MSR – The Bad News from France

From: http://lpsc.in2p3.fr/gpr/gpr/rsfE.htm

The concept of MSFR

The CNRS has been involved in molten salt reactors since 1997. Starting from the Molten Salt Breeder Reactor project of Oak-Ridge, an innovative concept called Molten Salt Fast Reactor or MSFR has been proposed, resulting from extensive parametric studies in which various core arrangements, reprocessing performances and salt compositions were investigated to adapt the reactor in the framework of the deployment of a thorium based reactor fleet on a worldwide scale (see next paragraph below). The primary feature of the MSFR concept is the removal of the graphite moderator from the core (graphite-free core), resulting in a breeder reactor with a fast neutron spectrum and operated in the Thorium fuel cycle. MSFR has been recognized as a long term alternative to solid fuelled fast neutron systems with unique potential (negative safety coefficients, smaller fissile inventory, easy in-service inspection, simplified fuel cycle…) and has thus been selected for further studies by the Generation IV International Forum in 2008.

In the MSFR, the liquid fuel processing is part of the reactor where a small side stream of the molten salt is processed for fission product removal and then returned to the reactor. This is fundamentally different from a solid fuel reactor where separate facilities produce the solid fuel and process the Spent Nuclear Fuel. Because of this design characteristic, the MSFR can thus operate with widely varying fuel composition. Thanks to this fuel composition flexibility, the MSFR concept may use as initial fissile load, 233U or enriched (between 5% and 30%) uranium or also the transuranic elements currently produced by PWRs in the world.

For more details, please consult the bibliography page of the MSFR.

Historical studies: from the MSBR to the MSFR - Parametric studies

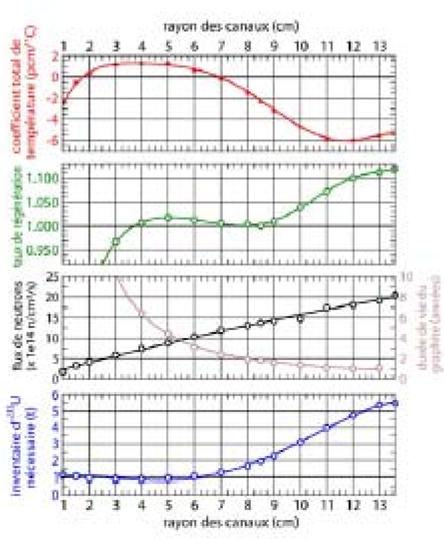

Figure 2 : Évolution de différents paramètres en fonction du rayon des canaux de sel.

Value of various parameters versus channel radii

Within the frame of our studies for nuclear energy production with innovative systems, we have concentrated our efforts on the thorium fuel cycle in molten salt reactors (MSRs). These reactors, based on a liquid fuel circulating in a solid moderator, have been operated successfully in experimental tests done in the 1960s. However, a power reactor project, the Molten Salt Breeder Reactor (MSBR) was discontinued at the time. Although it has been re-evaluated several times during the last decade, the MSBR suffers from several major drawbacks. In particular, the concept aims at obtaining the highest breeding ratio thanks to a high performance and, as a result, constraining, on-line fuel processing system. Today, this fuel reprocessing is deemed non-feasible. Moreover, recent re-evaluations have determined that the MSBR has a slightly positive global temperature coefficient, while, at the time, a negative global temperature coefficient had been announced. With this new finding, the reactor becomes potentially unstable. For these reasons, the MSBR concept, although it is still considered to be one of the reference MSRs, cannot hope to reach industrial status.

In view of finding solutions to these problems and thus define the Thorium Molten Salt Reactor (TMSR) concept, we have carried out several investigations. Like any nuclear reactor, the TMSR must satisfy several constraints beyond the criteria established by the Generation IV International Forum. Our studies consist in analyzing the combined impact of several parameters of the core on these constraints. With this approach, we aim at avoiding a thorough exploration of avenues that seem promising in a given domain to later discover that they are incompatible with other criteria. A large number of core parameters have been submitted to this analysis, leading to a detailed study of the characteristics of MSRs in the thorium fuel cycle, and a better understanding of the physical phenomena that govern their behavior. This has led to a considerable broadening of our field of research. Beyond these studies, our initial evaluations of the moderating ratio revealed unexpected core behavior, i.e. the breeding ratio is not at all monotonous. From this finding, we studied the variation of many core characteristics over a wide range (Figure 2).

Excepting the very thermalized configurations, the temperature coefficient gets better as the thermalization is reduced, all the way to the fast spectrum. We thus confirm the poor safety characteristics of the MSBR, whose spectrum was too soft. Moreover, thanks to the increased number of available neutrons, the breeding ratio is much better for fast spectrum configurations than for epithermal spectra. In parallel, a hardening of the spectrum implies both a shortening of the life time of the moderator and, as a consequence, an increased flow of irradiated graphite that needs to be handled, as well as an expectedly larger fissile matter inventory. We note that other aspects of the geometry such as the core volume or its fractioning into several moderation zones can lead t1/10/07sible to reduce the per GWe inventory by increasing the specific power in the core. However, the graphite irradiation issue does not receive a satisfactory solution. The adjustment of core fractioning into several differently moderating zones flattens the neutron flux so that the damage to the graphite is more homogenous but this does not radically improve the moderator life-time. The fastest configuration, because it contains no graphite in the regions of intense flux in the core, is the only one that does not suffer from this drawback.

If the core is surrounded with a fertile blanket, breeding can be obtained without resorting to very efficient on-line fuel processing. Indeed, reprocessing the full core volume within 6 months suffices in most standard configurations, i.e., if the number of neutrons lost through captures in the moderator or because of neutron escapes, is sufficiently small. The fast spectrum configurations have such good performances in this respect that they can do without a fertile blanket.

With these studies, we have gained new understandings of the behavior of MSRs, ranging from very thermalized neutron spectra to fast spectra. Our results represent a split with previous knowledge in this field. The traditional association of the thorium fuel cycle, the MSR, and the (epi)thermal neutron spectrum is now becoming history, since fast spectra lead to very satisfactory results, indeed much better ones. This reopens the issue of starting such a reactor with plutonium. While it generated too many TRUs in the (epi)thermal spectrum, this avenue can no longer be ignored in the case of the fast spectrum MSR.

The problems raised by the MSBR have thus found solutions. The temperature coefficients can be made negative, either by hardening the neutron spectrum, or with a tighter knit moderator network. Breeding can be obtained with fuel processing that is simpler than that considered for the MSBR thanks to the thorium blanket (or even without one in the fast spectrum configuration). Finally, the moderator's short life-time is an issue that can be solved with the fast spectrum configuration by including no graphite in the core.

This work demonstrates that very acceptable reactor configurations can be defined that best respond to each constraint and this is true of all neutron spectra types. Without ignoring the other solutions, we are turning our attention more particularly to the single salt channel configuration both in its conventional version, and in a very high temperature version.

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