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Experimental verification of design input of the SPHINX concept of MSR (project EROS – Experimental zero power salt reactor SR-0)

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Abstract

The Molten Salt Reactor (MSR) – SPHINX (SPent Hot fuel Incinerator by Neutron fluX) concept is dealing with the solution of a principle problem of sustainable development of nuclear power – current reactors spent fuel treatment by means of nuclear incineration. It means burning of fissionable part of its inventory and transmutation of other radionuclides by use of nuclear reactions with neutrons in an MSR – SPHINX system.

In the SPHINX R&D program, there are besides computational analyses also experimental activities involved in the program, which serves for a verification of design inputs for designing of a demonstration unit of the MSR-type. The experimental program EROS will focus on a large-scale experimental verification of design inputs by use of MSR-type inserting zones into the existing light water moderated experimental reactor LR-0, which may allow to modify it to experimental zero power salt reactor SR-0. There will be a detail description of the proposed program given in the paper together with the so far performed experiments and their preliminary results.

Keywords: Transmutation; Molten salt reactor; Liquid nuclear fuel; Innovative nuclear reactor concepts; GEN IV reactors

1. Introduction

There have been new tendencies of significant decreasing of amount and potential danger of nuclear waste getting up in the world of nuclear power during the last decade. The development of a convenient for those purposes technology has been in fact a rehabilitation of the so called nuclear transmutation technologies well known since the beginning of the first nuclear era, however, having been evaluated in those times as technologically and therefore even economically demanding to a non-acceptable level.

Therefore, an attempt to develop new modifications of those technologies under different conditions at the end of the first nuclear era has been supposed to be promising and acceptable for an efficient closing of nuclear fuel cycle. These new modified transmutation technologies should make it possible to return a fuel component contained in nuclear fuel burned up in conventional nuclear reactors back to nuclear fuel cycle and to turn a significant part of long-lived nuclear waste (heavy metals from the transuranium region) to useful energy without rests and by an irreversible way.

This could be, besides other positive features, a way, which according to our contemporary knowledge could exclude or at least minimize a non-desirable misusing of those nuclear materials. One of the most promising in this sense systems has been the concept of liquid fuel based on molten fluorides (MSR) which development started in USA as early as in the mid 40s and reached a level of nearly demonstration unit in Oak Ridge National Laboratory in the 60s before it was interrupted in 70s of the last century. The substantial part of the MSR project study has been incorporated into suitable forms of international collaboration during the 90s; in 2001, into the European Union's, so called 5th Framework Programme as the project MOST (Molten Salt Technology).

Molten-Salt Reactor (MSR) represents one of the promising high temperature nuclear reactor types for future generation of electricity and of heat for hydrogen production. It also could be used as transmuter to burn plutonium and other

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transuranium elements occurring in the spent nuclear fuel of nowadays-existing nuclear reactor types as introduced by Hron (2004). This seems to be of great importance because the spent fuel management strategy represents one of the most serious problems, which should be appropriately solved for further sustainable development of nuclear power. Molten-Salt Reactor is usually characterized, as a non-classical nuclear reactor type due to a specific character of its fuel, which is liquid – constituted by a molten fluoride salt mixture circulating between a reactor core and a heat exchanger. The fission material (uranium and/or transuranium elements) is dissolved in carrier molten salt, which is also a heat-transferring agent.

The typical fuel of the Molten-Salt Reactor working as the nuclear transmuter is a mixture of fluorides of plutonium and other transuranium elements (Np, Am, Cm), called usually as minor actinides, dissolved in the carrier fluoride salt. The other, very promising mode of Molten-Salt Reactor operation is based on the use of Th–U fuel cycle with minimized production of long-lived nuclear waste in comparison to the U–Pu fuel cycle currently used in present reactor types. In this mode, the MSR works as a reactor-breeder producing own fissile material ^{233}U from fertile ^{232}Th. Essentially the main advantages of MSR comes out from the prerequisite, that this reactor type should be directly connected with the "on-line" reprocessing of circulating liquid (molten-salt) fuel. This fuel salt clean up is necessary within a long run to keep the reactor in operation. As a matter of principle, it permits to clear away typical reactor poisons like xenon, krypton, lanthanides, etc. and also the products of burned plutonium and transmuted minor actinides. On the other hand, the technologies of liquid transuranium molten-salt fuel processing from the current spent fuel and of the on-line reprocessing of MSR fuel represent two killing points of the whole MSR technology, which have to be successfully solved before MSRs deployment in the future as recommended by Garnier et al. (2005).

MSR concepts were investigated by ORNL (USA) in the 60s and 70s. A favorable feedback experience was gained from the successful operation of the MSRE, an 8 MWth experimental reactor, between 1965–1969. In the frame of the Molten-Salt Reactor Program, a reference breeder design with a thermal spectrum and thorium fuel cycle (MSBR) was then proposed and intensively analyzed. The considerable amount of results accumulated by ORNL forms a significant basis for the demonstration of the viability of an MSR breeder concept. However, no realization was done at a significant scale and the premature termination of the program in 1975 left a number of open questions.

2. Renaissance of MSR technology in the frame of Generation IV International Forum

About 25 years of interruption of any significant activities in the area of MSR technology development has caused rather difficult conditions for present day effort in the research and development of MSR technology in the frame of Generation IV International Forum. Moreover, the theoretical aspects of nuclear reactor with liquid fuel flowing through the reactor core likewise of the on-line reprocessing technology are so different from solid fuel reactor concepts, that the knowledge and methods used in classical reactor technology are often nearly inapplicable for MSR systems.

In September 2002, the Generation IV International Forum (being created, in that time, by 10 countries deeply interested in further and prosperous development of nuclear power) selected six nuclear reactor system concepts for further development as the fourth generation of nuclear power reactors. Among this six selected systems also appeared MSR. From the point of view of this system the rest five systems are significantly improving the so far developed and operated, we may call "conventional" reactors which are nearly exclusively utilizing solid and immobilized fuel and operated in uranium – plutonium fuel cycles. The MSR has been the only one concept with a significant innovation – liquid fuel circulating in the primary circuit and allowing an at least quasi-continuous recycling of fuel in a closed fuel cycle. The closed fuel cycle may be tailored to an efficient burn up of plutonium and minor actinides or to an efficient breeding ^{233}U and shifting the whole fuel cycle towards thorium–uranium cycle nearly avoiding generation of transuranium elements.

In December 2002, the Generation IV Technology Roadmap was issued which describes the required system research and development (R&D) necessary to develop each of the selected systems and the approximate time to completion. For a coordination and leading of the R&D effort of the countries interested in individual systems, there have been the Steering Committees formed for each reactor concept including MSR. The decision of the creation of MSR SC has been made by the GIF Policy Group at its meeting in March 2004 and the participating or establishing member countries (USA, France and Euratom) have been nominated. Let us note, that in the year 2003, the Euratom Community joined the GIF originally creating 10 countries as the 11th member.

During the year 2005, there have been organized two meetings of the MSR SC. They decided beside others a principal division of the interest and responsibility of individual members for different priorities in the MSR R&D program:

1. Demonstration of feasibility and evaluation of performance of MSR as a ^{232}Th–^{233}U breeder according to 'Generation_IV_criteria_(France).
2. Evaluation of the performance of MSR for the amount and hazard of nuclear waste namely the LWR spent fuel/ (Euratom).
3. Exploration of the potential of molten salts as an efficient coolant for solid fuel reactors, as an alternative to gasses or liquid metals (USA).

3. The R&D program of MSR – SPHINX concept

One of the principal features of the project SPHINX of an MSR in the role of a burner (how it has been devoted to