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Buffer-IPyC separation process in TRISO fuel particles simulated with Bison code

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Changing the World's Energy Future

Zuzanna Krajewska

Idaho National Laboratory

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Zuzanna Krajewska

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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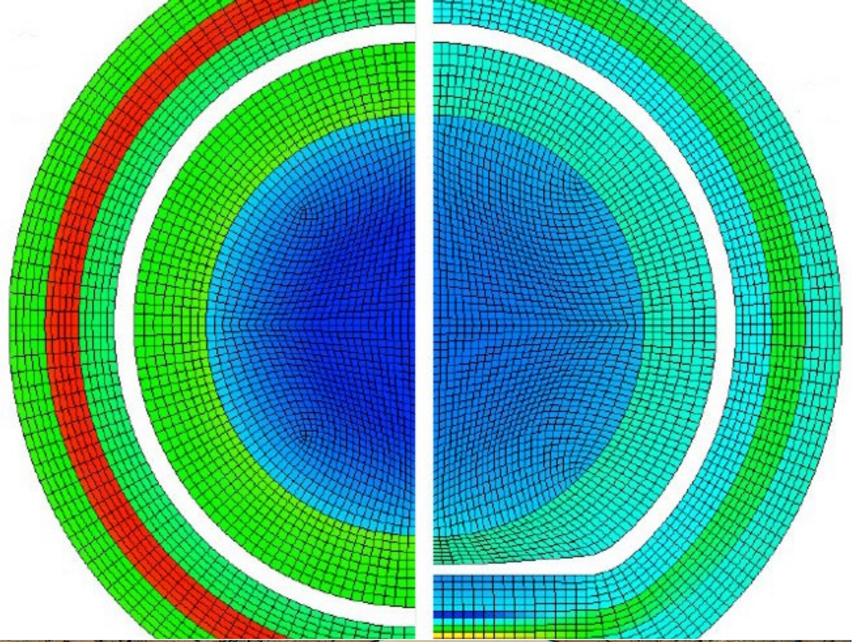

