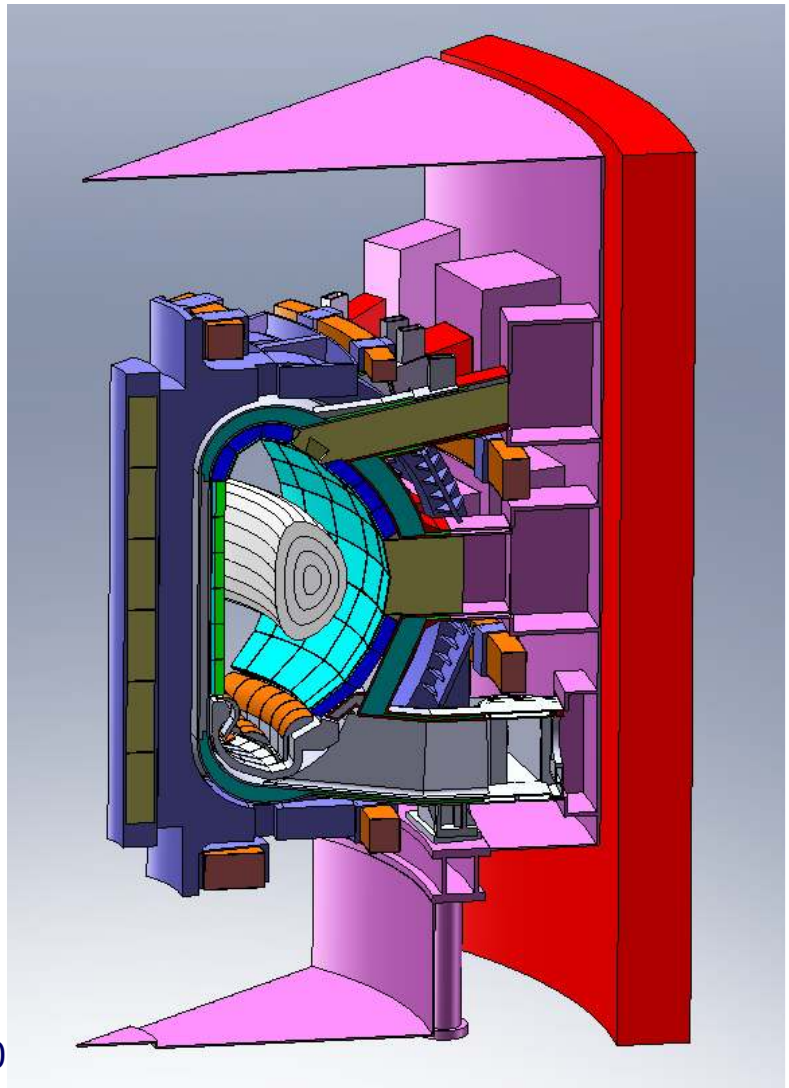
- Final result: Alite003v0.x_t consisting of 30 SW parts in 6 assemblies
- Tested for meshing in ATTILA for varying sizes



