Development of a stress analysis code for TRISO particles in the framework of the PUMA Project

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Introduction

The PUMA project, a Specific Targeted Research Project of the European Union EURATOM 6^{th} Framework Program, is mainly aimed at providing additional key elements for the utilisation and transmutation of plutonium (Pu) and minor actinides (MA) in future (high temperature) gas-cooled reactor designs. The latter are promising tools for improving the sustainability of the nuclear fuel cycle, hereby also contributing to the reduction of Pu and MA stockpiles, and to the development of safe and sustainable reactors for CO_2-free energy generation [1].

Objectives

TU Delft participates in the optimisation of the fuel design of HTRs fuelled with plutonium and/or minor actinides. To this end, the failure rates of TRISO coated fuel particles will be calculated during irradiation by coupling a neutronics, thermal-hydraulics and a fuel depletion code system, which will deliver the fuel temperature and power density profiles, to an in-house developed stress analysis code, called PASTA (PArticle STress Analysis), as shown in Fig. 1 [2].

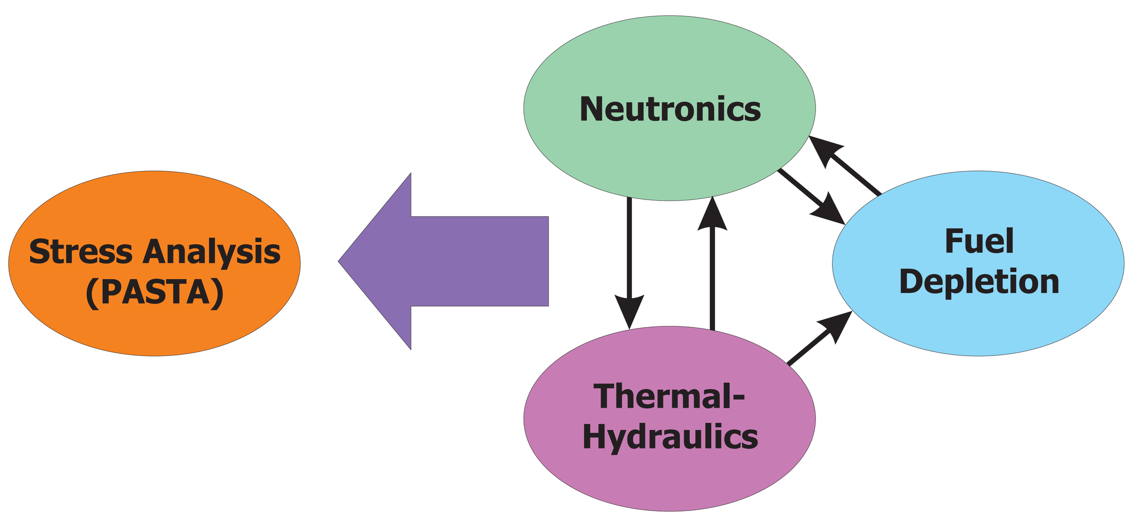

Figure 1: Overview of the fuel performance model.

Methodology

- Improvement of the stress analysis model: a confident calculation of the fuel failure fraction relies on an accurate description of the possible failure mechanisms. Considering the typical response of a particle during irradiation shown in Fig. 2, a crack-induced failure model has been incorporated in PASTA.

