CZECH EXPERIMENTAL PROGRAM ON MSR TECHNOLOGY DEVELOPMENT

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12 November 2019

Meet the presenter

Dr. Jan Uhlíř works for the Research Centre Řež, Czech Republic as a Senior Researcher of the Nuclear Fuel Cycle Program. Prior to that, he worked for the ÚJV Řež - Nuclear Research Institute, which is the mother company of the Research Centre Řež. In the period from 1990 to 2012, he was the Head of Fluorine Chemistry Department. His long-term practice is mainly in the fluoride pyrochemical partitioning technologies, recently of those devoted to MSR fuel cycle. He has been a leader of several national projects devoted to the nuclear fuel cycle, pyrochemistry and molten salt technology granted mainly by the Ministry of Industry and Trade of the Czech Republic.

Jan is a representative of the Czech Republic in the Working Party on Scientific Issues of the Fuel Cycle of the OECD-Nuclear Energy Agency, a member of the MSR Provisional System Steering Committee of the Generation Four International Forum as a representative of EURATOM and a member of the High Scientific Council of the European Nuclear Society.

Jan earned his M.S. in Chemical Engineering and PhD. in Nuclear Fuel Technology at the University of Chemistry and Technology in Prague.

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Czech Experimental Program on MSR Technology Development

Beginning of activities in MSR research and development in Czech Republic reaches the second half of 1990s.

The first approach was motivated by the effort to utilize this technology within the P&T systems.

As the nuclear share in the Czech Republic exceeds 1/3 of electricity generation and moreover the country plans to increase it, the solution of spent fuel management has been an important point of further nuclear development.

Originally, we believed that the combination of accelerator driven technology and liquid (molten salt) fuel could be the suitable solution for the incineration of transuranium elements and long-lived fission products from spent nuclear fuel.

- First studies of this system were done in 1998.
- The proposal of the national project was submitted to the Ministry of Industry and Trade of the Czech Republic in 1999.

First steps of the Czech MSR program

R&D activities were initiated by Dr. Miloslav Hron, who then leaded the Czech MSR program until about 2010.

A big motivation at the beginning was the organization of the ADTTA99 conference held in Prague – Průhonice.

Activities in R&D on MSR technology in 2000 - 2010

GEN IV International Forum[SM]

Ministry of Industry and Trade begun to support the MSR technology development in 2000.

Right from the start, the R&D activities included a significant experimental program. The program took full advantage of the opportunities offered by the nuclear research center in Řež, where research and experimental nuclear reactors have been placed side by side with radiochemical complex and fluorine chemistry laboratories. For an experimental MSR program, this is the ideal combination.

Collaboration between research and industry

The main MSR projects were always solved by a consortium of Czech research institutions and industrial companies.

Main organizations and companies involved in the consortium were:

- ÚJV Řež – Nuclear Research Institute (original leading company)
- Research Centre Řež (present leading company)
- COMTES FHT
- Energovýzkum Ltd. Brno
- Institute of Nuclear Physics of the Academy of Sciences of Czech Republic *(2000 - 2005)*
- Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague
- ŠKODA JS (Nuclear Machinery)
- MICo Ltd

When we moved from the idea of subcritical system to classical MSR technology, Institute of Nuclear Physics left the team.

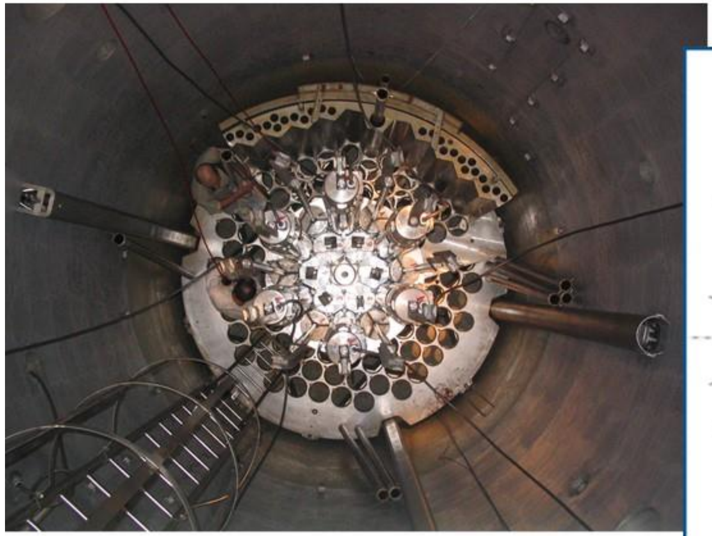
Main aims of the Czech Program on MSR Technology Development

- To appropriately contribute to the knowledge of MSR reactor physics, core design and safety, structural material development and to the technology of Th – U fuel cycle.
- To focus on R&D of technologies applicable within the MSR on-line reprocessing of liquid fuel.
- To verify experimentally selected important areas of MSR technology and to solve existing bottlenecks.
- Three main domestic projects solved or launched during the first decade of the century contributed to the development of MSR technology:
  - “Transmuter LA-10”
  - “System SPHINX with liquid fluoride fuel”
  - “Fluoride reprocessing of spent fuel from GEN-IV reactors”
- Moreover Czech scientists and researchers also actively participated in several MSR projects of EC-EURATOM, IAEA and contributed to the work of Gen-IV as representatives of EURATOM.

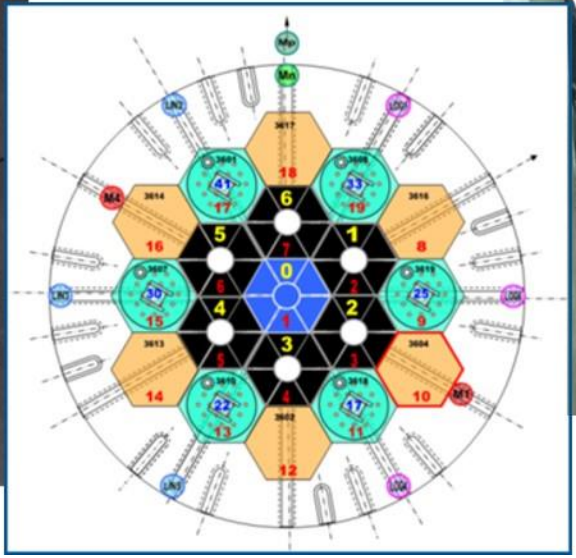
Main experimental activities

MSR physics and neutronics

- Investigations of MSR physics were focused on the experimental measurement of fluoride salt neutronics in the LR-0 and LVR-15 reactors of the Research Centre Řež.
- Basic principles of the method of measurement were successfully verified and selected neutronic data of several fluoride salt mixtures containing U and Th were obtained by irradiation of instrumented probes inserted into central part of LR-0 reactor core where the standard VVER fuel assemblies served as neutron driver.



Inserted zone for LR-0 reactor



Main experimental activities

Fuel cycle technology

- Development of the Thorium – Uranium Fuel Cycle covered both the verification of MSR liquid fuel processing (LiF-BeF_2-UF_4 and LiF-BeF_2-ThF_4) and the laboratory investigation of on-line reprocessing technology.

Investigation of electrochemical separation processes from molten fluoride salt media applicable for MSR on-line reprocessing technology

Processing of pure UF_4 and ThF_4

Preparation of liquid fuels and preparation of pieces of LiF-BeF_2-UF_4 salt disposable for LR-0 reactor inserted probes

Main experimental activities

Structural material development

- Development of structural material for MSR technology, which started in ŠKODA JS - Nuclear Machinery and continued in COMTES FHT company, was crowned in 2011 by experimental production of tubes and sheets from new nickel-alloy called MONICR (Ni-Mo-Cr type super-alloy)

Present development of MONICR alloys is under way in COMTES FHT in the collaboration with other companies including the Research Centre Řež.