Average mesh size = 35cm
RAM ~ 20%*
Mesh elements ~ 665,000

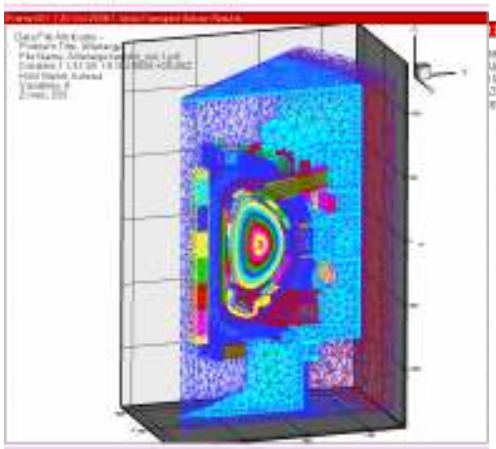


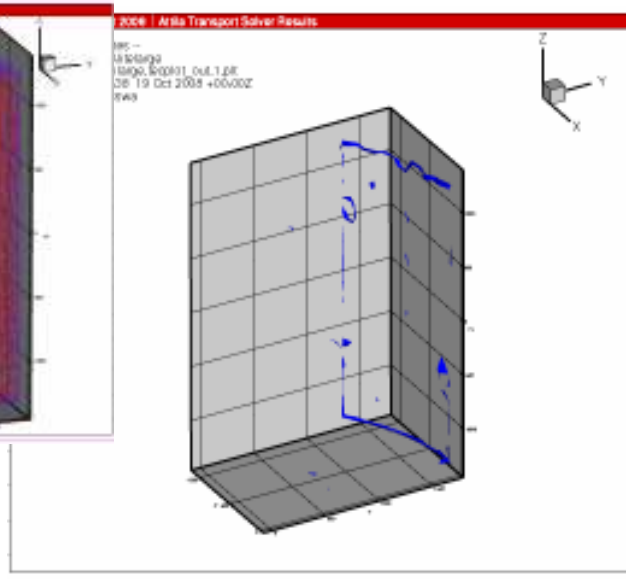
Average mesh size = 20cm
RAM ~ 65%*
Mesh elements ~ 2,200,000

