Investigating the effects of homogenisation in fusion blankets

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Abstract

For fusion to become a reliable source of electricity through the next century breeder blanket technology must be simulated, developed and perfected. There are currently a variety of sources of uncertainty in neutronics simulation. These include poor nuclear data, the effect and specification of blanket ports and spatial homogenisation (simplified geometry). Neutronics models typically employ spatial homogenisation to reduce computation time.

The author is investigating the impact of spatial homogenisation on pebble bed neutronics. A code has been written that can generate pairs of MCNP models, one homogenised and one with fine pebble structure. Preliminary results for small beds show a difference in TBR between the two models of up to 9%. Predicted TBR values are only narrowly > 1, hence work to quantify and reduce the uncertainty on this parameter is justified. Further investigation of spatial homogenisation's effects are warranted.

Future work will include investigation of density variation in randomly close packed (RCP) and its effects on fast flux. Additionally the author has plans to incorporate several small pebble bed modules in a larger, mostly homogenised DEMO neutronics model. The aim would be to quantify the difference in machine TBR with a fusion relevant neutron source.

Spatial homogenisation

Harnessing magnetic confinement fusion for power generation requires an intimate understanding of the nuclear processes occurring in the reactor blanket. This is largely achieved through neutronics modelling. Neutronics and now coupled multi-physics simulations are enabling the design of blankets which will breed tritium, extract heat and shield much of the machine.

However, the vast majority of the simulations required to calculate TBR, volumetric nuclear heating, shutdown dose rate adopt a simplified geometry for their calculations as shown in figure 1.

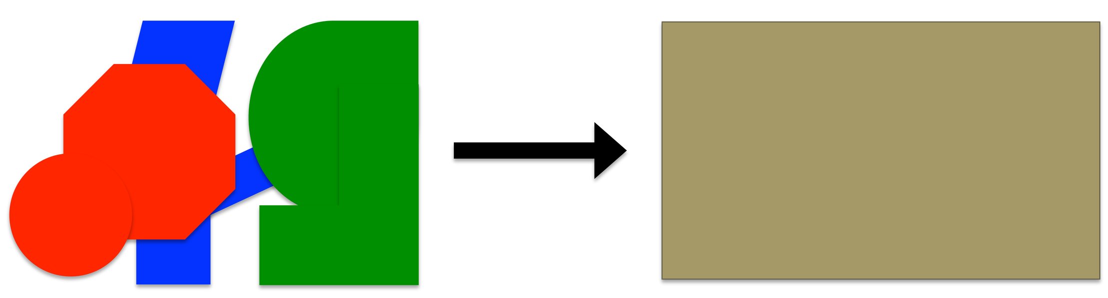

Figure 1: Homogenising a complex geometry with several different features and materials into a bulk medium with a single, albeit lengthy materials definition and no complex structure.

This process of spatial homogenisation reduces the running time of neutronics simulations with complex geometries by orders of magnitude. However, low fidelity geometry will influence the results of neutronics simulations. The severity of this is a function of many variables. Breeder designs with bulk, liquid coolants and breeders such as FLiBe, LiPb or DCLL (Dual Coolant Lithium Lead) are less likely to produce spurious results than those with complex, fine-structured geometry like pebble beds.

Pebble code

To investigate the effects of spatial homogenisation in fusion pebble beds, the author has written a code to generate parametrisable geometry for a neutronics package, MCNP6.