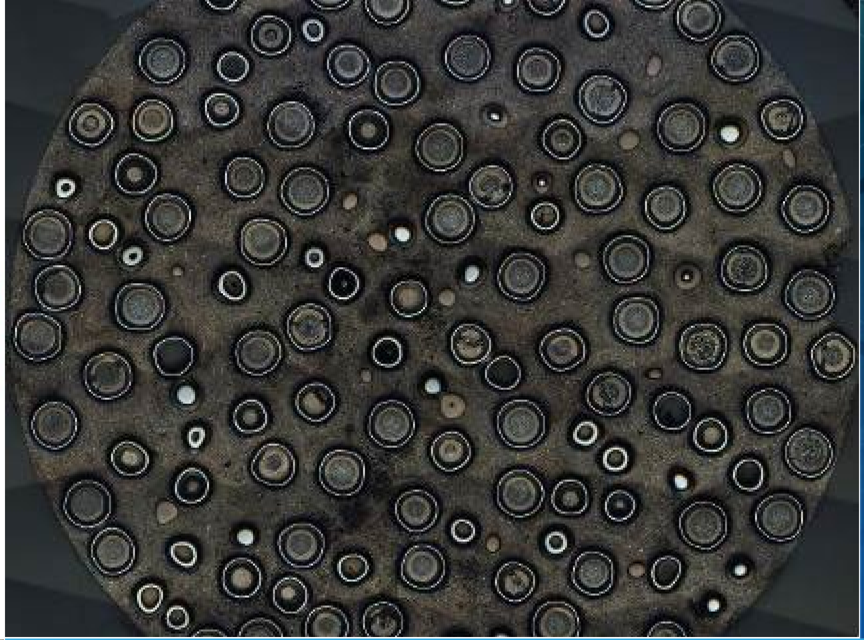

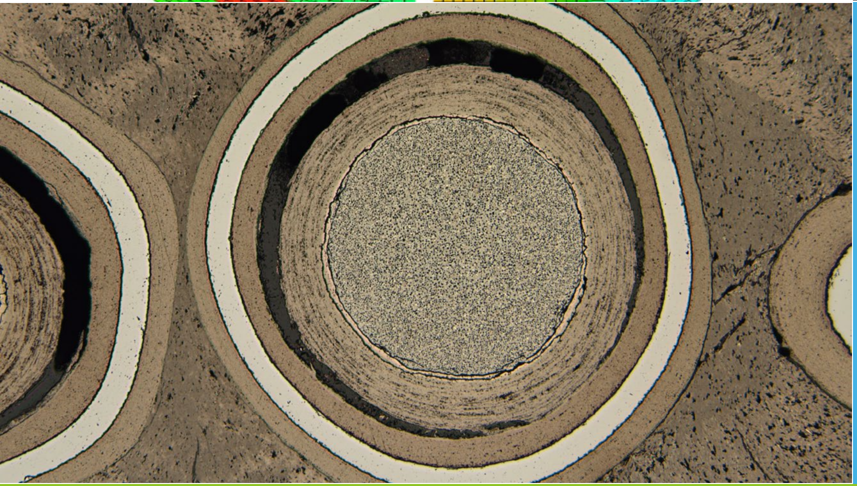

July 9, 2024

Zuzanna Krajewska
PhD

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Introduction

The purpose of the work was to explore the experimental results of the debonding mechanism that occurs at the buffer-IPyC junction, with the use of the Bison simulation code.

The focus of the simulations was on two models:

- Debonding restricted — no gap formation between buffer-IPyC layers.
- Debonding enabled — partial or full debonding, creating a gap between the buffer and IPyC layers.

The inputs are based on data from the AGR-1 experiment. Both considered cases were performed on spherical and aspherical TRISO fuel particles.

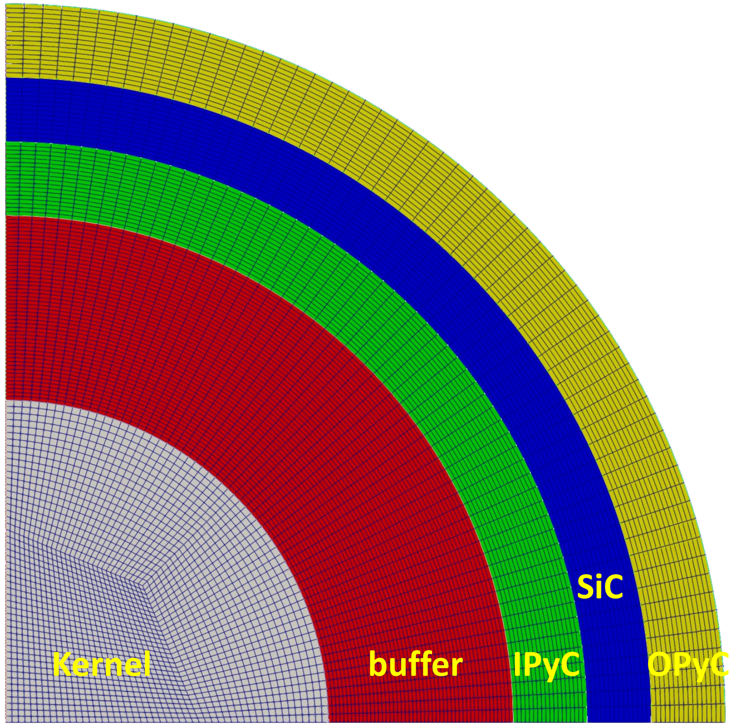


Fig.1 Finite element mesh (number of sectors = 60) for the spherical TRISO particle.

The buffer-IPyC gap formation input file contains information for the average TRISO sample geometry.

Fig. 1 represents the finite element mesh of the quarter TRISO particle.

Tab. 1 presents essential parameters from the AGR-1 experiment.

To perform simulations, proper boundary conditions must be included in the input file:

- Temperature of 1075[K] on the exterior.
- Pressure of 1e5 [Pa] on the exterior.
- DirichletBC Model*, which describes the displacement between buffer-IPyC layers.
- PlenumPressure*, which allows correct application of pressure in all coordinate directions ($startup\ time$ = 0, $initial\ pressure$ = 0).

* Bison Source Documentation

Tab.1 Input parameters for Bison simulation.

