DIRECT CALCULATION OF SAFETY-RELATED PARAMETERS FOR COUPLED TRANSIENTS USING MONTE CARLO NEUTRONICS PLUS SUBCHANNEL THERMAL-HYDRAULICS

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ABSTRACT

The recent development of *high-fidelity* coupled neutronic-thermalhydraulic tools based in Montecarlo (MC) transport codes provides a complete independent calculation alternative for a wide range of safety-related parameters within light water reactors. In particular, the application of such approach for short-time coupled transients at full-scope models represents a compelling work path. A novel implemenation of a coupled tool betweeen the well-known Serpent 2 (MC neutronics) and SUBCHANFLOW (subchannel TH) codes is here used to study short time RIA-kind scenarios (i.e. Reactivity Initiated Accidents) in SPERT-IIIE reactor, showing the aptness of this approach to obtain key safety-parameters for coupled transients within a realistic PWR geometry and operational conditions avoiding almost all traditional approximations.

KEYWORDS: Monte Carlo, Serpent 2, SPERT-IIIE, coupled transients

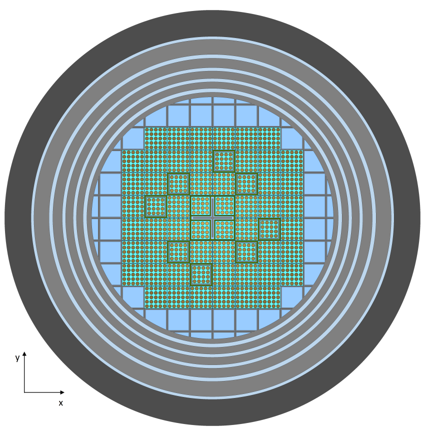
1. INTRODUCTION

The development of highly accurate methodologies in reactor physics, usually defined as *high-fidelity* is oriented to provide multiphysics results through the use of calculation tools with a lower number of approximations within the modeling approach. In particular, the use on MC based neutronics within full-scope light water reactors represents a novel approach that avoids almost all traditional approximations [1–3]. Besides, the combination with subchannel thermalhydraulics (TH) allows the development of full-scope analysis where the direct obtention of pin-level parameters (such as power peaking factors or DNBR) arises as one of the most interesting applications.

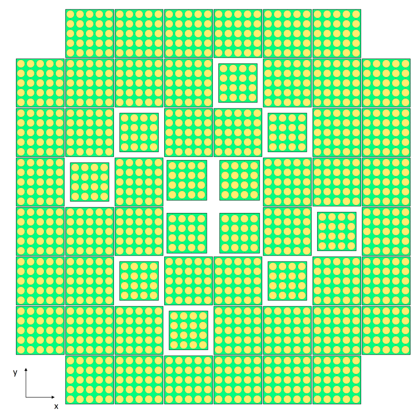
It is thus the objective of this work to show the capability to obtain safety-related parameters for realistic transient cases using a coupled tool betweeen Serpent 2 (MC neutronics) [4] and SUBCHANFLOW (subchannel TH) [5], named here directly as *Serpent-SCF*. This tool has proven to be suitable for steady-state, burnup and transient scenarios [1–3,6], where capabilities have been already assessed within traditional PWR and VVER designs. For such purpose diverse analyses for the experiments within the well-known SPERT-IIIE reactor [7] campaign are considered, that reproduce the geometrical and operational condition of short time-scope coupled transients (i.e. RIA-kind) within PWR geometries. The aptness of the approach to tackle calculation of the evolution of typical key-parameters such as DNBR, fuel enthalpy rise and cladding temperatures avoiding almost all traditional considerations (i.e. cell-core approach, pin-power reconstruction, fuel assembly TH, etc.) will be thus studied.

2. THE SPERT-IIIE REACTOR

The proposed analysis is developed using the experimental data from the SPERT-IIIE transient tests T-84, T-85 and T-86, which start from a reactor power of 20MWth to then insert 0.46$, 0.87$ and 1.17$ respectively [7]. These transient cases reproduces a RIA-kind scenario within typical PWR geometrical and operational conditions, where the reactivity is inserted through a sudden withdrawal of a central control rod and the negative temperature feedbacks compensate this effect. In-depth analyses for the former two transients can be gathered in in previous works [2], where the same models are here considered, depicted in the plots presented in Figs. 1a and 1b.