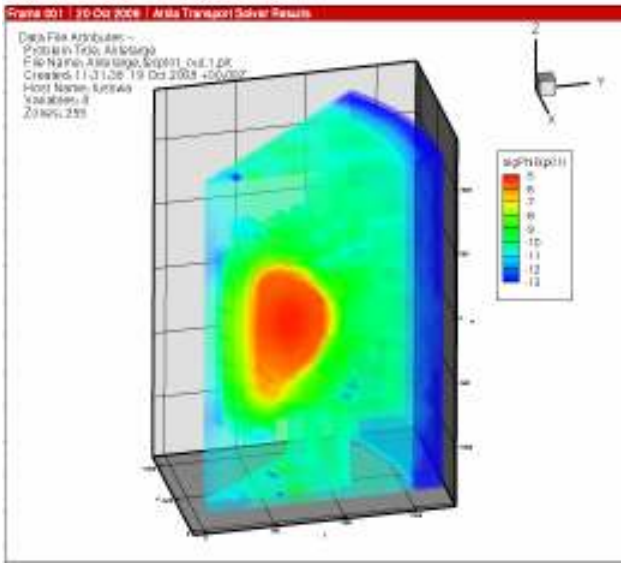


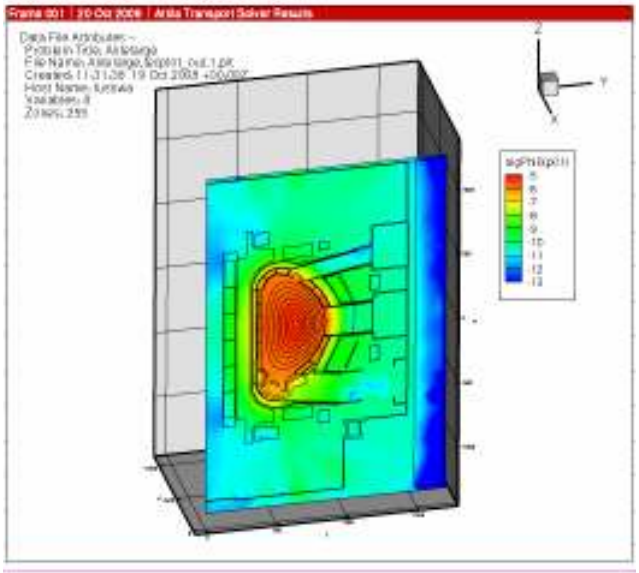
* dedicated 8Gb
2.4GHz machine

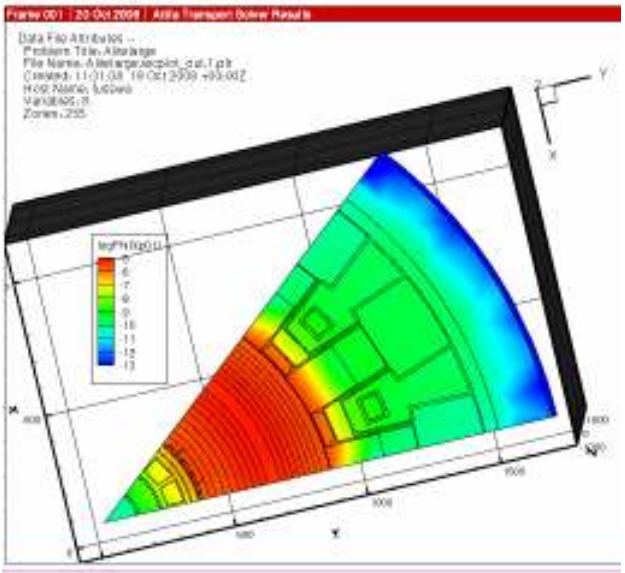
Preliminary results: Attila neutron transport calculation





