Progress in Experimental Development of MSR and FHR Technologies

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INTRODUCTION

A technology of nuclear reactor systems with liquid molten salt fuel has been investigated in the Czech Republic since 1999. After 2005, the studies cover also the areas of thorium – uranium fuel cycle technology, material research and development of selected components of the Molten Salt Reactor technology. An important milestone for further research was the year 2012, when a cooperation agreement (Memorandum of Understanding) on the development of MSR reactors was concluded between the Ministry of Industry and Trade and the US – Department of Energy. Under this agreement, ORNL has provided the UJV Řež and the Research Center Řež with the $^{7}LiF\text{-}BeF_2$ fluoride salt (FLIBE) for research on neutron properties realized on LR-0 reactor in Řež.

Today a new four years (2017 – 2020) project of MSR/FHR technology development is the key component of the Czech R&D program on fluoride salt-cooled nuclear reactor systems. The project is a follow-up and broadening of existing Czech activities in MSR. The aim of the project is to contribute to the development of MSR and FHR reactor technology in the area of reactor physics, nuclear – chemical engineering and material research. The project is solved by a consortium of Czech research institutions and industrial companies leaded by the Research Centre Řež.[1]

EXISTING RESULTS OF THE MSR PROJECT

The main work-packages of the project are:

- Theoretical and experimental physics of MSR/FHR system
- Chemistry and chemical technology of MSR
- Structural materials and components of MSR/FHR technology

The main results achieved in individual work-packages during the first year can be summarized in following:

In the area of **theoretical and experimental physics of MSR/FHR system** the experimental work was focused on neutronics measurement with the FLIBE and other fluorides. Experiments with FLIBE and thorium and uranium fluorides neutronics have been carried out at LR-0 experimental reactor of Research Centre Řež.[2] The tests with FLIBE were performed with real MSR/FHR reactor (66-33 mol %) $LiF\text{-}BeF_2$ coolant salt containing Li-7 isotope (99.994 mol %), which was provided by ORNL and were aimed at studies of neutron spectrum shape to confirm previous results with LiF-NaF salt. Neutron spectra in the 0.8–10 MeV energy range were measured with a Stilbene scintillator (10 × 10 mm) with neutron and gamma pulse shape discrimination. For criticality and neutron spectrum calculations, an LR-0 model has been analyzed using MCNP6.1 with data from various nuclear libraries (ENDF/B-VII.1, ENDF/B-VII.0, JEFF-3.2, JEFF-3.1, JENDL-3.3, JENDL-4, RUSFOND-2010, CENDL-3.1). The older versions of libraries (ENDF/B-VII.0 and JEFF-3.1) were used for comparison with older data and data from benchmarks. Different data libraries were used only for definition of the material insertion; the definition of fuel, moderator, and structural materials is fixed in ENDF/B-VII.0 to suppress the other possible effects to criticality (e.g. from fuel) that are not being investigated in this study. ENDF/B-VII.0 is approved by the national regulator for use in performing licensing calculations at LR-0. The free gas model was used for thermal neutron scattering treatment in case of FLIBE, TEFLON, and stainless steel canister description, and the photo-neutron production is switched off in the physical model.

In the **area of chemistry and chemical technology of MSR** the research on electrochemical separation from molten fluoride salt media method continued. This partitioning technique can be applied within the on-line reprocessing of MSR fuel. During 2017, experimental tests concerning quantitative U-Gd electrochemical separation and reference electrode component´s mutual interactions were realized. Separation of uranium from gadolinium in LiF-CaF2 melt was realized by the means of current-modulated electrolysis with reactive working electrode (Ni). The experiments proved the possibility of good electrolytic resolution to separate actinide species from lanthanides when the current-modulated electrolysis is used thanks to Ni-U alloys formation.[3] Within the studies of reference electrode design and the search for the source of its long-term instability, the reduction of Ni^{2+} ions into Ni metal inside BN body was observed; the mechanism of this reaction will be studied in the next period.

Further effort in **chemical technology** was aimed mainly to the molten fluoride salt loop program. In 2017 the out of pile FLIBE loop was built and put in operation in the Research Centre Řež. The loop is intended to the MSR/FHR technological research, mastering of higher amount of FLIBE salt handling, engineering and control systems verification and for the testing of structural materials and mechanical components of the MSR and/or FHR technologies. The new FLIBE loop is electrically heated and thermally insulated and consists from impeller, two experimental channels for samples, freeze valve and a storage tank. The total volume of the loop is about 18 liters. The structural material of the loop is Inconel 718. The working temperature range is from 550 °C to 750 °C. The started loop test program covers the material corrosion tests, development and verification of special graphite gasket seals and further development of pumps and valves for fluoride salt media.

Fig 4: FLIBE loop in the Research Centre Řež

In the area of **structural materials and components of MSR/FHR technology** the effort was focused on further development of nickel-based superalloy MONICR, verification of special gaskets for molten fluoride salt media and on the design of pumps (impellers) for MSR technology.

The development of nickel-based superalloys is done in the company COMTES FHT. Existing program covered the basic corrosion and irradiation tests of MONICR alloy (similar to American alloy Hastelloy N), a further development of the alloy semi-pilot production and further tests of high/temperature microstructure stability, high-temperature mechanical stability and radiation embrittlement are studied in the new project, in which a molten fluoride salt loop program was initiated. The out of pile loop program will contribute to the preparation of the MSR mock-up design, which should be a final stage of the new project.

The aim of work in 2017 was the further development and verification of experimental production and tests of advanced nickel-based superalloy MONICR, including melting, casting and forming with the focus on microstructure evolution and subsequent experimental production of selected components and equipment from this alloy. Further tests were focused on the observing the microstructure evolution of the MONICR alloy after specific steps of thermomechanical processing.[4]

CONCLUSION

The new project focused on the development of MSR and molten fluoride salt technologies plays an important role in the Czech MSR/FHR program. The results achieved during the first year of the project build on previous research and create prerequisites for the successful development of MSR/FHR technology, especially in the context of international cooperation.

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