The composition of original MONICR alloy is:

Ni	Mo	Cr	Fe	W	Al	Ti	C	Co, Nb, Zr
bulk	13.2 %	6.85 %	2.27 %	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %

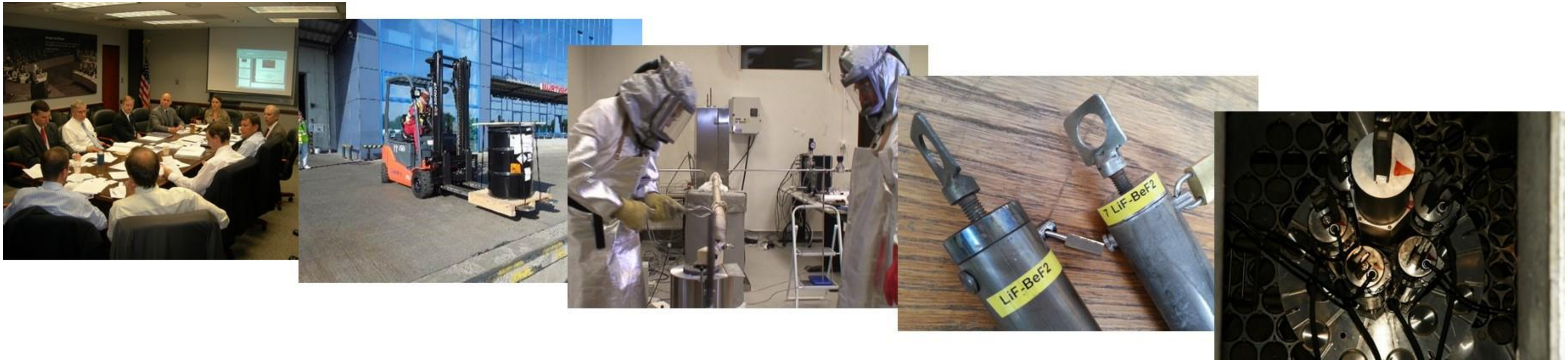
COMTES FHT company reached the experimental pilot production of MONICR alloy (ingots, sheets, wires, tubes).

Milestone in 2012: Signature of Memorandum of Understanding between Ministry of Industry and Trade (MPO) and US - Department of Energy

Before 2012, our MSR physics and neutronics experiments were limited by the fact that we made our reactor experiments with FLIBE salt containing LiF with natural lithium.

Based on the MoU concluded between MPO and US-DOE in 2012, in 2013 we obtained about 75 kg of MSRE coolant salt (Li-7 FLIBE) from Oak Ridge National Laboratory.

- The salt has been used for MSR / FHR neutronics experiments with the final target to determine the temperature evolution of reactivity coefficients. *(The experimental program with this salt started in 2014, experts from ORNL participated in the evaluation of measured data.)*



Experimental activities within the present MSR program

The present program is a follow up and the broadening of existing Czech activities in MSR. The new MSR project was approved by Ministry of Industry and Trade and is granted by the Technological Agency of the Czech Republic.

The project has also the technological character and is also solved by a consortium of Czech research institutions and industrial companies.

Organizations and companies involved in the consortium solving the project are:

- Research Centre Řež (leading company) – MSR physics, neutronics, fuel cycle, material testing
- ÚJV Řež – pyrochemical partitioning (electrochemistry of molten salts)
- COMTES FHT – further development of nickel alloys
- ŠKODA JS – development of selected equipment for MSR technology (impellers)
- MICo – development of selected equipment for MSR technology (flanges-gaskets systems)

Experimental activities within the present MSR program

The project has following work-packages:

- MSR reactor physics and salt neutronics
- MSR fuel cycle technology
- Development of structural materials for fluoride molten salt
- MSR / FHR materials studies (including the molten salt loop program)
- Development of MSR / FHR technology components and equipment
- Basic system studies (including NPPP)

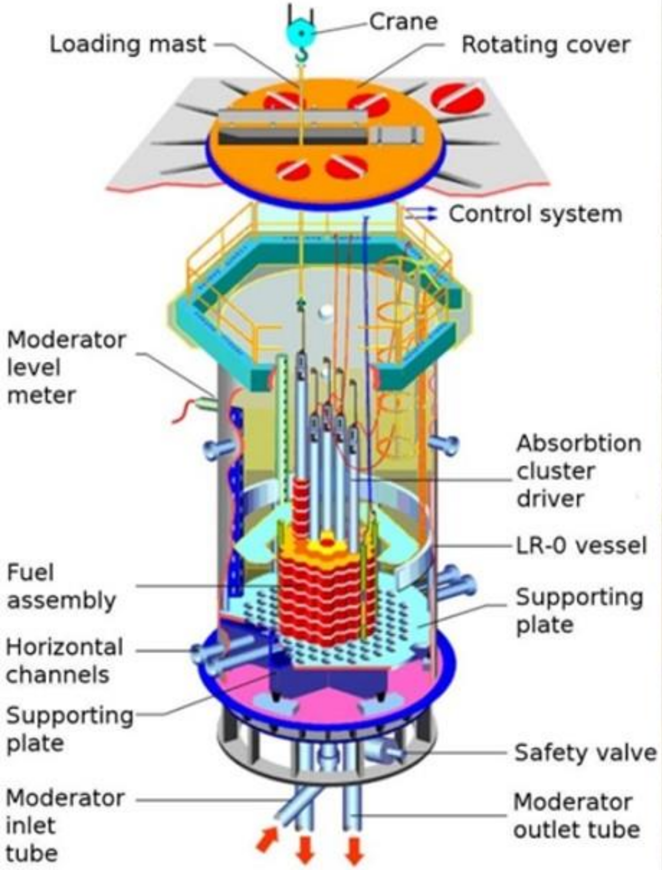
(The collaboration with US partners under the MoU is included in the first work-package.)

Results achieved in MSR physics and salt neutronics

After the measurement of neutron spectra in graphite, FLiNa and FLiBe, the effort was focused on the evaluation of neutronic characteristics of FLiBe (Li-7) and fluorine.

