Development of a thermomechanical analysis method as part of the ESFR-SMART EU project for the quantification of SFR core reactivity change due to core distortion

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Introduction

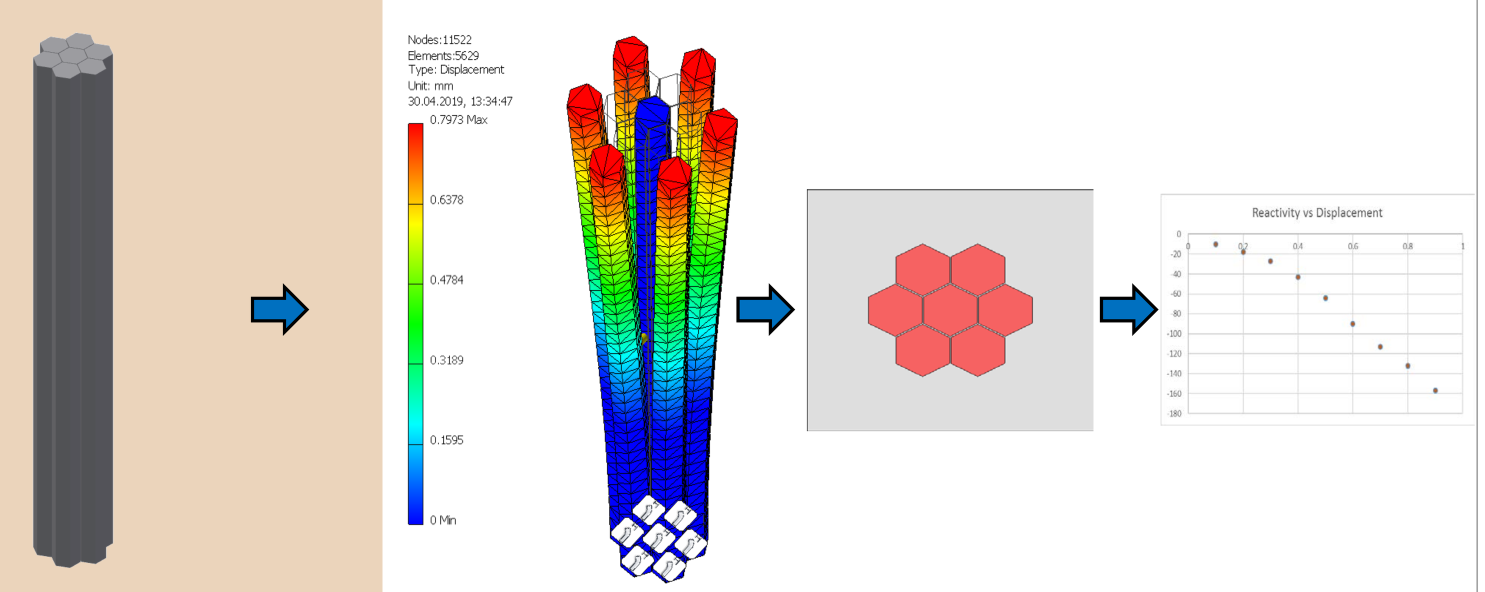
As part of the ESFR-SMART EU project a core thermomechanical analysis method is under development for the purpose of the quantification of the reactivity effect related to the core distortion due to external forces. Such an effect may accompany the sodium boiling phenomenon.

Methodology

The proposed method consists of two major phases:

- **The simulation of the core deformation through a CAD (Computer Aided Design) based finite element solver.**
- **The evaluation of the reactivity effect of the core distortion in Serpent 2 Monte Carlo code through the obtained, deformed model.**

CAD model (Computer Aided Design) development → Finite Element Analysis → Monte Carlo Simulation → Reactivity effect results



Verification

- **For the verification of the results, obtained from the Finite Element solver, an analytical solution was calculated for a cantilever beam deformation.**
- **To calculate the deformation of the beam, the following equation has been used [1]:**

$$\Delta x = \frac{F}{6EI}(z^3 - 3Lz^2)$$

- **Where F is the force applied on the beam, E is the Young modulus of the beam material, L is the length of the beam and z is the position of the applied force.**

Sensitivity analysis on the mesh size of the finite element simulation

Finite element mesh size [mm]	Deformation [mm]		Error relative to analytical solution [%]	
	F=5000 N	F=1000 N	F=5000 N	F=1000 N
150	11.583	2.317	1.03	1.03
50	11.656	2.331	0.41	0.42
25	11.661	2.332	0.36	0.38
5	11.664	2.333	0.34	0.34
Analytical solution	11.704	2.341	-	-