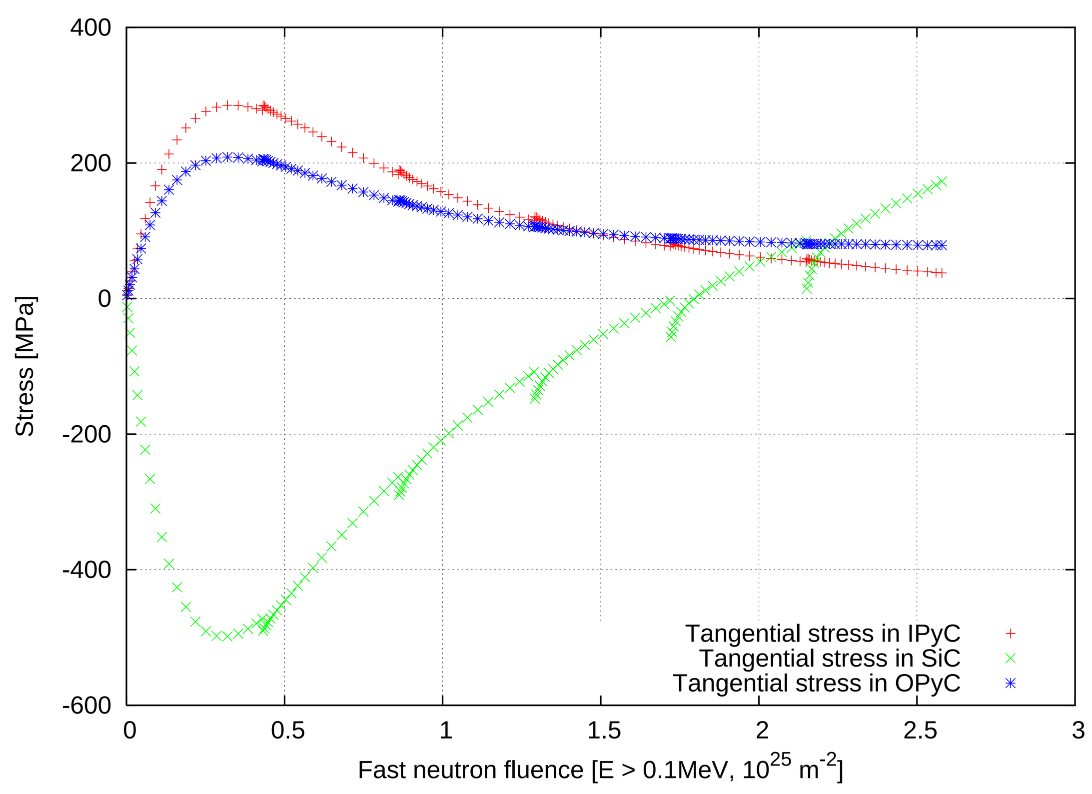

Figure 2: Maximum tangential stresses in the coated layers of a particle irradiated in a PBMR-400 pebble bed reactor.

The aim of the crack model is to describe the impact of a cracked IPyC and/or OPyC layer on the total failure probability of the SiC layer (generally calculated by a Weibull distribution in a pressure-vessel model), hence the particle. Cracking of a PyC layer can occur, inducing a high tensile stress at the PyC-SiC interface even though the average stress in SiC is compressive. The different scenarios that can occur during irradiation are depicted in Fig. 3.

- Extension of the model to include specific mechanisms related to Pu/MA fuel kernels, such as helium production and diffusion.

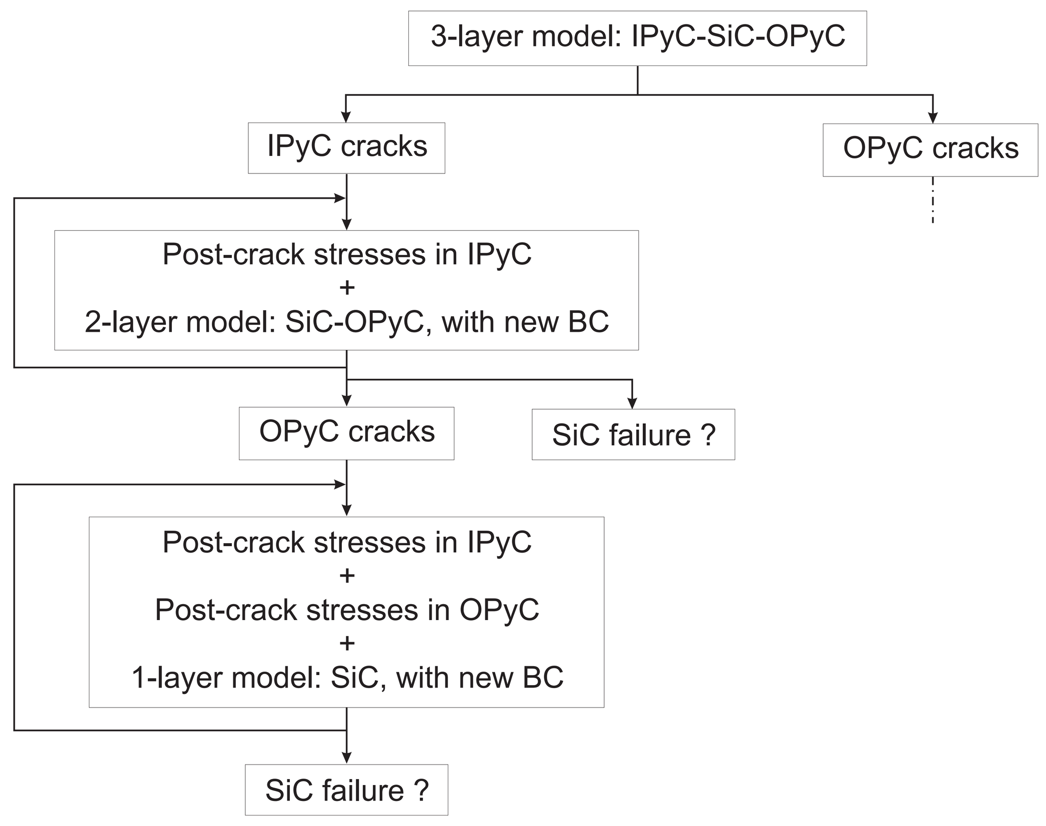

Figure 3: Description of the crack-induced failure model.

- Application of the calculation scheme in Fig. 1 to Pu/MA fuel kernels and optimised particle designs delivered by other partners.

Conclusion

The HTR can fulfill the purpose of Pu and MA incineration due to its unique and unsurpassed safety features. The success of such an option relies on the integrity of the fuel coated particle. Improvement of an in-house developed stress analysis code is in progress and will make the prediction of the fuel failure more reliable.

The target burn-up, hence transmutation of Pu/MA, will be confronted with failure fractions of the fuel particles from which an adequate design should be retained for the purposes of the PUMA project.

References

[1] J.C. Kuijper. PUMA - Plutonium and Minor Actinides Management in Thermal High-Temperature Reactors. *2007 Int. Congress on Advances in Nuclear Power Plants*, Nice, France, May 13-18, 2007.

[2] B. Boer et al. Mechanical Stresses in Fuel Particles and Graphite of High Temperature Reactors. *Joint Int. Top. Meet. on Mathematics & Computation and Supercomputing in Nuclear Applications*, Monterey, California, April 15-19, 2007.

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