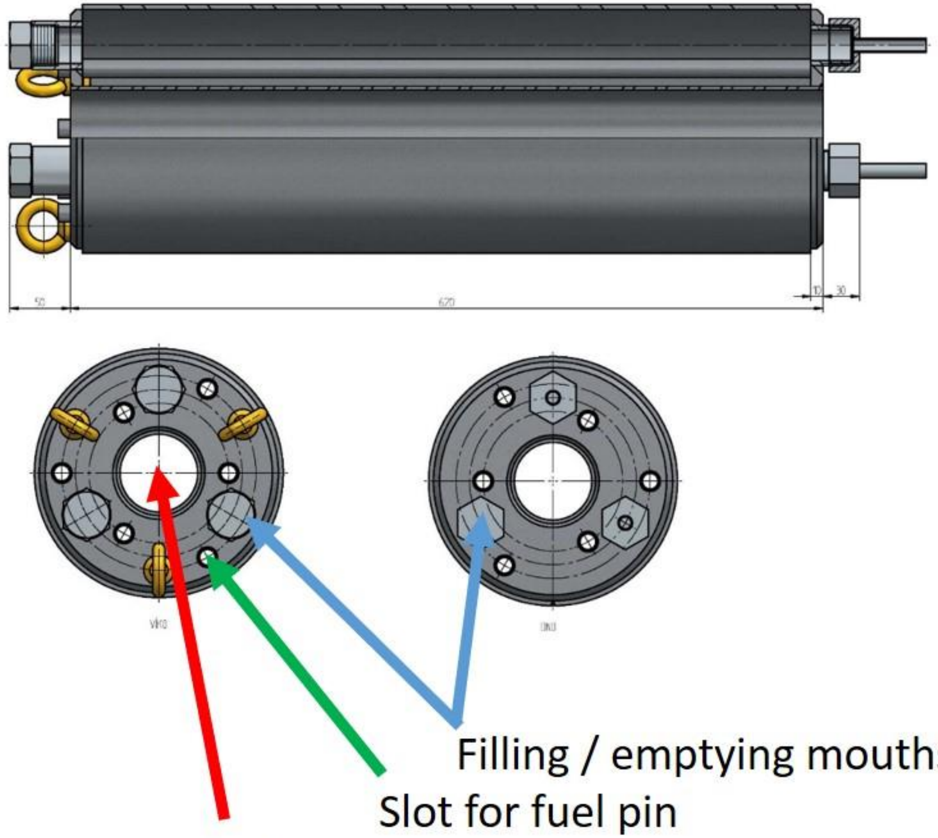
- Till now, the measurement was realized for inserted zones with FLIBE and Teflon – influences on multiplication factor
- Also the fission rate indexes of ^{235}U and ^{238}U in FLIBE were measured and evaluated
- The new heated inserted FLIBE zone (for the measurement at the temperature range 500 – 750 °C) is under development

The experiments have been done at LR-0 reactor



Losa, E., Košťal, M., Juříček, V.; Neutronic tests of fluoride salt based MSR/FHR coolants; Transactions of the American Nuclear Society; 2017; 116, pp. 1167-1169
Košťál M., Rypar V., Milčák, J., Study of graphite reactivity worth on well-defined cores assembled on LR-0 reactor; Annals of Nuclear Energy; 2016; 87, p. 601
Košťál, M., Veškrna, M., Cvachovec, Forget, B., Harper, S.: Comparison of fast neutron spectra in graphite and FLINA salt inserted in well-defined core assembled in LR-0 reactor, Annals of Nuclear Energy 83, pp. 216-225, 2015

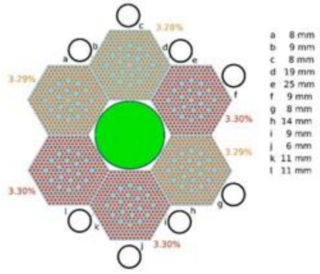
Inserted zone for Li-7 FLIBE neutronics measurement at room temperature



Filling / emptying mouths

Slot for fuel pin

Slot for neutron spectrum measurement (recoiled proton method)



Measurements with FLIBE showed perfect agreement in neutron spectrum, the results of k_{eff} are influenced by content of ^{6}Li residuum in supplied salt.

Experimental program for FLIBE neutronics prepared for 2020

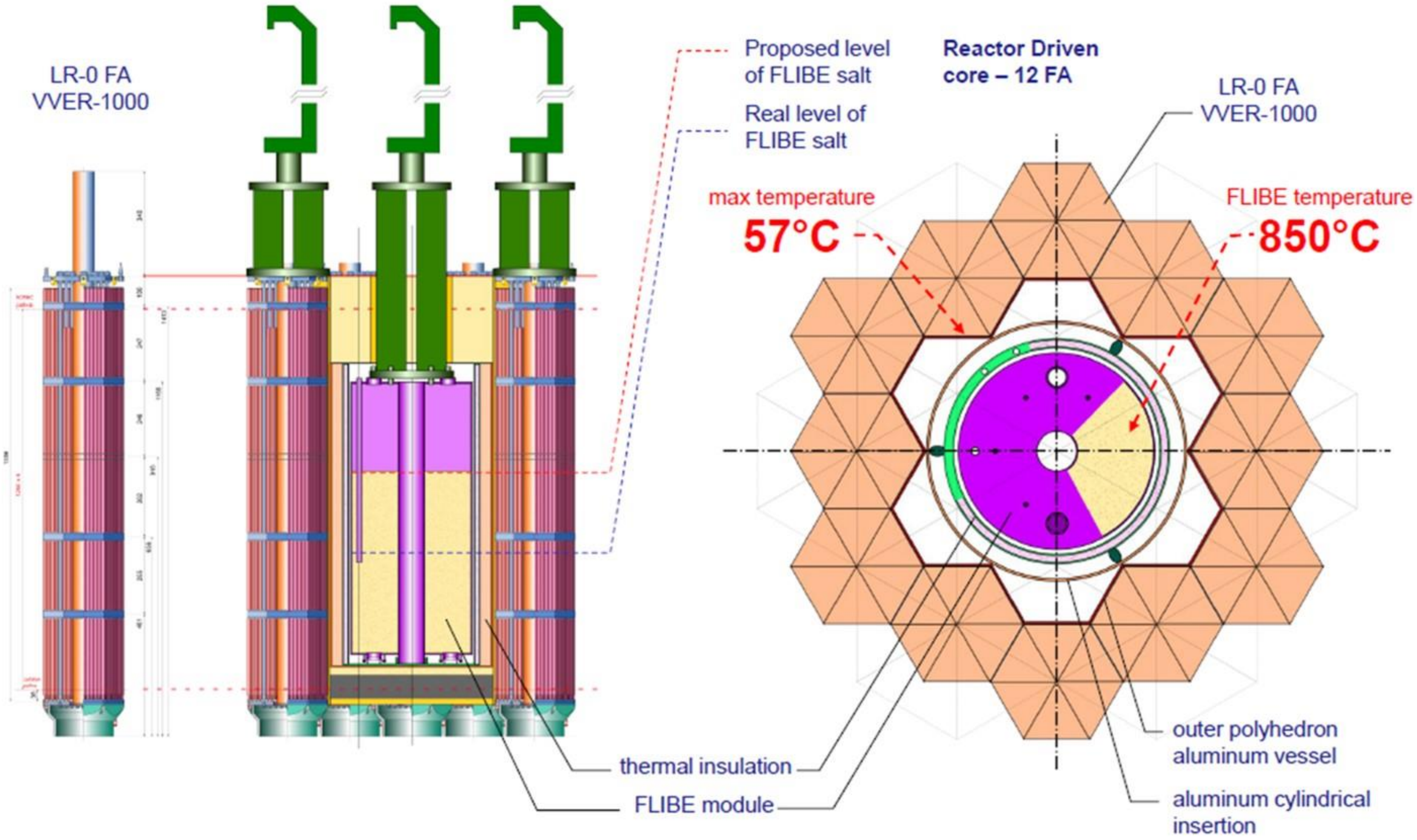
Today the main effort is focused on the preparation of "hot" FLIBE zone which could enable to realize the neutronics experiments at the temperature range of 500 – 750 °C (working temperature range of MSRs and FHRs).