Monte Carlo analysis

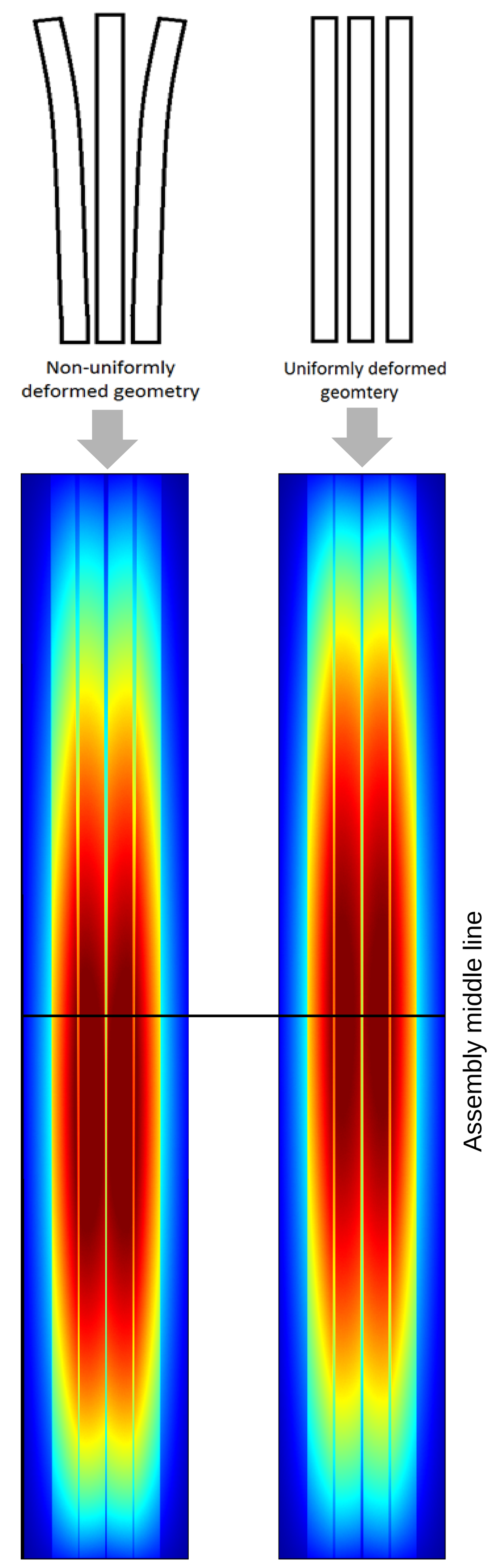
- **To use the calculated geometry shape model in the Monte Carlo analysis, a built-in interface was used.**
- **To test the interface and to observe the accuracy of a CAD model, four sample analyses were done.**

These four cases and the resulting multiplication factors are given in the table below.

Set-up	Monte Carlo calculated Keff (std: 1.6 pcm)	$\Delta\rho$ (pcm)
Undeformed geometry Input from CAD	1.00446	-
Undeformed geometry Standard input	1.00449	3
Deformed geometry (non-uniformly) Input from CAD	0.99739	-
Deformed geometry (uniformly) Standard input	0.99853	114

Deformation effect

- **A shift in the fission rate has been observed due to different deformation approximations.**
- **There is an increased leakage at the bottom of the subassembly and decrease at the top for the Non-uniformly deformed case.**
- **This phenomenon is the cause of the 114 pcm reactivity change between the deformed cases, which is around 16% of the total effect.**



Fission rate spectrum

Conclusion

- **The developed methodology for reactor core thermomechanical analysis has been successfully implemented for seven subassemblies.**
- **A difference has been observed between the uniform deformation method and the newly proposed non-uniform deformation method.**
- **To obtain results for an actual problem, the Phenix reactor core is currently under investigation and the results are going to be compared to the Phenix end-of-life experimental measurements [2].**

References:
[1] – J. M. Gere, B. J. Goodno *Mechanics of Materials* (Eighth ed.). pp. 1083–1087. ISBN 978-1-111-57773-5.
[2] - B. Fontaine et al., “Description and preliminary results of PHENIX core flowering test”, Nuclear Engineering and Design 241 pp. 4143– 4151 (2011)

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