Approximation of The Neutron Diffusion Equation on Hexagonal Geometries Using a h-p finite element method

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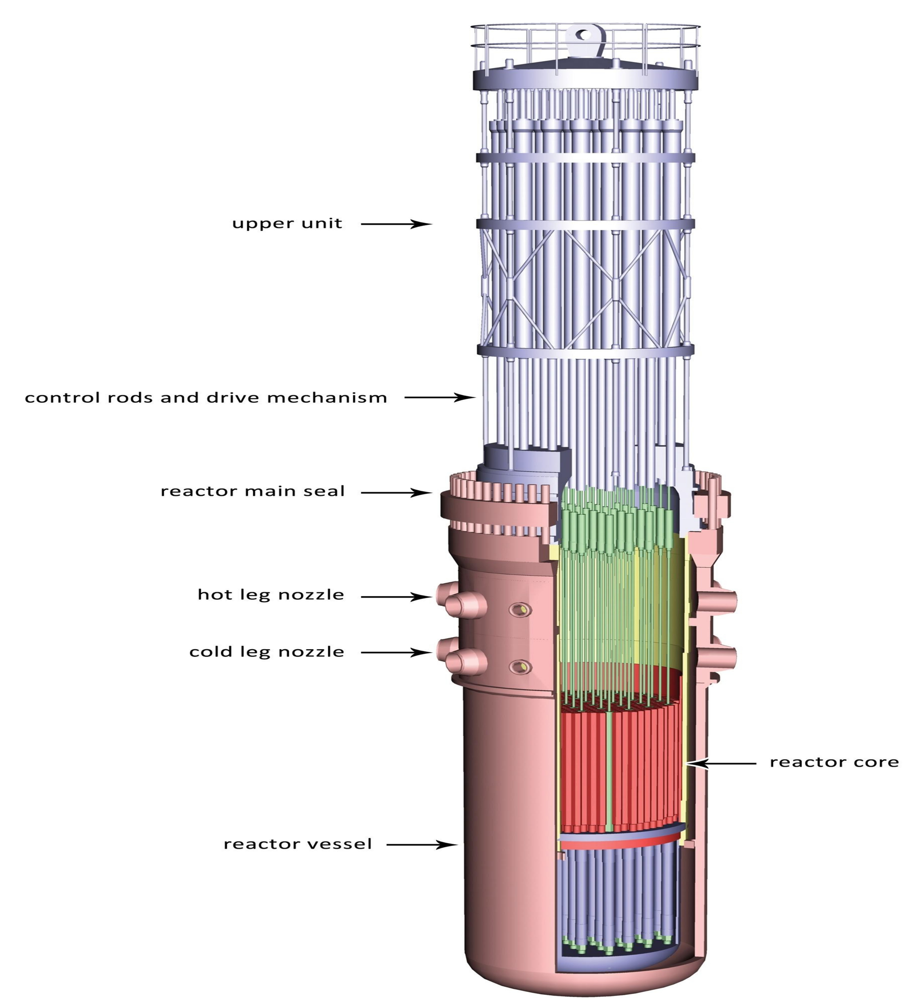
Introduction

The design, analysis and control of nuclear reactors require solving numerically the neutron transport equation (or an approximation of it) in order to determine the neutron distribution in the reactor, and hence validate and verify design and safety parameters

Objectives

- Development of different tools for the analysis of reactors with hexagonal geometry based on a finite element method with h-p refinement capabilities.
- Validation of the developed method.
- Implementation of a method to solve the time dependent neutron diffusion equation.

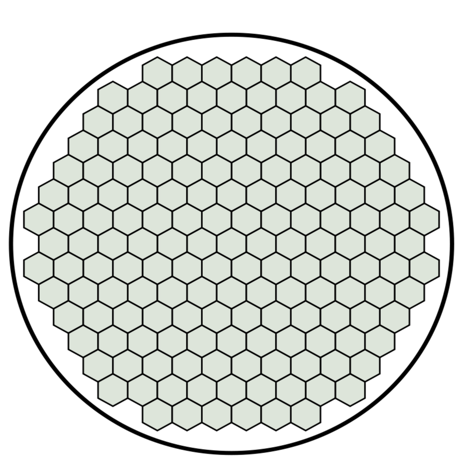


- Improvement of 3D neutronic codes .
- The treatment of the rod cusping problem.