The way to perform the experiments will be following (after filling the container by FLIBE):

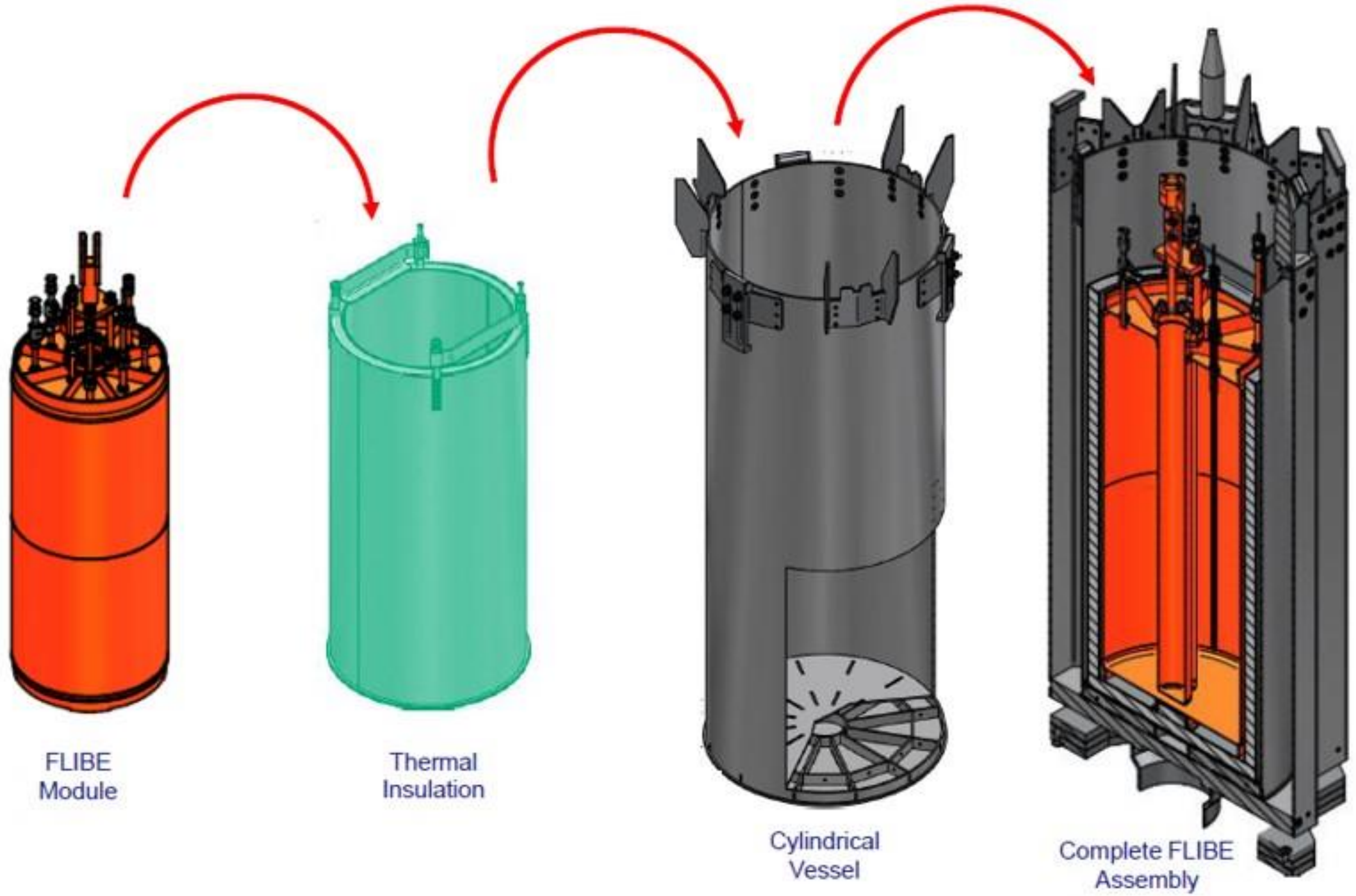
1. Preheating of the new FLIBE container in the oven outside the reactor to about 800 °C (Container is designed for about 70 kg of FLIBE)
2. Insertion of the container of the vessel into the experimental channel (the experimental channel takes up the space of seven VVER fuel assemblies into insulation vessel
3. Insertion) and connecting with the necessary instrumentation
4. Insertion of the experimental channel into the central part of LR-0 reactor
5. Pumping the water into reactor to reach the criticality

The series of measurement will be done at several temperatures reached by gradual cool down of the salt in the container in LR-0. Typical time for individual experiment will be about 2 – 4 hours.

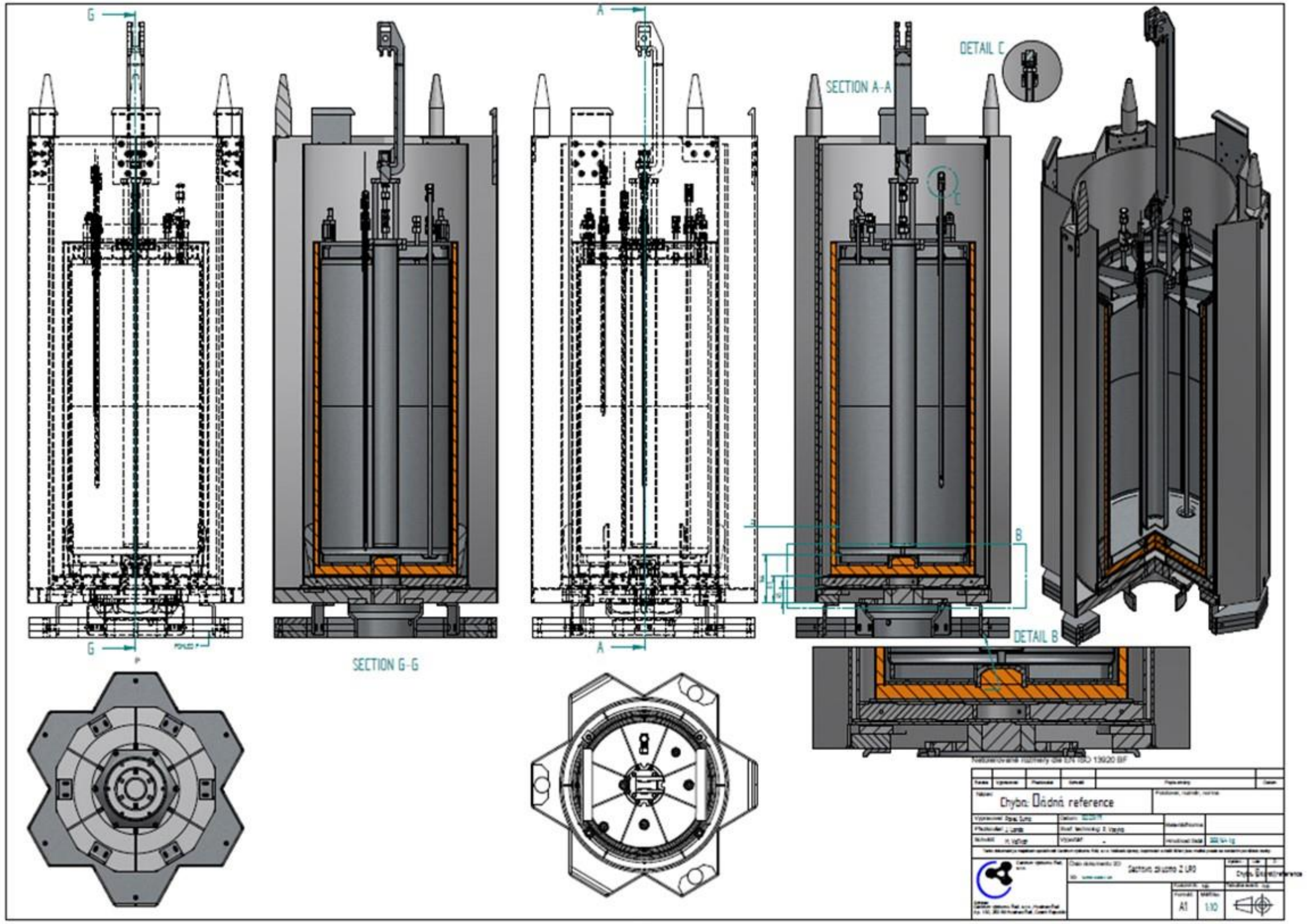
"Hot inserted FLIBE zone for LR-0"