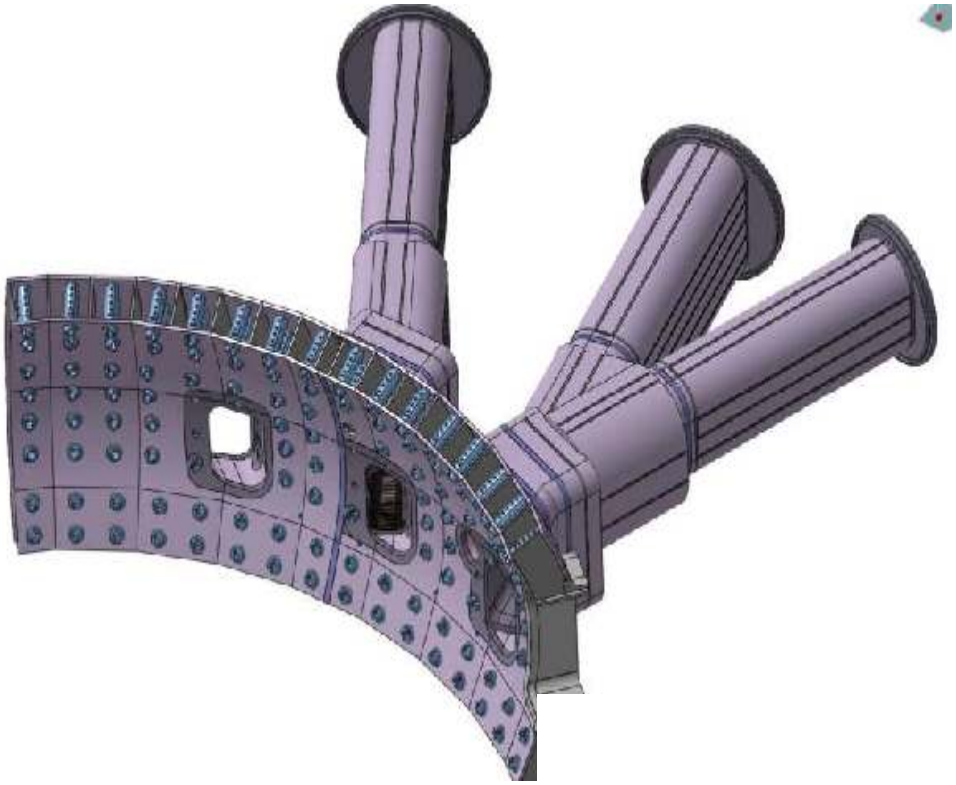






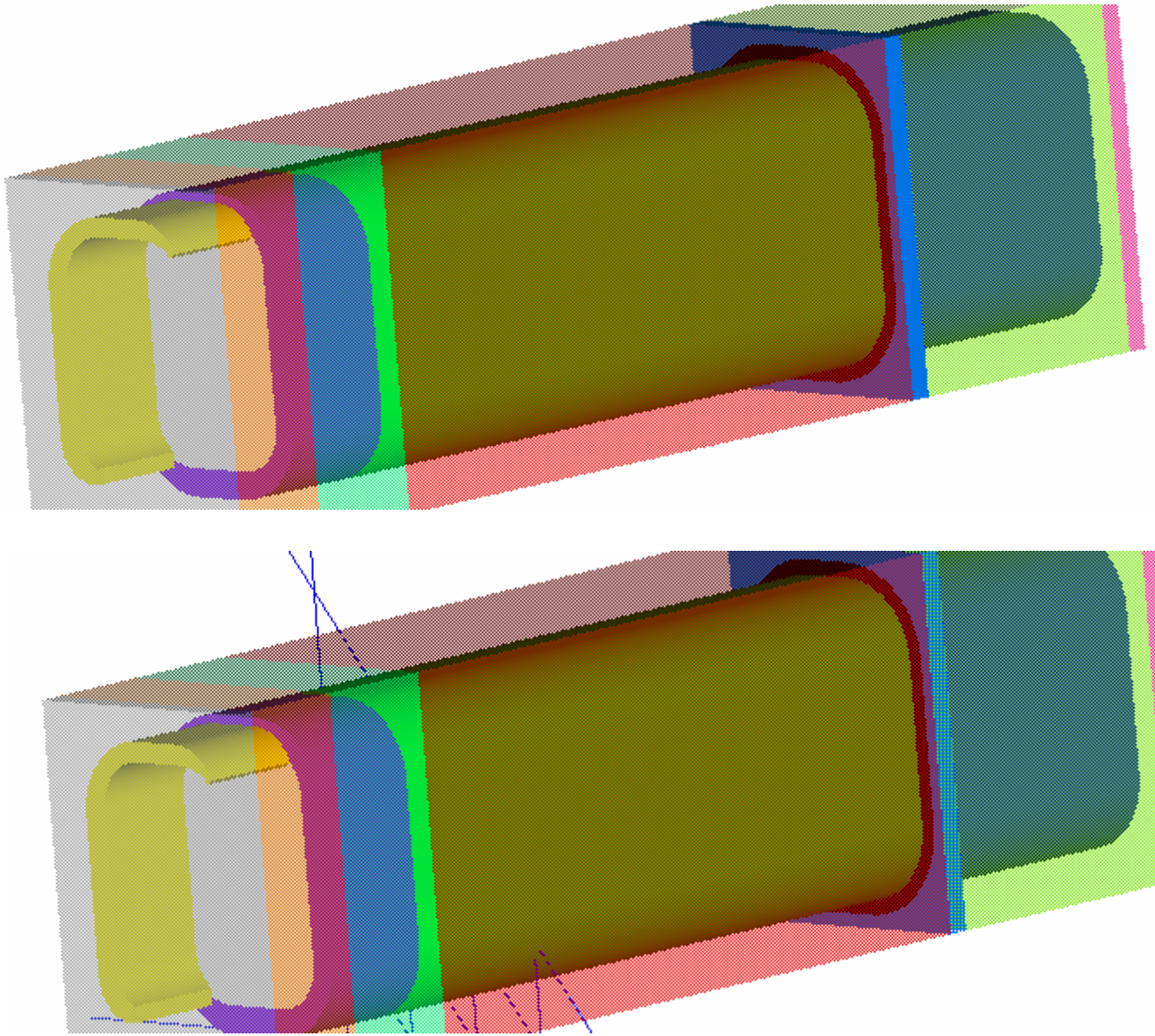
Alite003v0.x_t
850,000 elements
S_8P_1
15n0g
reduced density
RAM ~6 GB
CTM ~94h