VVER - Reactors

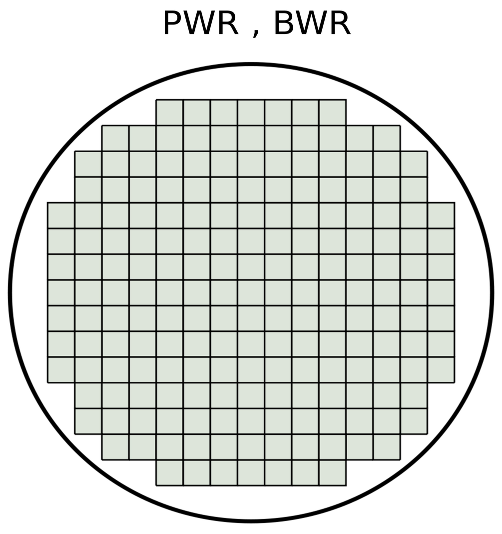
It is interesting to develop efficient nuclear reactors simulators based on hexagonal meshes because most of the new reactors under construction are of VVER type that differ from the PWR and BWR, mainly in the geometry of fuel elements. In the BWR and PWR the fuel elements are rectangular prisms and in the VVER reactors the fuel elements are hexagonal prisms .

VVER

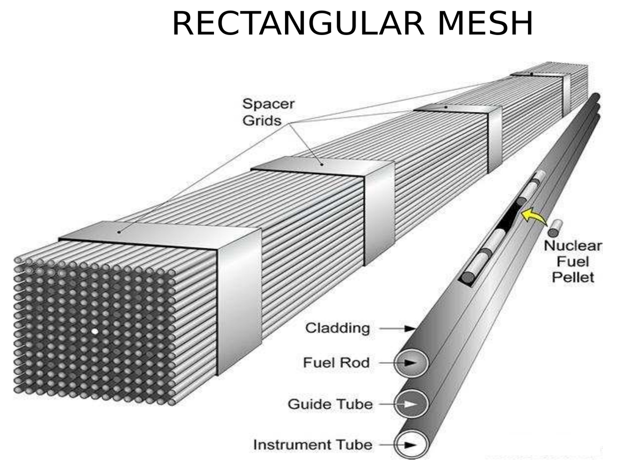


HEXAGONAL MESH

PWR , BWR



RECTANGULAR MESH



Core mesh for both VVER and PWR reactors.

H-P Mesh Adaptation

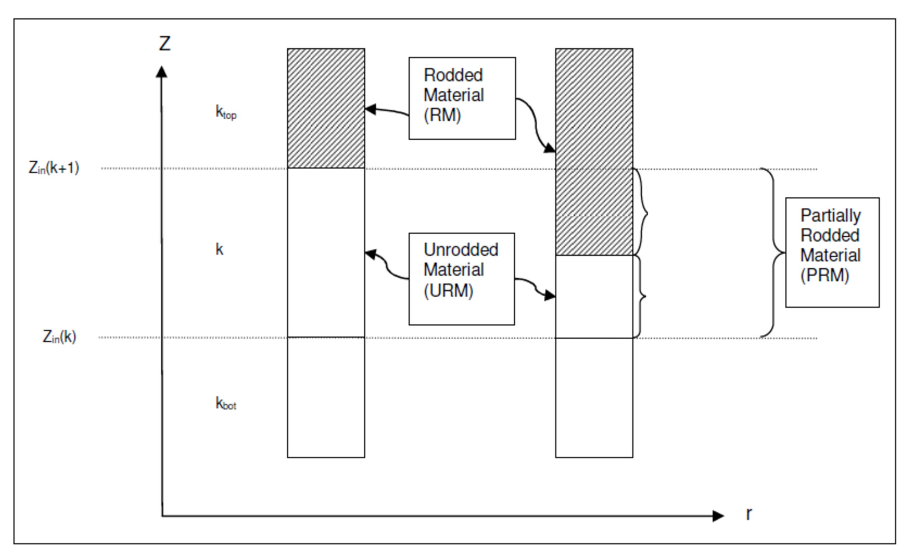
Adaptive Mesh Refinement is now an established technique for obtaining numerical solutions with higher accuracy and resolution, while requiring less memory and shorter CPU times.