(a) Serpent model x-y cut at centre of core.



(b) SCF model.

Figure 1: Models for SPERT-IIIE case [2].

3. RESULTS

The results for the three analyzed experiments are first discussed in terms of the consistency of the obtained evolution of the global parameters to then proceed to the detailed results and the calculation of safety-related parameters. To begin with, the total power evolution is compared with the experimental results in Fig. 2, where a good agreement is found for all cases. Afterwards, to show the *high-fidelity* capabilities of the tool, the evolution of power and temperature fields during the T-86 experiment are presented in Figs. 3a and 3b respectively, where is important to note that no pin-power reconstruction methodology was required. On top of that, the maximum increase in clad temperature comparison for such cases is presented in 1.

Finally, diverse *traditional* PWR safety-related parameters are analyzed, where unfortunately the comparison of such evolution with experimental values is not possible. Consequently, the DNBR and enthalpy-rise evolutions are presented in Figs. 4a and 4b, where, as expected, the T-86 experiment represents the most-demanded scenario.

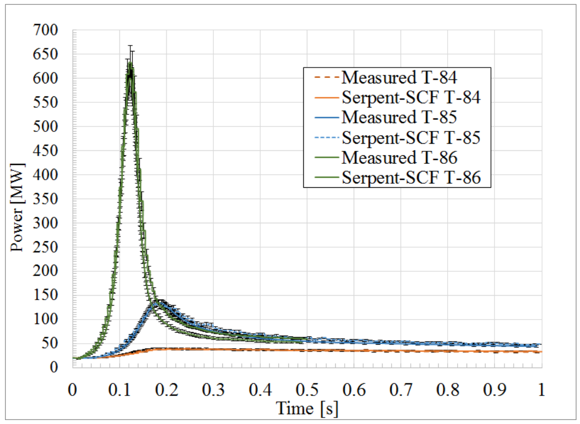
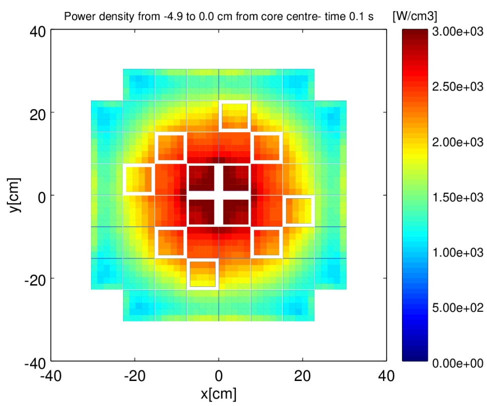
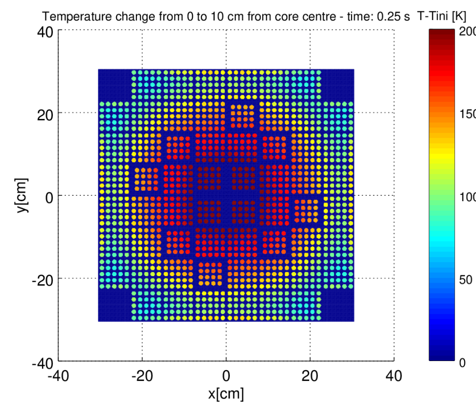


Figure 2: Power evolution comparison.



(a) Power at t = 0. s.



(b) Temperature difference (to initial) t = 0.25 s.

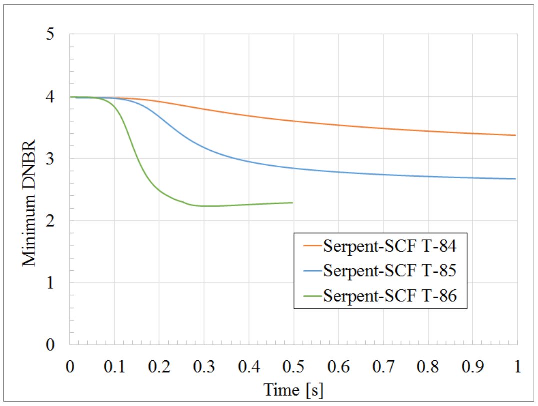
Figure 3: Power and temperatures evolution for case T-86.