CAD to Physics Code 1: Complicated ITER duct



CAD to Physics Code 2 Simple ITER Duct

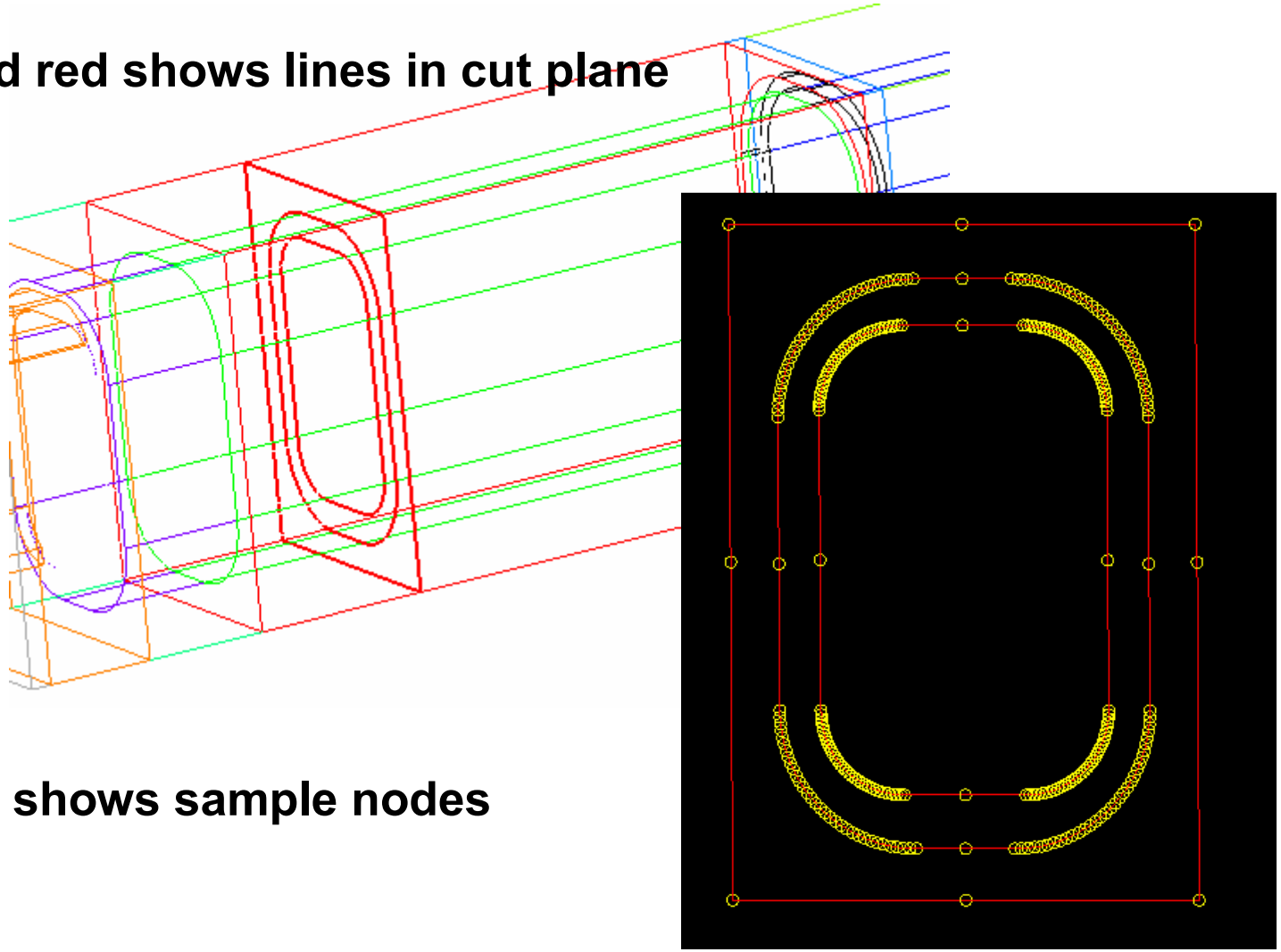
UKAEA Fusion Working in Europe



CAD to Physics Code 2 : CADfix cut plane

UKAEA Fusion

Bold red shows lines in cut plane



Yellow shows sample nodes

Conclusion

- Neutronics: typically regenerate CAD using SolidWorks. Convert from BREP to CSG for MCNP code using MCAM, or save as BREP (Parasolid format) for Attila. Tri- and tet-mesh using Simmetrix mesher bundled with Attila
- Duct modelling: preferably get Design Office to defeature or use CADfix and sweat. Use 3rd party or CADfix mesher to generate tri mesh. Use CADfix API (FORTRAN) to write mesh in vtk legacy format for input to physics code.
- Tokamak edge: *A Suggestion* - use CADfix to cut vertical slice and save as oversampled set of points in plane, use axisymmetry.