❖ To discretize the neutron diffusion equation a FEM with *h-p adaptivity* will be used .This method allows to use heterogeneous meshes, and leads to different refinements such as

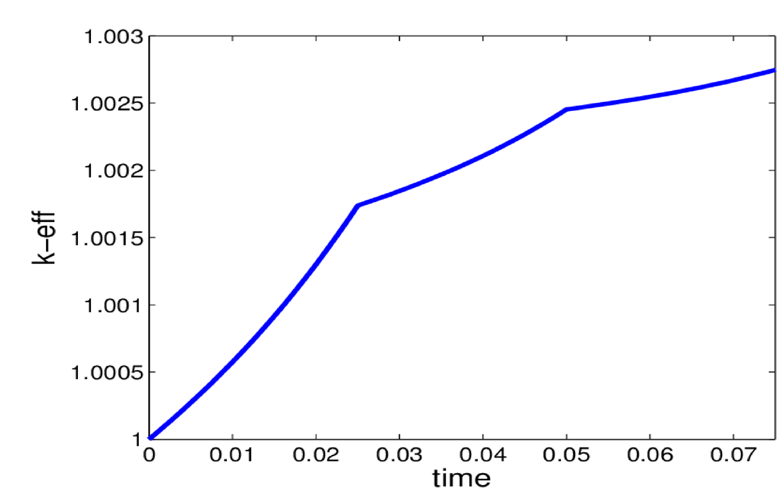
- H-refinement : subdivide cells in order to reduce the cell size.
- P-refinement : increase the polynomial degree .

Rod Cusping

The rod cusping is unphysical behaviour of the keff of the reactor or the average power that appears on the calculation results when the volume weighted method is used to interpolate the cross sections of a partially rodded node by means of the portion of the rod inserted on the node.