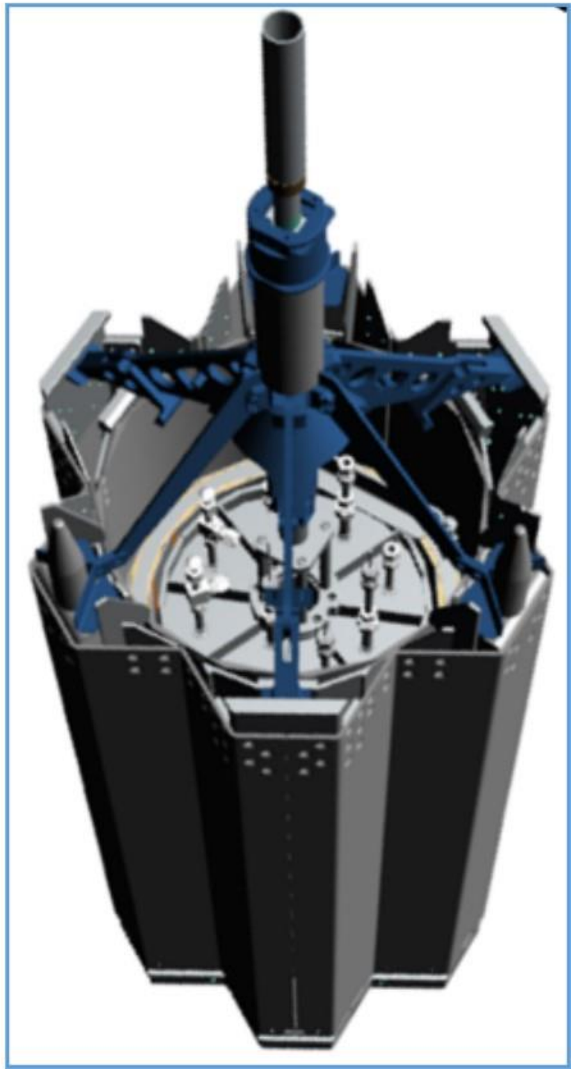


Schematic design of hot FLIBE zone

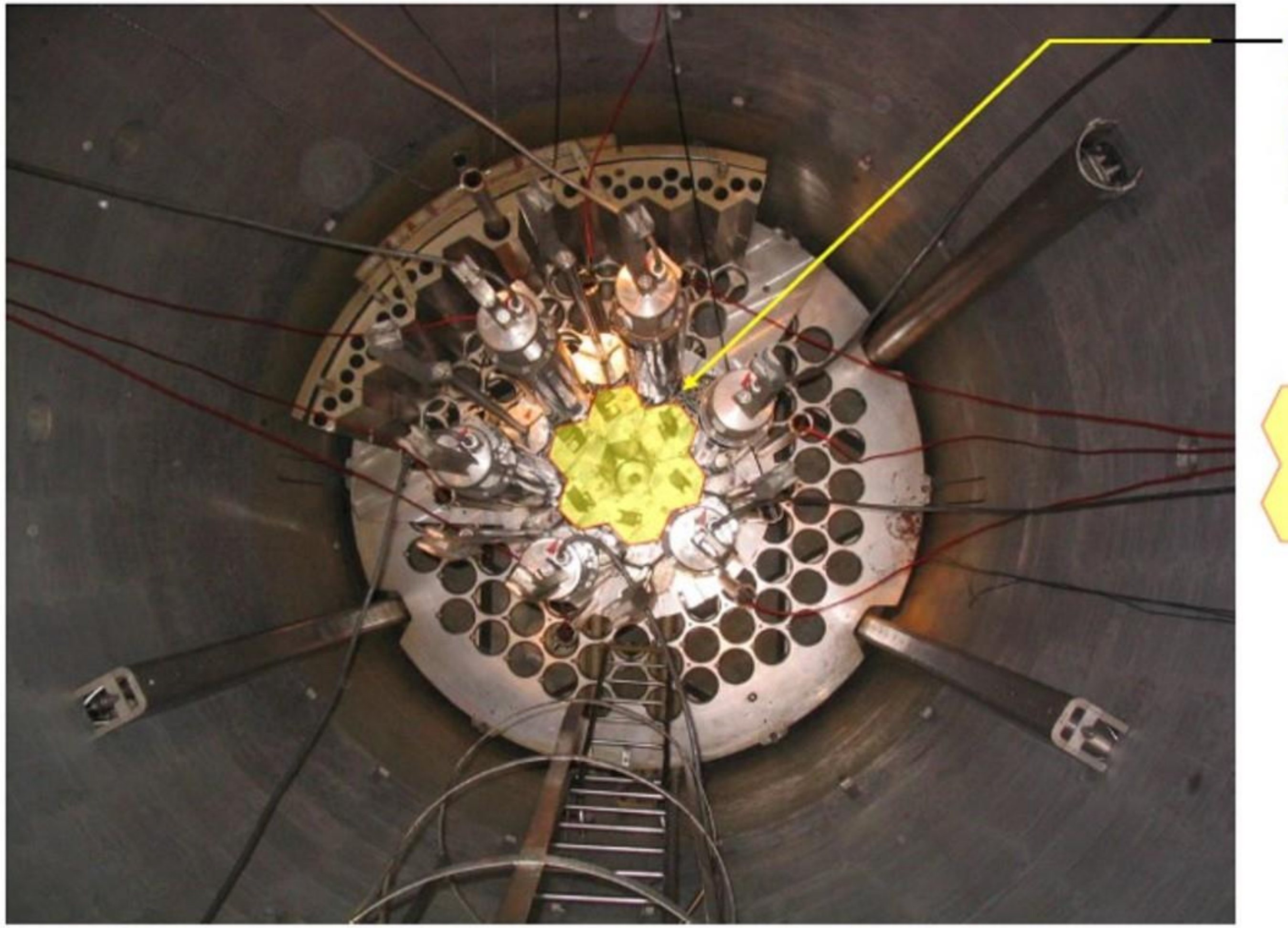


Assembly of the hot inserted FLIBE zone for LR-0

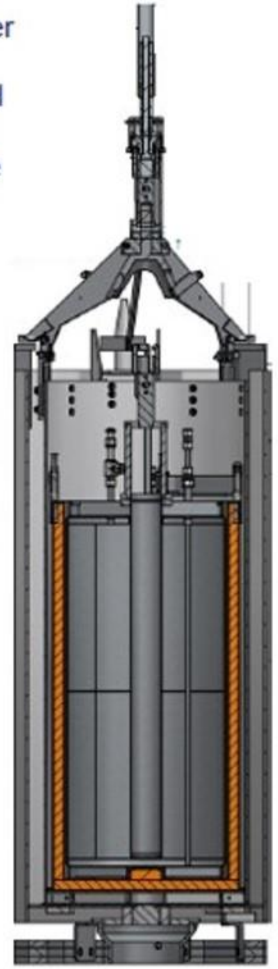




Position of the zone in LR-0”