Thank you

Quantities determined by neutronic analysis

UKAEA Fusion

- Nuclear heating for various components or diagnostics e.g. divertor components, first wall and superconducting magnetic coils.
- Nuclear damage quantities (e.g. dpa values relevant to weldability).
- He generation (relevant to component swelling).
- Blanket tritium breeding ratios for fusion power plants (DEMO studies).
- Optimisation of shielding/ports/doglegs for streaming paths.
- Neutron activation calculations (coupled MCNP with FISPACT codes).
  - shutdown dose rate and radioactive waste calculations.
  - time dependent depletion calculations e.g. depletion of Li compounds in a fusion blanket.

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MCAM: Monte Carlo Automatic Modeling System

UKAEA Fusion

- **MCAM 4.7* (currently released version)**

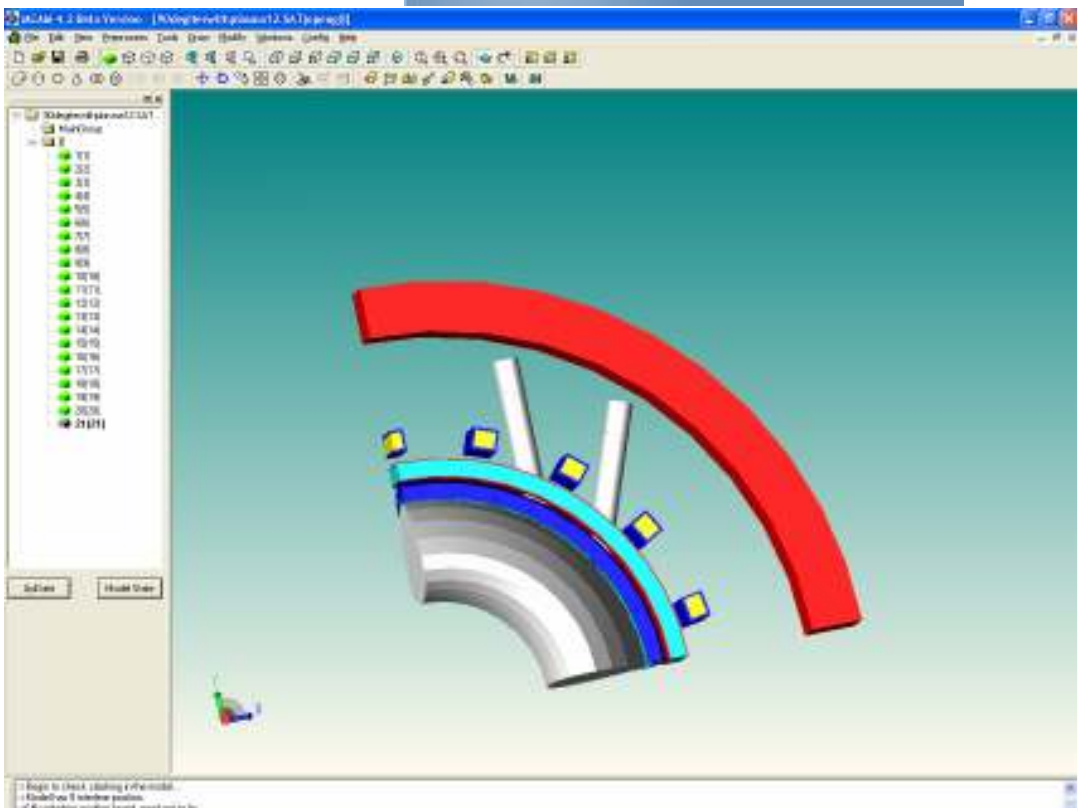
  Basic Functions:
  - Pre-processing Engineering CAD Models
  - Converting CAD Models into MC Models
  - Inverting MC Models into CAD Models
  - Visualising and Analysing MC Models
  - Creating CAD Models

- **MCAM 5.0 (not released yet)**

  To implement inversion/conversion function for TRIPOLI.