Input parameters.

Parameter	Value
Dimension	2D
Uranium enrichment	0.197 [wt-]
Uranium-Oxygen ratio	O_U=1.3613 C_U=0.3253
Bacon Anisotropy Factor	1.033
Energy per fission	$3.204 \cdot 10^{-11}$ $\left[\frac{J}{fis.}\right]$
Irradiation parameters	
Irradiation temperature	1075 [°C]
Fission rate	$9.0369 \cdot 10^{19}$ [fis./m^3/s]
Fast neutron flux	$7.8405 \cdot 10^{17}$ [n/m^3/s]
Effective Full Power Days	620 [days]

Buffer-IPyC junction - unzipping process

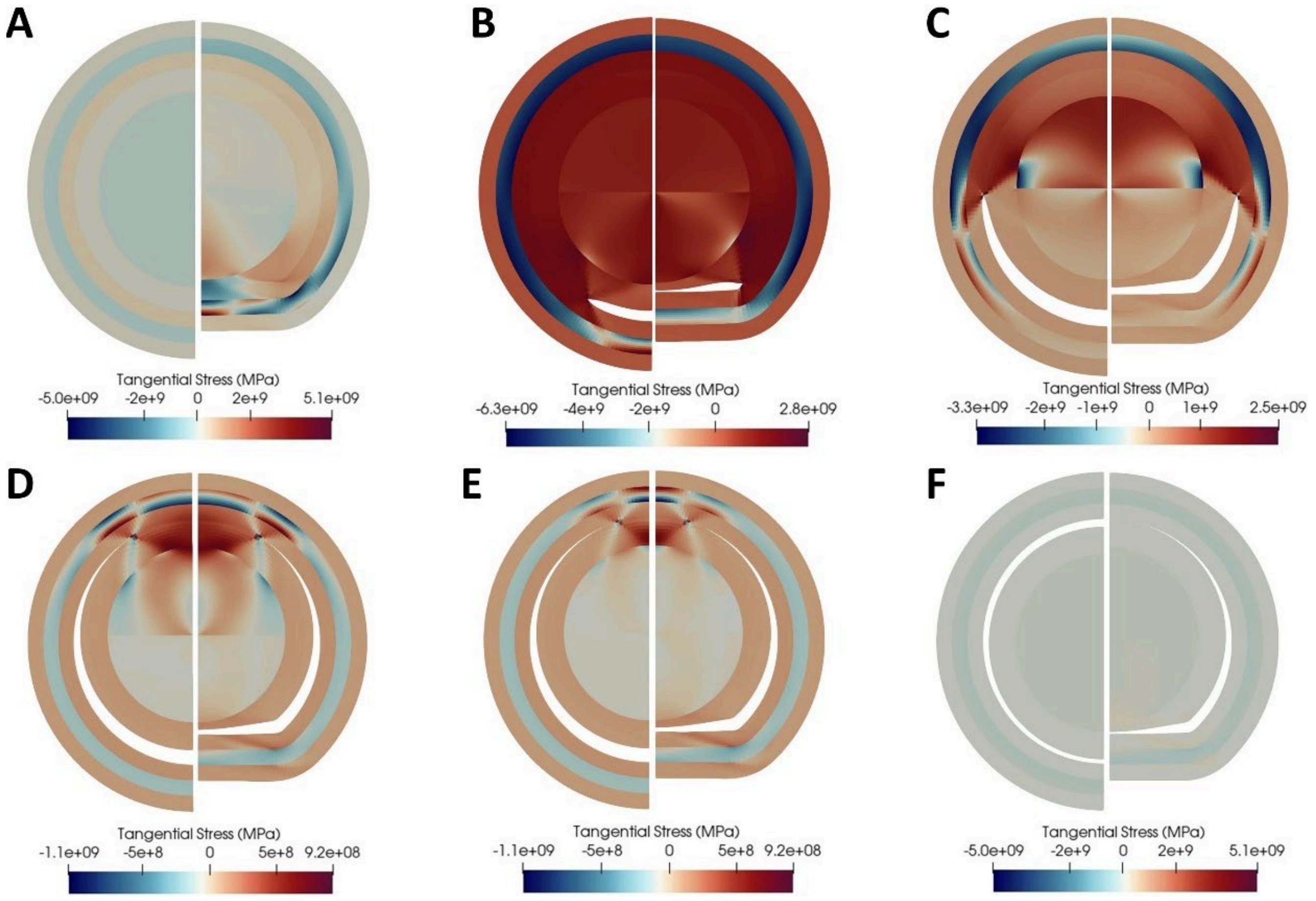


Fig.2 TRISO particle fuel. Left side represent the spherical fuel, the right side represent the aspherical fuel. (A) no debonding case; (B)–(E) partial debonding case; (F) full debonding case.

- Considering the process of gap formation - debonding or unzipping - a stress of 80 MPa is assumed necessary to initiate the separation between buffer-IPyC interface.
- The high stresses that develop ensure that the unzipping continues.
- In case "A" there is no gap formation between the buffer and IPyC layers. In that case we assume that the buffer layer is bonded to the IPyC layer along the whole surface.
- The TRISO particles "B–E" represent the cases where the gap between the buffer-IPyC layers is forming.
- Case "B" shows unzipping between the buffer and IPyC layers reaching the level of 30% of the interface, while in the case of "C" it is 50%, "D" – 80%, and "E" – 90% of the interface has debonded.
- Case "F" represents the scenario, where a complete gap between both coating layers is observed. It might be noticed, that in the case of the aspherical TRISO particle, the full debonding is not observed.