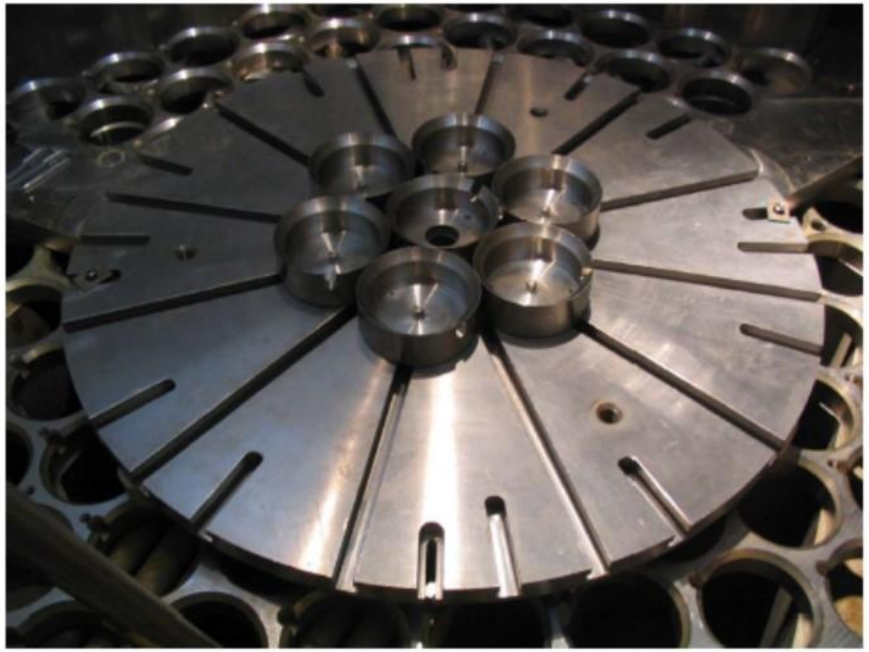
Placement of outer water-proof polyhedron vessel for FLIBE modul into the LR-0 core ~ 7FA



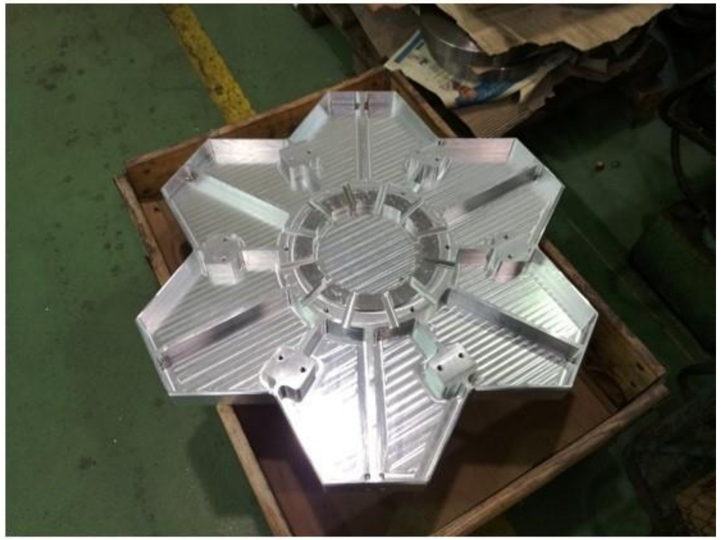
Complete module for insertion to the reactor core

Present status - view of LR-0 reactor core with new “nest” for FLIBE zone

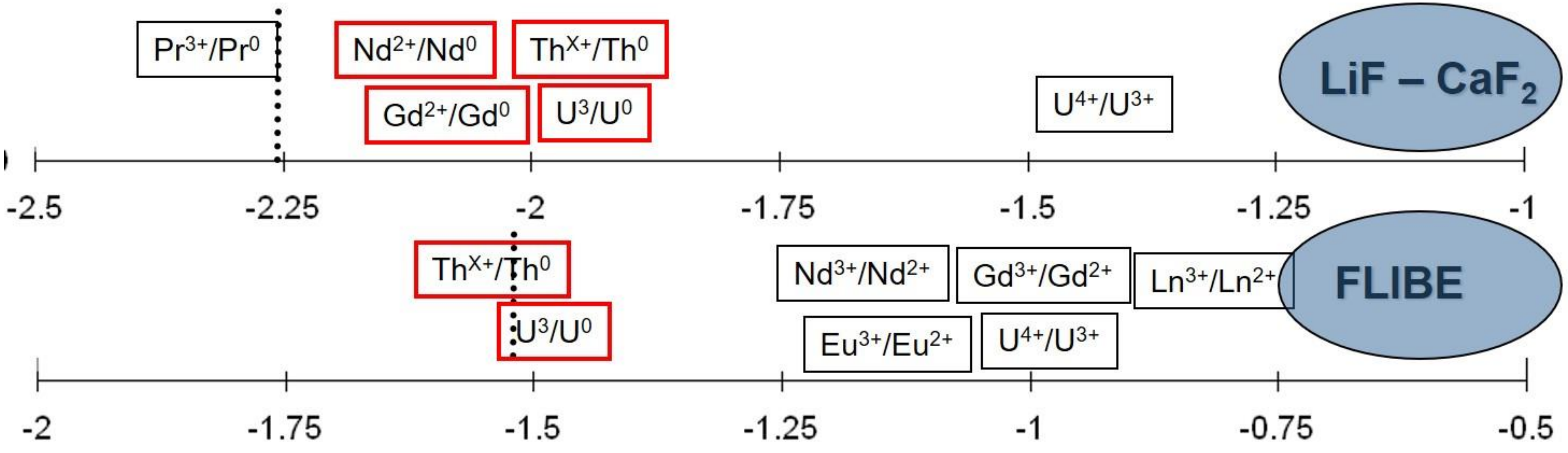
LR-0 Fuel Assemblies



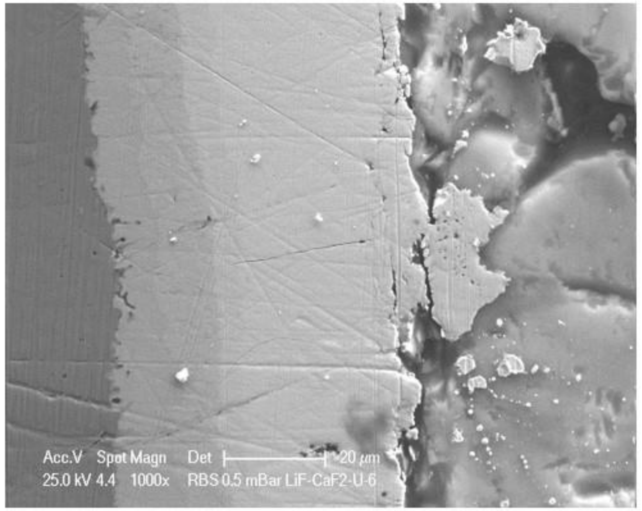
Special plate with „nests“ for FA placement or FLIBE assembly respectively



MSR fuel cycle - Electrochemical behavior and possibilities of the electrochemical extraction of U, Th and several Lns defined:

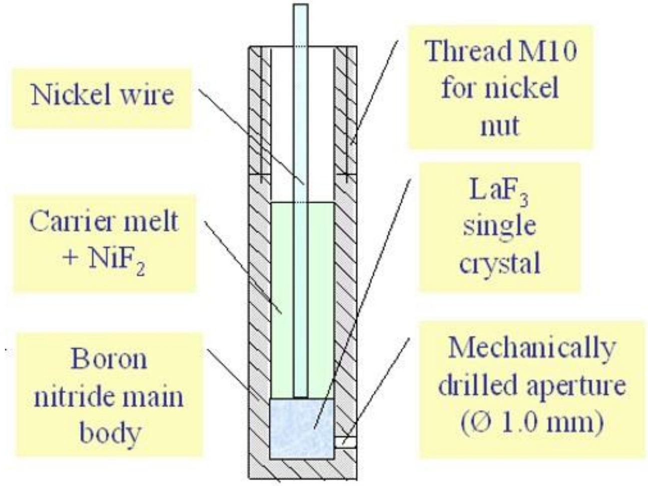


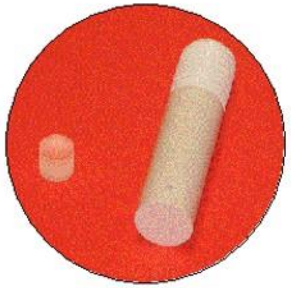
U deposit



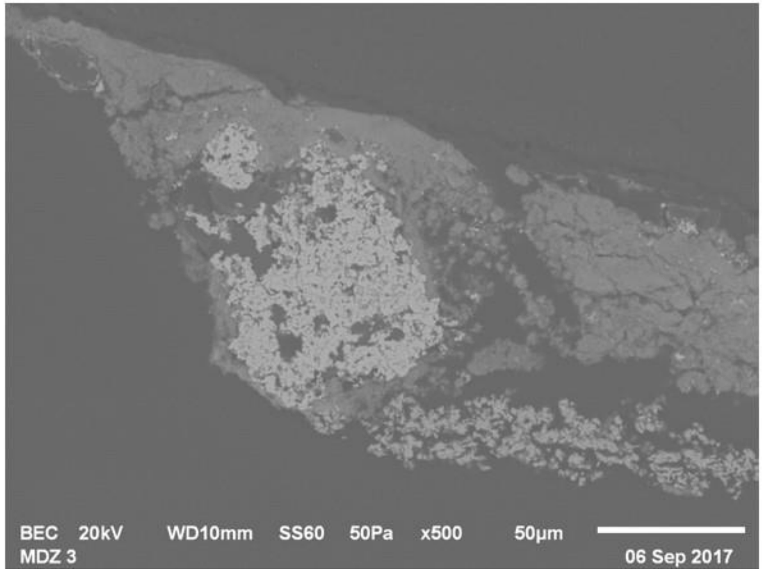
Elements with the deposition potential beyond the electrochemical window of a melt can be deposited using a reactive electrode

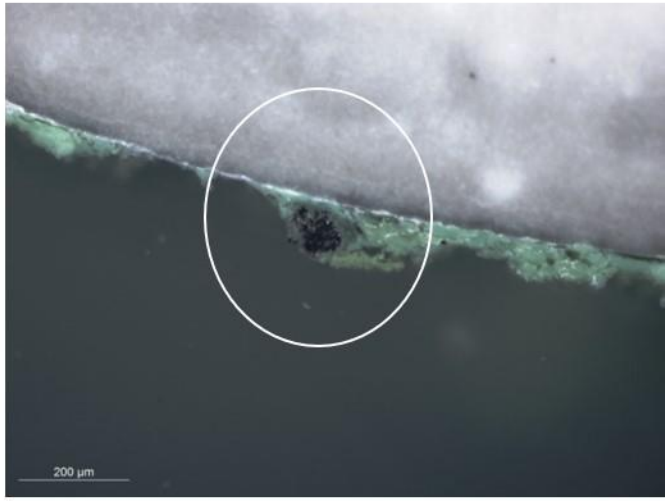
Study of the BN-FLiBe-NiF_2 interaction
(collaboration of ÚJV Řež with University of Wisconsin Madison)



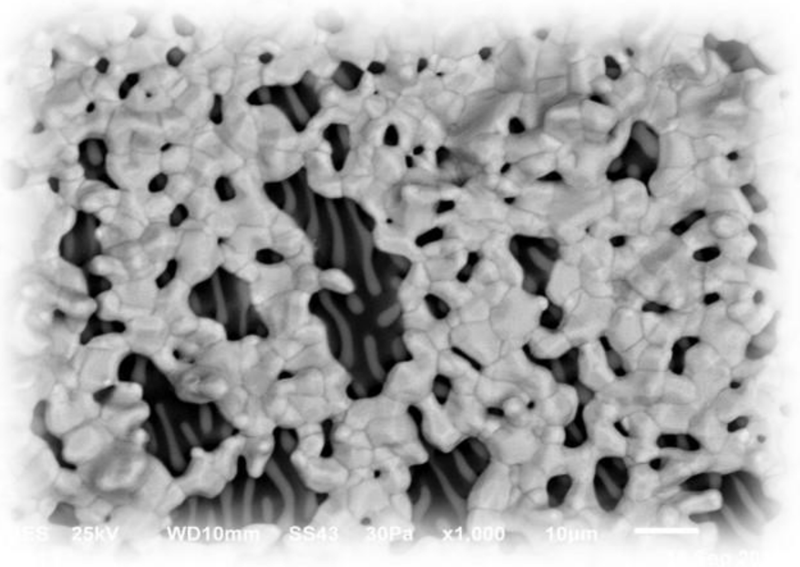


- Important for the reference electrode (RE) design
- Issue of the Ni^{2+} stability in presence of BN – can affect RE performance

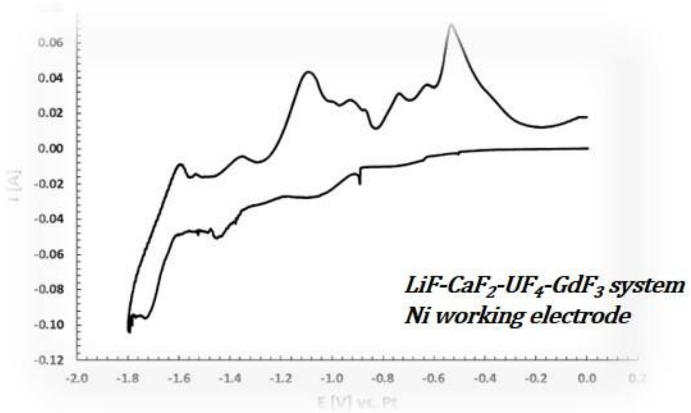


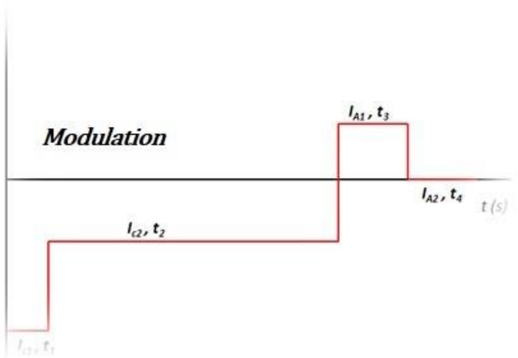


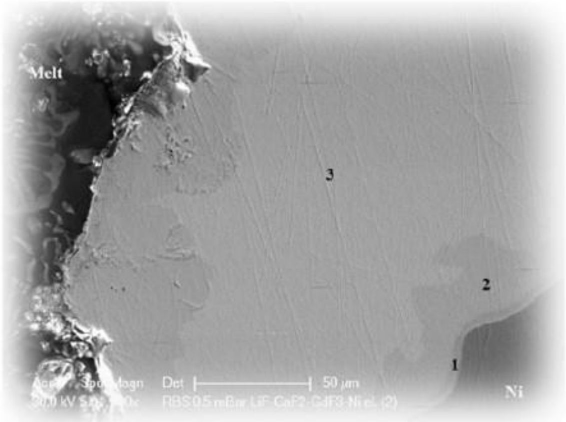
Actual work and future plans in electrochemistry



- Focus on quantitative separation of uranium/gadolinium from molten fluorides
- Tune-up of the parameters of current-modulated electrolysis
- Updating the rules for Ni/Ni2+ reference electrode usage (principles, material testing)
- Molten salts electrochemistry set-up placed in the hot cells
- Protactinium electrochemistry in molten fluorides (collaboration with JRC Karlsruhe