- **Future MCAM versions?**

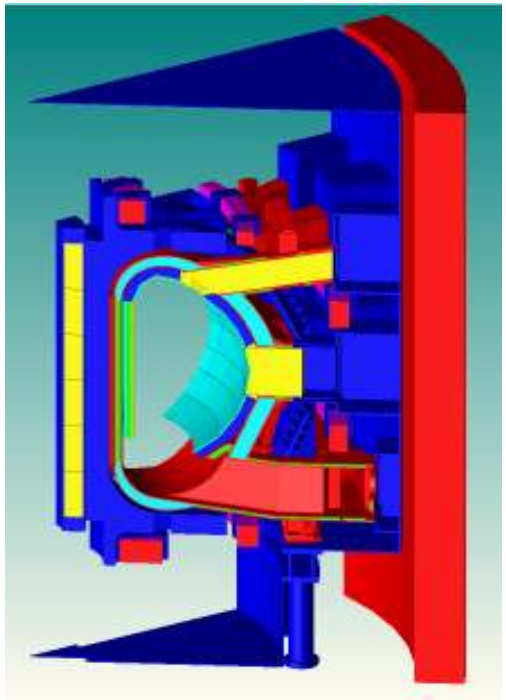
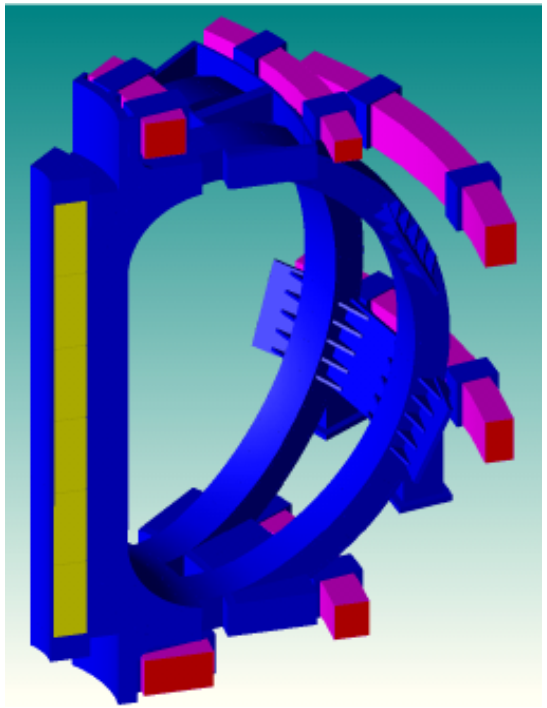
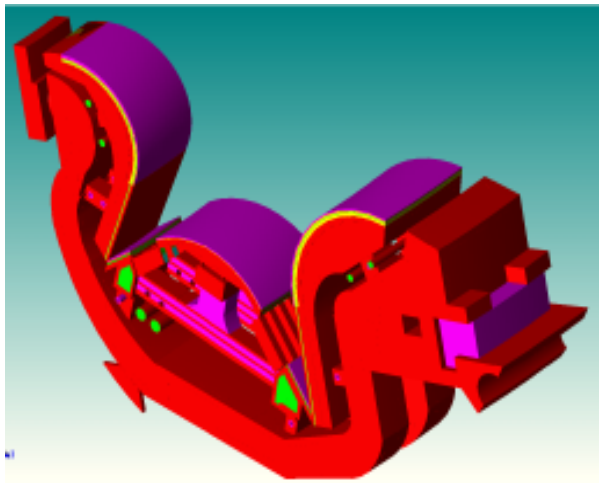
  Spline surface processing (discretise spline surfaces)



http://www.fds.org.cn

***Y Wu et al., CAD-based interface programs for fusion neutron transport simulation, Fus. Eng. Des, Article in press, 2009.**

Conversion of a reference ITER model into CAD for Attila calculation

UKAEA Fusion

- For ITER we have a reference radiation transport analysis geometry model and source (A-lite), which existed only as an MCNP input file (geometry and source routine).
- We would like to modify this ITER model so that 1) we can easily insert diagnostic and heating devices into the ports in a CAD environment and 2) run the model using ATTILA.
- Goal: need to develop a CAD version in suitable format (error-free, Parasolid .x_t).