Table 1: Maximum clad temperature raise comparison.

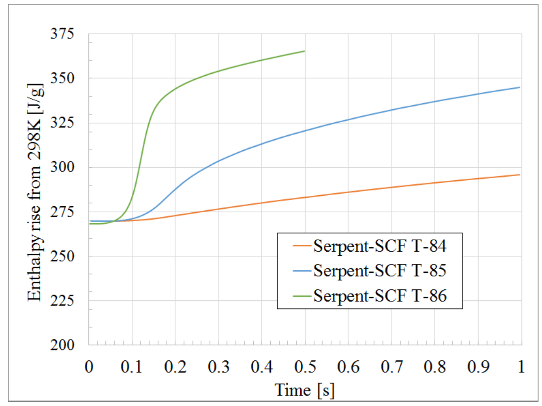
Case	Measured [K]	Calculated *Serpent-SCF*[K]
T-84	8.3	6
T-85	11.1	18
T-86	22.2	25

4. CONCLUSIONS

The capability to obtain safety-related parameters for transient scenarios using MC-based plus subchannel TH was assessed. Typical parameters traditionally considered to characterize these



(a) DNBR.



(b) SCF model.

Figure 4: Evolution of safety-related parameters.

transients such as DNBR, fuel enthalpy rise and cladding temperatures where obtained using a novel implementation of the *Serpent-SCF* coupling within diverse transient scenarios from hot full power from SPERT-IIIE reactor. The aptness of the proposed approach to obtain such safety-related key-parameters avoiding almost all traditional considerations was assessed (i.e. cell-core approach, pin-power reconstruction, fuel assembly TH, etc.).

REFERENCES

[1] D. Ferraro, M. García, V. Valtavirta, U. Imke, R. Tuominen, J. Leppänen, and V. Sanchez-Espinoza. "Serpent/SUBCHANFLOW pin-by-pin coupled transient calculations for a PWR minicore." *Annals of Nuclear Energy*, **volume 137**, p. 107090 (2020). URL http://www.sciencedirect.com/science/article/pii/S0306454919306000.

[2] D. Ferraro, M. García, V. Valtavirta, U. Imke, R. Tuominen, J. Leppänen, and V. Sanchez-Espinoza. "Serpent/SUBCHANFLOW pin-by-pin coupled transient calculations for the SPERT-IIIE hot full power tests." *Annals of Nuclear Energy*, **volume 142**, p. 107387 (2020).

[3] D. Ferraro, M. García, V. Valtavirta, U. Imke, R. Tuominen, J. Leppänen, and V. Sanchez-Espinoza. "OECD/NRC PWR MOX/UO2 core transient benchmark pin-by-pin solutions using Serpent/SUBCHANFLOW." *Annals of Nuclear Energy*, **volume 147**, p. 107745 (2020). URL http://www.sciencedirect.com/science/article/pii/S0306454920304436.

[4] J. Leppänen et al. "The Serpent Monte Carlo code: Status, development and applications in 2013." *Annals of Nuclear Energy*, **volume 82**, pp. 142 – 150 (2015). URL http://www.sciencedirect.com/science/article/pii/S0306454914004095.

[5] U. Imke et al. "Validation of the Subchannel Code SUBCHANFLOW Using the NUPEC PWR Tests (PSBT)." *Science and Technology of Nuclear Installations*, **volume 2012**, p. 12 (2012). URL http://downloads.hindawi.com/journals/stni/2012/465059.pdf.

[6] D. Ferraro, M. García, U. Imke, V. Valtavirta, R. Tuominen, J. Leppänen, and V. Sanchez-Espinoza. "Serpent / SUBCHANFLOW coupled burnup calculations for VVER fuel assemblies." In *International Conference on Physics of Reactors 2020* (2020).

[7] Arne P. Olson. "SPERT III E CORE: FACILITY SPECIFICATION." IAEA Technical Report Series No. 480, available at https://www.iaea.org/publications/10578 (2015).