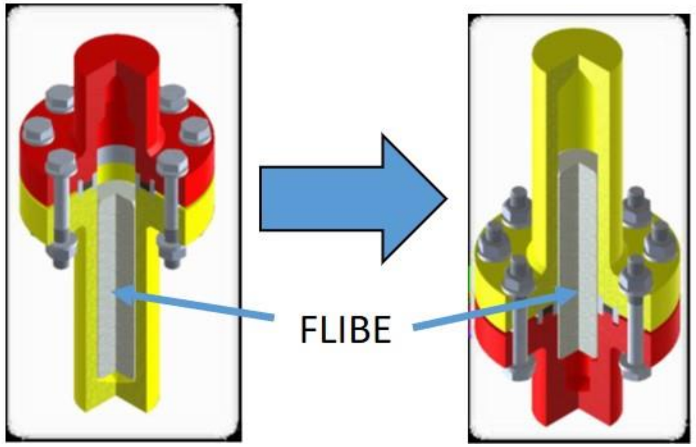
Structural materials and components of MSR / FHR technology

Further development of the MONICR alloy semi-pilot production and further tests of high-temperature microstructure stability, high-temperature mechanical stability and radiation embrittlement are studied in the project.

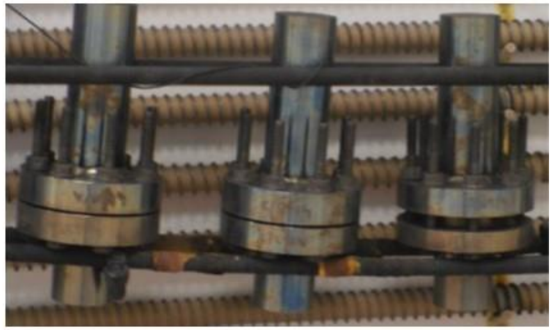
- The influence of hot deformation on recrystallization (1200 °C)
- The influence of cold deformation on recrystallization

Development of flange design and graphite gaskets for MSR – program of MICo company

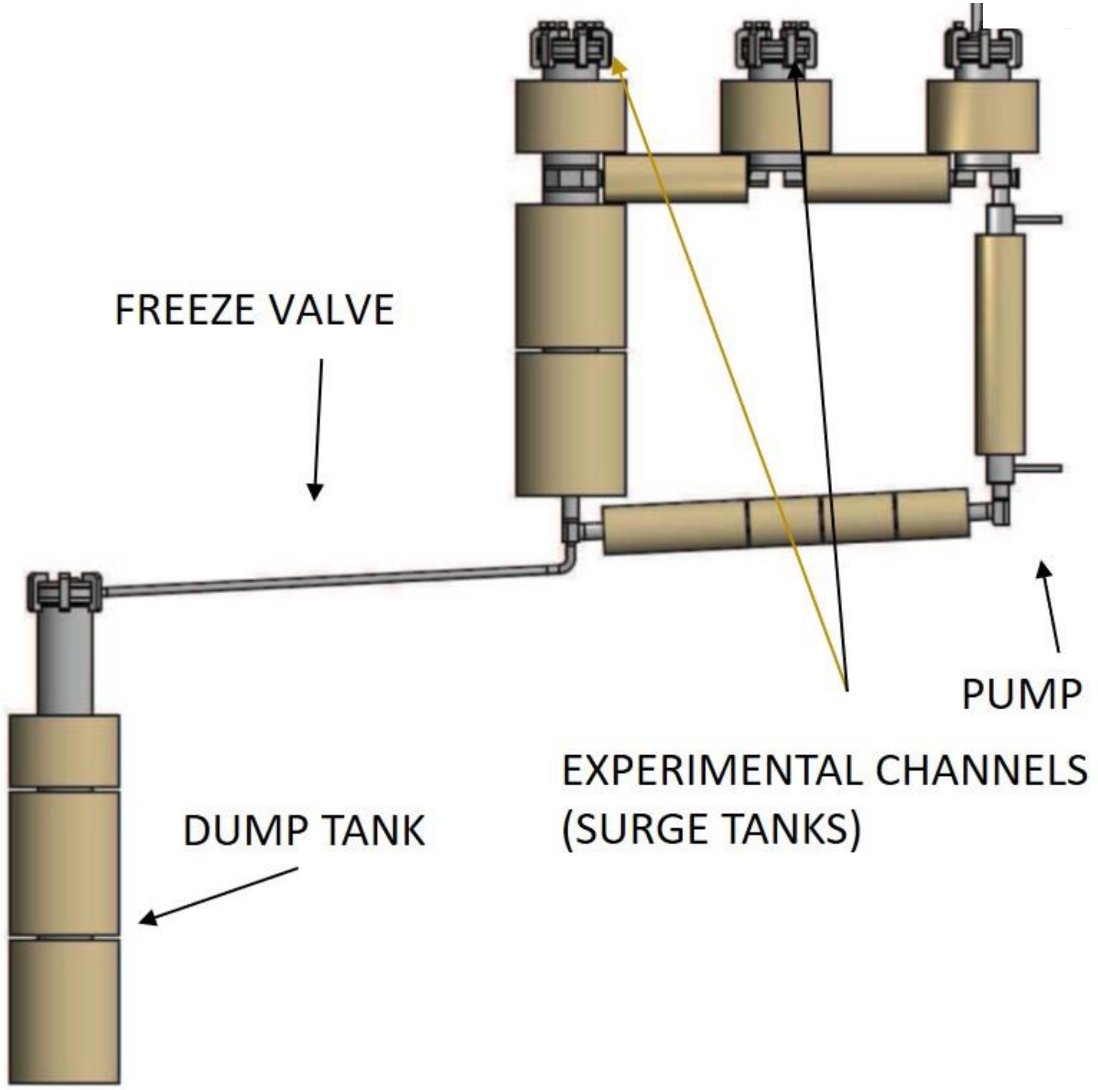
Inconel 718 was selected as the metallic material, expanded graphite and mica were selected as flexible materials



Testing at 600 °C



FLIBE loop for material research



Salt:	LiF-BeF_2
Materials:	nickel-based alloy (Inconel 718, MONICR]
Temperature:	< 760°C
Loop volume:	about 6 liters + dump tank
Forced circulation	impeller pump
Electric power:	< 25 kW

Forced FLIBE loop with freeze valve

The loop program is intended to the material and MSR/FHR component tests and subsequently for the thermohydraulic experiments and verification of thermohydraulic code data.

Corrosion, mechanical and irradiation tests of MONICR, development of impellers for fluoride salt media

The long term corrosion and mechanical tests of MONICR are ongoing in COMTES FHT and in Research Centre Řež. These tests cover also the mechanical tests (creep) in the molten salt environment.

Development of pumps (impellers) is under progress in ŠKODA JS.

Conclusions

- Czech MSR program is in the long run focused on experimental development of selected areas of MSR and technology, which can be also partially applied for FHR system.
- As the Czech Republic intends to continue in the utilization of nuclear power and to increase its present nuclear share, the country wants also to appropriately contribute to the development of advanced reactor technologies.
- Present state support of the development of MSR technology should create the conditions for Czech companies to be among the suppliers of selected parts of MSR technology.

Upcoming Webinars

18 December 2019	TRISO Fuels	Dr. Madeline Feltus, DOE, USA
29 January 2020	Thermal Hydraulics in Liquid Metal Fast Reactors	Dr. Antoine Gerschenfeld, CEA, France
26 February 2020	SFR Safety Design Criteria (SDC) and Safety Design Guidelines(SDGs)	Mr. Shigenobu Kubo, JAEA, Japan