This work presents a preliminary analysis of the coupled thermo-hydraulics and neutronics of circulating nuclear fuel systems like the thermal Molten Salt Reactor (MSR), one of the “Generation IV” International Forum concepts [1]. This kind of nuclear reactor adopts a molten salt medium, which flows through channels in a graphite moderated core and plays the role of both heat generator and coolant [2]. In the core fissile material occurs within the flowing fuel salt, which then circulates in a primary heat exchanger, where the heat is transferred to a secondary liquid salt coolant; the fuel salt then flows back to the reactor core (see Figure 1).

MSRs are featured by a strong coupling between neutronics and thermo-hydraulics, which can be properly treated in a multi-physics approach. In this paper a simple 2-D geometry, representing a typical channel of a sub-critical MSR that comprises both the flowing molten salt fuel and the graphite matrix, has been considered. Physics of such system can be modelled by means of eight coupled partial differential equations, describing the fluid motion and the balances of energy, neutrons and precursors (see Table 1). With reference to this complex and highly non-linear system, a code-to-code comparison tool has been developed to catch some relevant features of both the steady state and the dynamic behaviour of the considered MSR channel. Analyses have been carried out for both laminar and turbulent flow regimes, focusing on the influence that graphite has on such system, in the light of a thermo-hydraulic validation discussed in a parallel work on the basis of both an analytical framework and a code-to-code (COMSOL® vs. FLUENT®) comparison [2]. In particular, the time constants of some physical quantities have been determined: the neutron flux, the precursors concentration, the fluid temperature and the graphite temperature, whose time evolution is of extreme interest for the investigation of the dynamic behaviour as well as for the most appropriate control strategy to be adopted in the current development of Molten Salt Reactors for Generation IV.

In short, this study has provided important information about the channel behaviour of a sub-critical MSR and paved the way for further progress concerning more complex and design-oriented simulations, which should consider more representative geometries of the power channels (i.e. not of the whole reactor core) and more models in the neutronic modelling of both the molten salt and the graphite, as well as for their “nuclear” interaction.

**SUMMARY**

**RESULTS**

The initial state assumes the reactor to be at zero power, with an established hydrodynamic pattern. A start-up transient has been simulated, adopting for the external neutron source a cosine spatial shape [4]. The physics of the system brings to the attainment of a steady state by relaxing the initial conditions. Simulations have been carried out for both cases a) and b) in turbulent flow with a Reynolds number (Re) equal to 8 x 10^5. Moreover, for the case a), further analyses have been performed with Re = 9 x 10^5 and compared to the simulations with laminar flow of Ref. [4].

In laminar flow the buoyancy effect (according to the Boussinesq approximation) is more important than in the turbulent one because the fluid temperature is higher, and the fluid recirculation is more evident: as a consequence, the precursors are more concentrated in the upper part of the domain for the turbulent case (see Figure 3). The different flow regimes significantly influence the dynamic behaviour of the system, as shown in Figure 4: the time constant of the fluid temperature in the two considered turbulent regimes is lower than in laminar flow, showing a relevant dependence on the imposed inlet velocity, which also affects the precursors time evolution.

**Case a**

A specific feature of the graphite + molten salt (fuel/coolant) system, unlike the externally cooled solid fuel rods adopted in the conventional nuclear reactors, is shown in Figure 5: initially, the heat is transferred from the fuel/coolant to the graphite matrix, but a situation is eventually reached where the radial heat flux is inverted between them. This behaviour is clear in Figure 6: in the simulated transient, and in any case in steady state operation, the graphite temperature is higher than the molten salt temperature, due to the assumed heat transfer boundary conditions. The radial temperature profile of the graphite is affected by the heat transfer coefficient (h) and the heat generation of the fuel/coolant, significantly influencing the temperature of the graphite, which starts from the value of the Nusselt number (Nu = 461) obtained in this case results in a very good agreement with that achievable by means of the well-known Dittus-Boelter correlation, as thoroughly discussed in [3]. As shown in Figure 6, the neutron flux, the precursors concentration, the fluid and graphite temperatures exhibit different time scales, which are relevant for the operation and the control of the reactor and, more in general, of the overall nuclear power conversion system, as discussed in (4). It must be noticed that the time constant of graphite is much greater than the other ones; moreover, its order of magnitude is very good agreement with that achievable by means of the well-known Dittus-Boelter correlation, as thoroughly discussed in [3].

**Case b**

A specific feature of the graphite + molten salt (fuel/coolant) system, unlike the externally cooled solid fuel rods adopted in the conventional nuclear reactors, is shown in Figure 5: initially, the heat is transferred from the fuel/coolant to the graphite matrix, but a situation is eventually reached where the radial heat flux is inverted between them. This behaviour is clear in Figure 6: in the simulated transient, and in any case in steady state operation, the graphite temperature is higher than the molten salt temperature, due to the assumed heat transfer boundary conditions. The radial temperature profile of the graphite is affected by the heat transfer coefficient (h) and the heat generation of the fuel/coolant, significantly influencing the temperature of the graphite, which starts from the value of the Nusselt number (Nu = 461) obtained in this case results in a very good agreement with that achievable by means of the well-known Dittus-Boelter correlation, as thoroughly discussed in [3]. As shown in Figure 6, the neutron flux, the precursors concentration, the fluid and graphite temperatures exhibit different time scales, which are relevant for the operation and the control of the reactor and, more in general, of the overall nuclear power conversion system, as discussed in (4). It must be noticed that the time constant of graphite is much greater than the other ones; moreover, its order of magnitude is very good agreement with that achievable by means of the well-known Dittus-Boelter correlation, as thoroughly discussed in [3].

**REFERENCES**