The effects of core zoning on the graphite lifespan and breeding gain of a moderated molten salt reactor

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1. Introduction

The MSR is one of the six reactor types chosen in the Generation IV initiative (Generation IV International Forum, 2002). It employs a circulating liquid fuel which can be readily pumped between the core and the external heat exchangers in the primary loop. The produced heat is removed from the core by the salt itself and it is transferred to a clean intermediate liquid that then transfers heat to either a steam or a gas cycle. The reactor vessel and the piping are designed so that criticality can be achieved only in the core. Usually fluoride salts are considered for the primary loop of the reactor and the preferred cation components are Li, Be, Na, Zr. The actinides are dissolved in the salt mixture as fluoride salts. The MSR considered in this paper employs a graphite moderator in the core and the salt flows through channels of the graphite structure.

The MSR has advantages on fuel fabrication, neutron economy and high temperature operation due to the low absorption, high boiling point and low vapor pressure of the salt. The fluid fuel is a unique feature of the reactor which provides exceptional breeding capabilities because the composition of the salt can be continuously varied by chemical processes during operation. As a result, moderated MSRs which utilize the thorium fuel cycle can reach breeding. The fertile isotope of the thorium fuel cycle is $^{232}$Th which forms $^{233}$U after a neutron capture followed by two beta decays. The intermediate products are $^{233}$Th and $^{233}$Pa. The half-life of these two isotopes is 22.3 min and 27 days, respectively. This long half-life of $^{233}$Pa results in a high probability of capturing a neutron before it decays to uranium and the formed isotope will be $^{234}$U, a non-fissile isotope. To avoid this, it is possible to extract part of the protactinium from the salt during operation and to store it outside the core (Robertson, 1971). In this way, all the removed $^{233}$Pa will decay to $^{233}$U and the $^{233}$U production can be enhanced. Moreover, external stockpiles of protactinium and uranium are formed which are coupled to the reactor. The protactinium stockpile obtains its feed from the reactor while the $^{233}$U formed in the stockpile can be sent back into the core to maintain criticality if needed.

In this overview only the one-fluid, graphite-moderated MSR designs are discussed because this type of MSR is investigated in this paper. The MSR has been considered as a breeder reactor utilizing the thorium fuel cycle since the 1960s, when an extensive research program was conducted at the Oak Ridge National Laboratory (MacPherson, 1985). First, two-fluid non-modernized designs were investigated (MacPherson, 1958). Then, the interest turned to graphite-moderated designs as the knowledge increased on the behavior of graphite in molten salts and on the chemical separation processes of the fission products and actinides in the molten salt. This research program resulted in the design of the Molten Salt Breeder Reactor (MSBR) (Robertson, 1971). After the termination of the program, several graphite-moderated MSR designs were investigated which were based on the ORNL studies. The earliest of those are the FUJI reactors from Japan. From the numerous