Partially rodded nodes

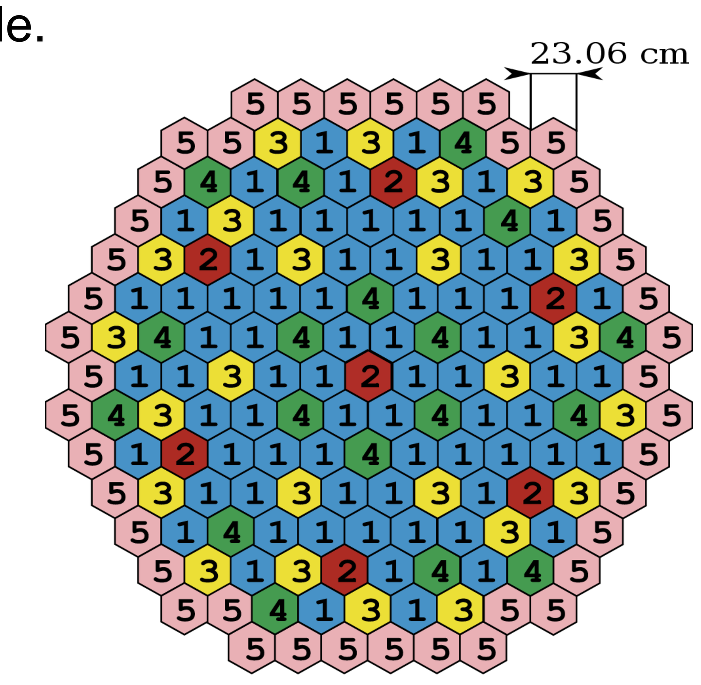


Rod Cusping effect

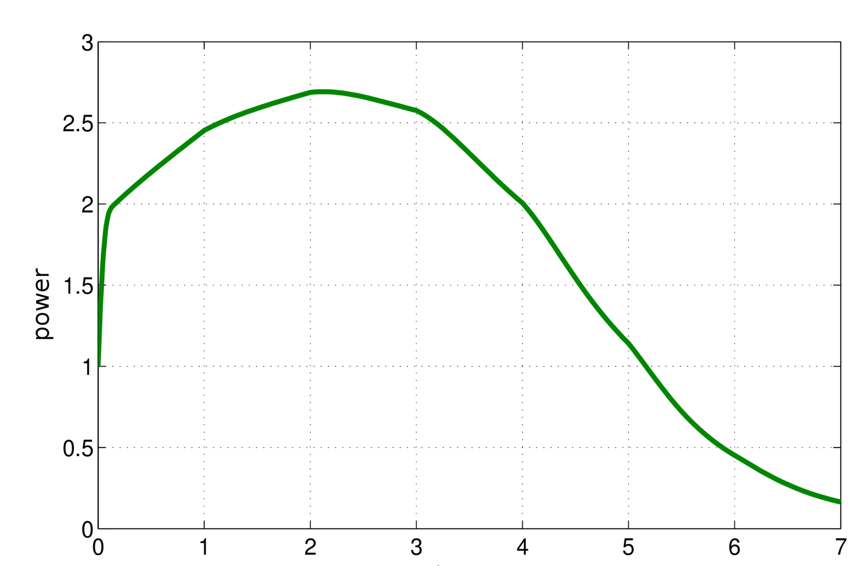
Many techniques exist for the treatment of the rod cusping problem.Our proposed solution to mitigate the control rod cusping problem will be implemented by the deal.ii library which has the possibility of using meshes that follow the movement of the control rod avoiding the problem of homogenization of partially inserted cells .

Results

To test the performance of the method presented , a VVER-1000 reactor results are presented as example.

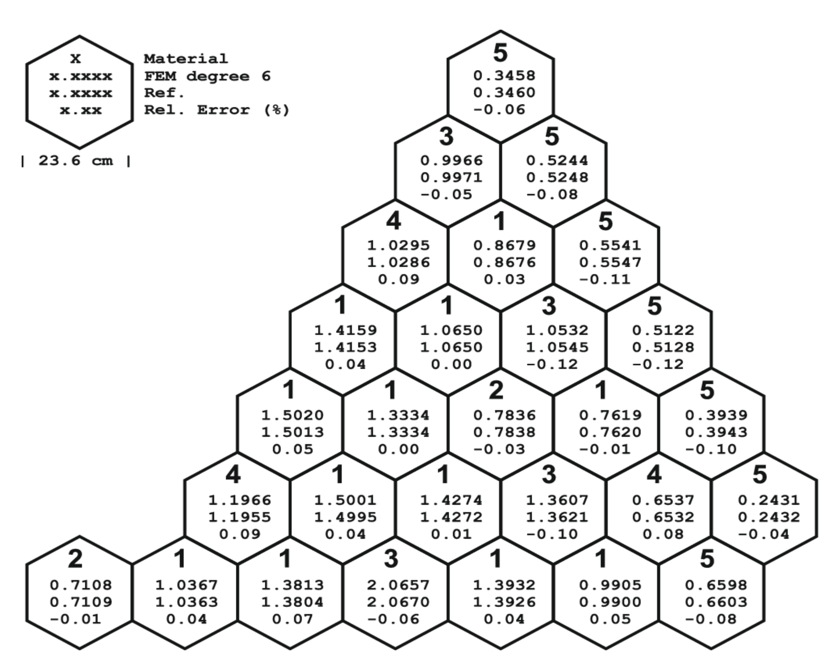


GeometryoftheVVER-1000reactor..



Critical eigenvalue and power distribution results for the VVER-1000 reactor.

Degree of FE	(k_{ef})	Δk_{ef} (pcm)	ε_{max}(%)	ε (%)	DOF	NNZ
1	1.004440	203	17.7	4.53	1070	18148
2	1.006440	203	1.47	0.35	4094	126628
3	1.006460	2.48	0.39	0.08	9074	442804
4	1.006450	3.48	0.13	0.06	16010	1130980
5	1.006460	2.48	0.14	0.05	24902	2402404
6	1.006460	2.48	0.14	0.05	35750	4515268
PARCS	1.006341	14.3	0.66	0.25		
Reference	1.006485					



Above on the right , the neutronic power distribution for each hexagon computed with the FEM method, together with the reference result and the percentage of the relative error on each hexagon.

On the left the different results obtained for the critical eigenvalue (keff) of this reactor core using number of cells = 3 × 163 (the number of assembly) = 489 are shown.

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