Asphercial fuel

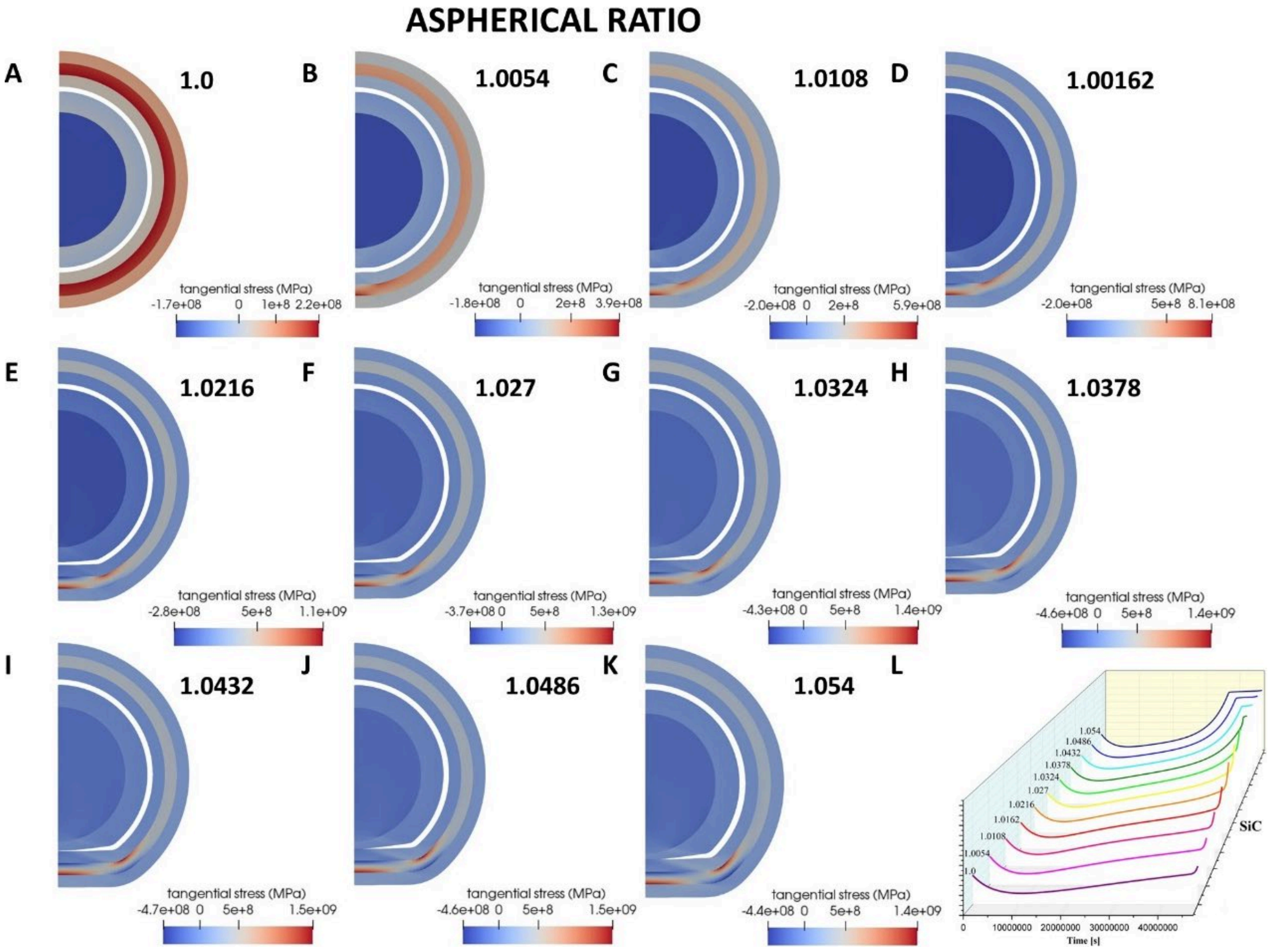


Fig.3 TRISO particle halves ''A–K'' with a different aspherical ratio.
The graph ''L'' presents how the SiC stress changes in time with increasing aspect ratio.

- Fig. 3 shows eleven cases of the aspherical TRISO particle with full debonding at the buffer-IPyC junction.
- Each case represents a different sphericity with aspect ratio* in the range of 1.0 to 1.054.
- Based on the obtained results it might be noticed that with increasing aspect ratio the tangential stress is increasing from 3.9e8 to 1.5e9 MPa.
- It can be also noted that due to increasing aspect ratio, the gap thickness between buffer and IPyC layers also increased.

*The aspect ratio is a measure of the severity of deformity in a TRISO particle.

- Tab.2 present the change of the gap thickness according to the asphericity of the TRISO particle.
- The gap thicknesses were determined for eleven TRISO halves presented at the Fig. 3.
- Each thickness was estimated in the mid-plane of each sample.

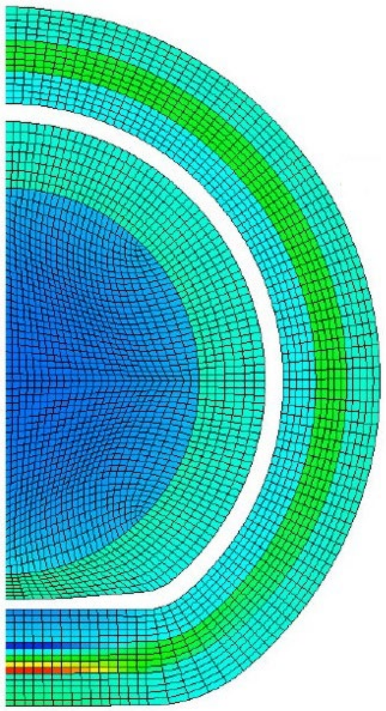
Tab.2 Gap thickness according to the aspherical ratio of the TRISO fuel

Aspherical ratio	Gap thickness[a]
1.0	14.1
1.0054	14.2
1.0108	14.2
1.00462	14.3
1.02016	14.5
1.027	14.7
1.0324	14.9
1.0378	15.2
1.0432	15.6
1.0486	16.1
1.054	16.5

[a] Gap thickness listed in units of [μm].

Conclusions

- Based on the experimental data obtained through the AGR-1 research program, it was possible to perform TRISO fuel simulations with the use of the Bison code.



- Both the simulated and experimental results show that:

1) The most likely case is gap formation along the buffer-IPyC interface.
2) Partially unzipped particles occur less likely.
3) The least possible scenario is the situation where there is no gap formation at the buffer-IPyC junction.

- Results obtained for both spherical and aspherical fuel were nearly identical.

- Fuel asphericity influences the thickness of the gap that occurs at the buffer-IPyC junction, such that with increasing aspect ratio the gap thickness increases.

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