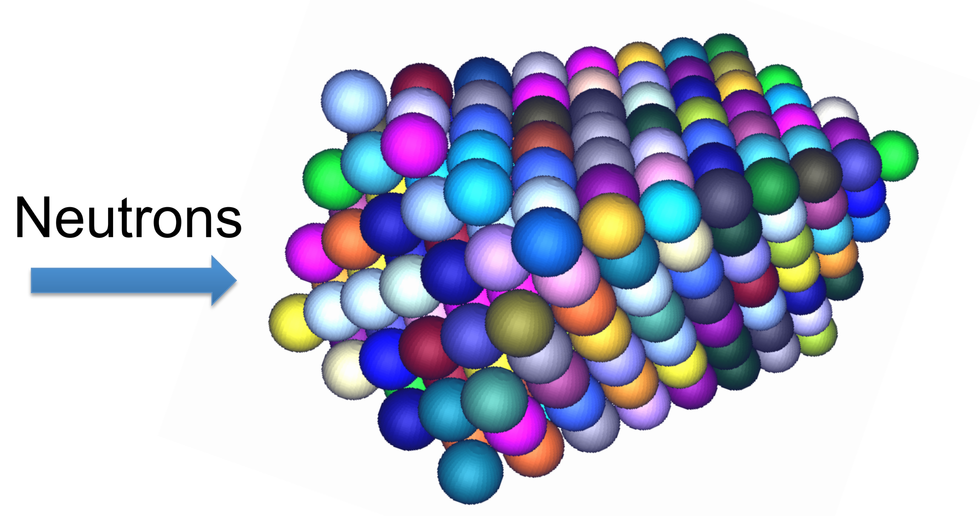

Figure 2: FCC lattice Li pebble geometry created by author's code. This is compared with a block of equal mass but lower density to account for the FCC packing factor.

While the breeder material is modelled as either pebbles or a homogeneous cuboid, mass is always conserved, as is the bounding volume. Initial results (see figure 3) show a difference in TBR between the bulk and the pebble case (which is pictured in figure 2).

