8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Coupled 1D thermohydraulic - 3D thermomechanical study of a space nuclear reactor

S. Pascal

CEA/DEN/DANS/DM2S/SEMT/LM2S
CEA Saclay, 91191 Gif-sur-Yvette (France)
serge.pascal@cea.fr

Key Words: *Thermomechanics, Thermohydraulics, Nuclear Reactor Design, Space Application.*

ABSTRACT

Since a few years now, CEA has been maintaining a waking state in its space application of nuclear energy by carrying out some conceptual studies on systems which could cover a power range of 100-500 kWe. Results of these ongoing studies are gathered on the OPUS project and have been already subjected to publication [1-3]. This project have led to the design of a gas cooled, fast nuclear reactor able to supply the energy required by a power system based on a Brayton cycle. This design has been driven by the usual constrain of space applications to lower the system mass as much as possible. Thus the choice of a gas cooled system enables to work at high temperatures in order to increase the thermodynamic cycle efficiency. The inlet and outlet coolant temperatures are set to 880K and 1,300K, respectively. This temperature level requires the use of ceramic materials for the core structures. In particular, the design of the fuel elements is based on the concept of fuel particle, already used in the past in High Temperature Reactors. In order to validate this design, Finite Element computations has been performed with Cast3M, the finite element software developed by the CEA. These computations simulate the thermomechanical behavior of the reactor at nominal power and for the duration of a mission, what represents an operating time of 2,000 Equivalent Full Power Days (EFPD). Our contribution aims at presenting the details of these computations.

The simulations first involve a homogenization model of the thermomechanical behavior of the fuel elements, since it is not possible to represent all the material heterogeneity, each fuel elements involving thousands of nuclear fuel particles. This model is based on an analytical approach derived by Hervé and Zaoui [4,5], which has been extended to irradiation-induced phase deformations [6]. Second, they are based on a coupled approach of the thermohydraulic and the thermomechanics of the system, since Cast3M either deals with fluid and structural mechanics. Coolant flow is modeled in 1D with the assumption that there is no pressure drop. The structures are modeled in 3D. The thermal power distribution in the core is fit to neutronic calculations of the system, performed with the Monte-Carlo code TRIPOLI™. The relation of heat exchange between the coolant and the structures is given by the Dittus-Bolter analogy. The heat radiated between the core and the pressure vessel, as well as the one radiated

away in space, are also modeled. Finally, the temperature of the system is fully resolved only by setting the inlet coolant temperature and mass flow and the power level of the reactor. Once the thermal problem solved, the mechanical behavior is computed. Contact modeling between the fuel assemblies lets them free to expand axially and then leads to particularly well estimate the stress level in the reactor core. The shrinkage or swelling of the materials under irradiation and the evolution of their thermal and mechanical properties are taken into account to screen the system evolution during a mission. For a 100kWe system, the results of these simulations show that the current reactor design seems able to stand all the duration of a mission.

REFERENCES

[1] E. Rigaut, X. Raepsaet, "First studies on the optimized propulsion unit system OPUS within the current nuclear space program in CEA", Proceedings of SNC 2005, San Diego, USA, (2005).

[2] X. Raepsaet, D. Marion, D, Valentian, "Nuclear Energy for Space: past CEA activities and ongoing OPUS studies", Proceedings of ENC 2005, Versailles, France, (2005).

[3] X. Raepsaet, S. Pascal, "Neutronic and Mechanical design of the reactor core of the OPUS system", Proceedings of ICAPP 2007, Nice, France, (2007).

[4] E. Hervé, A. Zaoui, "N-layered inclusion-based micromechanical modeling", International Journal of Engineering Science, Vol. **31**, pp. 1-10, (1993).

[5] E. Hervé, "Thermal and thermoelastic behavior of multiply coated inclusion-reinforced composites", Int. J. Solids Struct., Vol. **39**, pp. 1041-1058, (2002).

[6] S. Pascal; "Change-scale modeling of the thermomechanical behavior of particle-based nuclear fuel assemblies", Proceedings of SMiRT 18, Beijing, China, (2005).