Steady-state and dynamic behavior of a moderated molten salt reactor

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The moderated Molten Salt Reactor (MSR) is an attractive breeder reactor. However, the temperature feedback coefficient of such a system can be positive due to the contribution of the moderator, an effect that can only be avoided with special measures. A previous study (Nagy et al., 2010) aimed to find a core design that is a breeder and has negative overall temperature feedback coefficient. In this paper, a coupled calculation scheme, which includes the reactor physics, heat transfer and fluid dynamics calculations, is introduced. It is used both for steady-state and for dynamic calculations to evaluate the safety of the core design which was selected from the results of the previous study. The calculated feedback coefficients on the salt and graphite temperatures, power and uranium concentration prove that the core design derived in the previous optimization study is safe because the temperature feedback coefficient of the core and of the power is sufficiently negative. Transient calculations are performed to show the inherent safety of the reactor in case of reactivity insertion. As it is shown, the response of the reactor to these transients is initially dominated by the strong negative feedback of the salt. In all the presented transients, the reactor power stabilizes and the temperature of the salt never approaches its boiling point.

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1. Introduction

The Molten Salt Reactor (MSR) is one of the six reactor types chosen in the Generation IV initiative (Generation IV International Forum, 2002), which aims for safer, more efficient and proliferation resistant reactor designs. This reactor uses a liquid fuel consisting of molten fluoride salts which is circulated in the primary loop through the core and the heat exchanger. The actinides are dissolved in the salt mixture as a fluoride salt, while other fluoride salts (such as LiF, BeF\textsubscript{2}, NaF, ZrF\textsubscript{4}) are used in the mixture to provide a low melting point. The heat produced by fission in the core is mainly deposited in the salt itself. This heat from the radioactive liquid is then transferred to a clean liquid and ultimately either to a steam or a gas cycle.

The MSR is a unique reactor design and it has some characteristics which cannot be found in other reactor types. Firstly, the spatial distribution of the delayed neutron precursors is decoupled from the flux distribution because the delayed neutron precursors travel through the core and the whole primary loop with the fuel salt. As a result, the delayed neutrons are emitted in a different location than that of the fission event which produced the precursor and a part of the precursors will decay outside the reactor core. Thus, the kinetics of the MSR are different from other types of reactors. Secondly, most of the heat is directly deposited into the salt which acts as the coolant of the reactor. In case of a moderated system, part of the fission heat is deposited in the moderator by gamma and neutron heating. This heat is removed from the core by the salt as well. Therefore, the moderator is at a higher temperature than the salt during operation.

Several publications have discussed the physical aspects of liquid fuel reactor systems, from basic reactor physics problems (Lapenta and Ravetto, 2000), to theoretical aspects of these dynamic systems, which include the generalization of the quasi-static method for the MSR (Dulla et al., 2004), and the dynamic space and frequency dependent response of MSRs to stationary perturbations (Pazsit and Jonsson, 2011). One-dimensional coupled neutronics and heat transfer programs were developed for time-dependent analysis (Krepel et al., 2005; Lecarpentier and Carpentier, 2003) and benchmarked against experimental data of the MSRE together with many other codes (Depiech et al., 2003) in the framework of the MOST project (Kophazi et al., 2003).

Two independent code systems were developed for 3D dynamic calculations of a moderated MSR. These were used for simulation of various reactivity- and pump-driven transients as well as accident scenarios, such as fuel channel blockage of the MSRE (Haubenreich and Engel, 1970) and MSBR (Robertson, 1971). The first code was realized by the modification of computational tools designed for pressurized water reactors whereby the original...