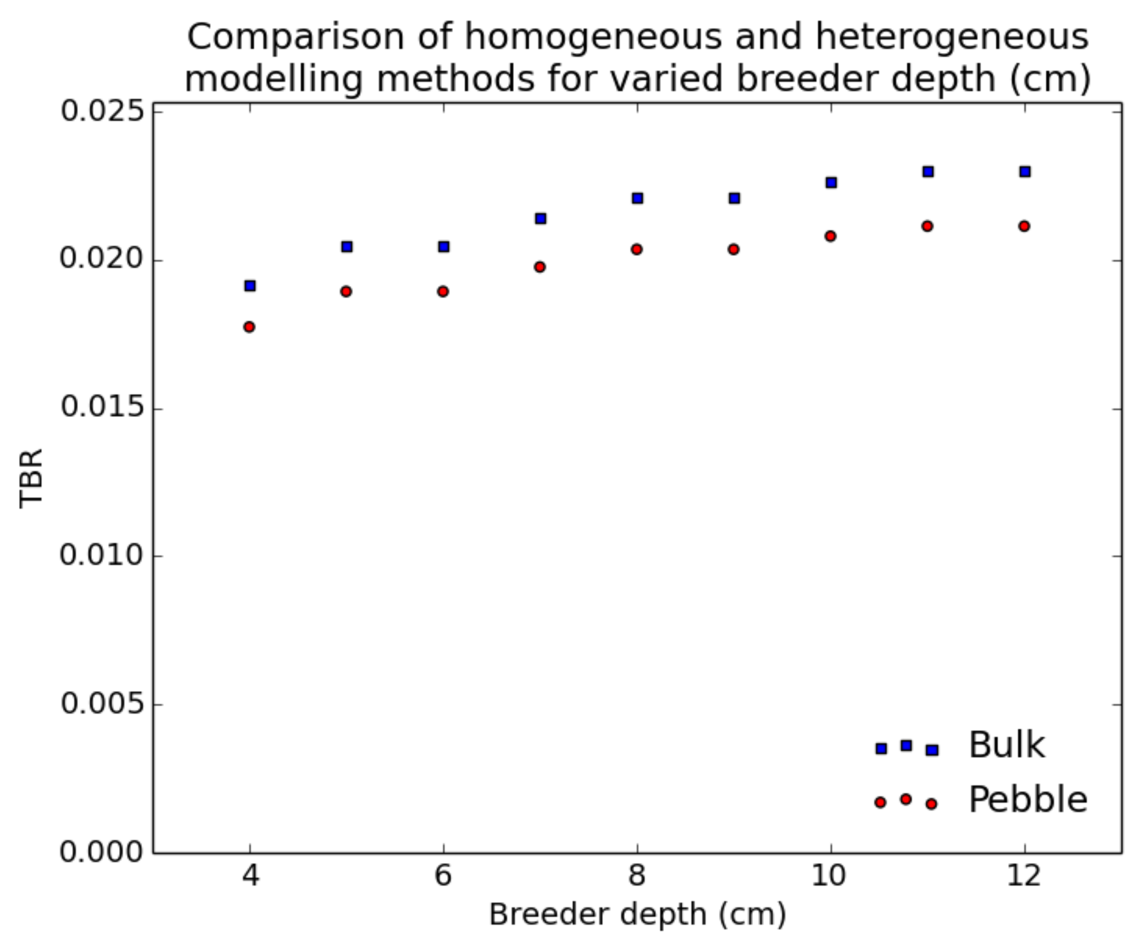

Figure 3: TBR for the bulk and pebble modelling approaches. Here the pebble bed depth is being varied between simulations. Both pebble and bulk cases currently utilise a simplistic materials definition that is to be improved.

Further work

The code currently produces an FCC lattice for the pebble case. In reality, a pebble block will contain randomly located pebbles. This random close packing (RCP) has been modelled with Discrete Element Methods (DEM). Figure 4 shows how the local packing factor varies with position in a RCP material. It can be seen that there are repeated layers by solid surfaces where the packing factor varies between extremes.

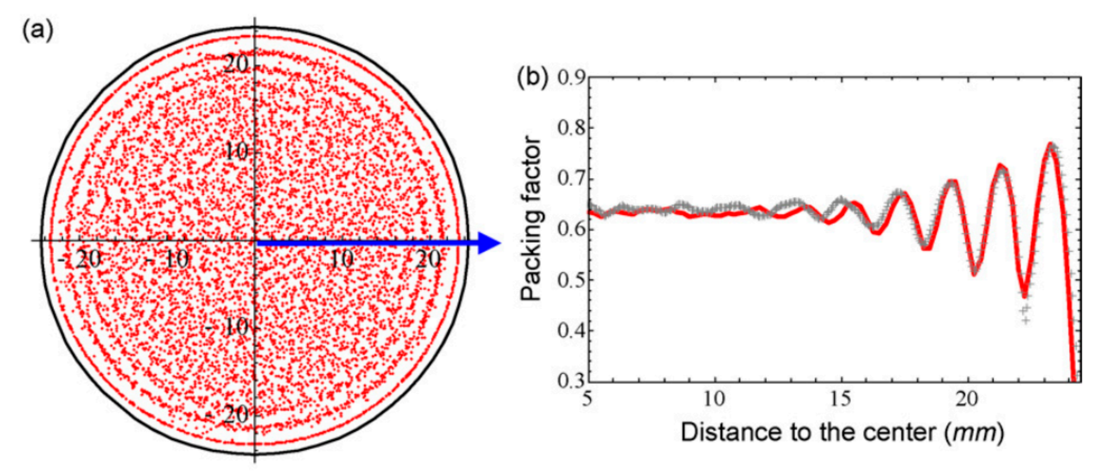

Figure 4: a) shows top down view of RCP placed pebbles in cylindrical container while b) shows the packing factor as a function of radial position [1]

When the RCP regime is employed, it produces channels of low packing factor. Theoretically, fast flux can stream down these channels, endangering magnets or other components.

Aside from the implementation of RCP, the author plans to increase the sophistication of the model's materials definition. Also, to incorporate the pebble and bulk breeder beds into a more realistic model with First Walls (FW), eventually the model should include cooling pipework (which is homogenised in traditional simulations).

Lastly, the author intends to locate a few instances of this heterogeneous pebble bed module into a full-sector model of DEMO to expose them to a realistic neutron source. This exercise may enable a confident extrapolation of the difference in TBR across an entire machine due to the neutronics modelling approach.

References

[1] Y. Gan, M. Kamlah, J. Reimann "Computer simulation of packing structure in pebble beds", *Fusion Engineering and Design* 85 **10-12** (2010) 1782-1787

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