Státní ústav radiační ochrany, v. v. i.
National Radiation Protection Institute

FLOW-SHEETING STUDIES OF THE FLUORIDE MSR TH-BREEDER AND MSR AN-BURNER

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R&D on Molten Salt Reactor technology

The technology of Molten Salt Reactor system has been studied and experimentally developed in the Czech Republic from 2000.

Right from the start, the R&D activities included a significant program in molten fluoride salt chemistry and MSR fuel reprocessing technology

Initially, the program focused on the possible use of MSR as actinide transmuter, later it concentrated on MSR thorium breeder operating in the thorium-uranium fuel cycle, and recently both options have been studied:

1. MSR An-burner with fluoride-based fuel and possibly also chloride-based fuel operating in the fast spectrum.
2. MSR Th-breeder with fluoride-based fuel operating in the thermal spectrum

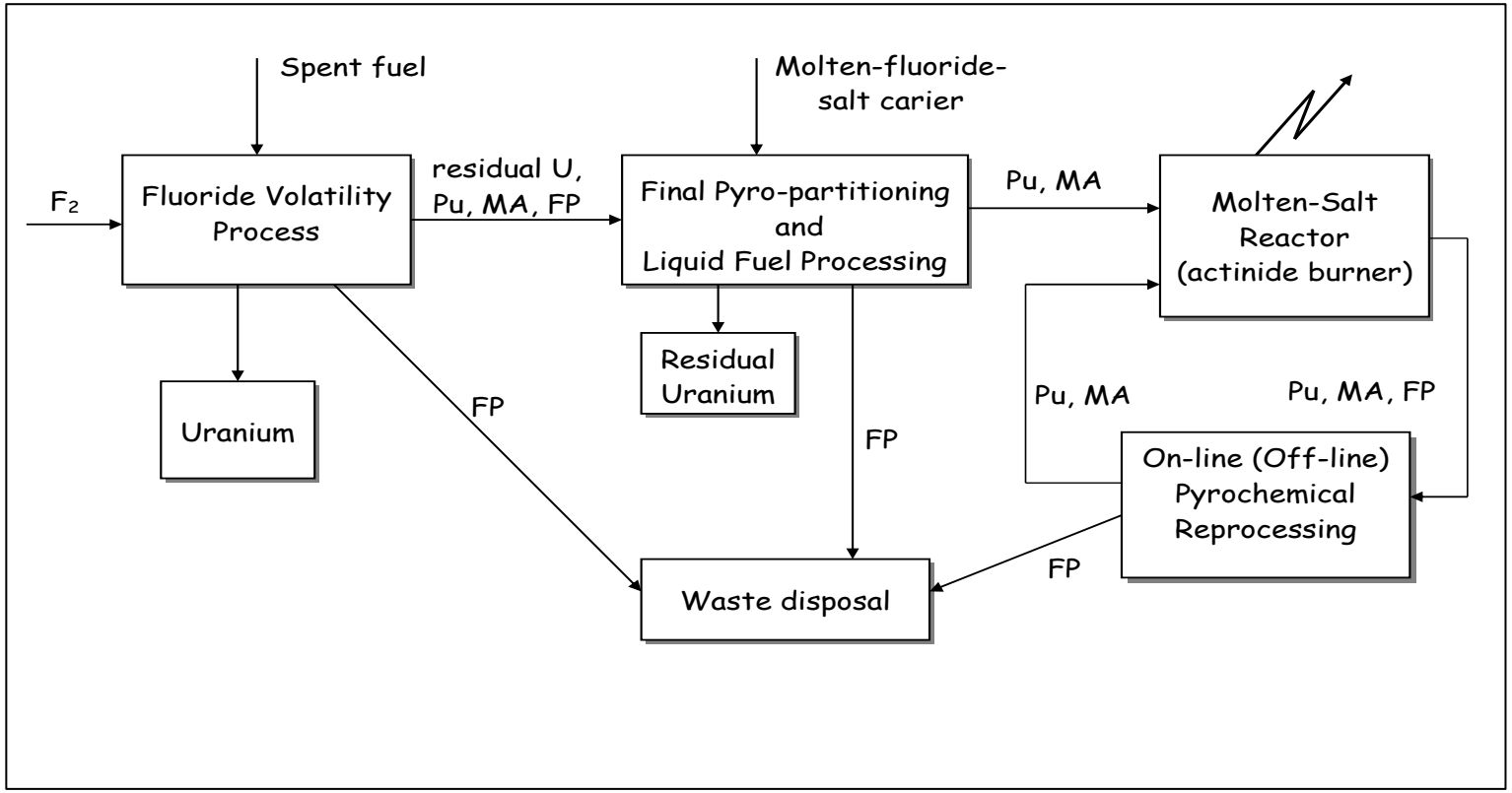
The flow-sheeting studies have so far focused primarily on fluoride fuels.

Chemical issues, including flow-sheet studies, were primarily solved at Nuclear Research Institute Řež (now ÚJV Řež) and in the Research Centre Řež; now, flow-sheeting studies, including safety issues, are also being addressed by National Radiation Protection Institute.

Flow-sheeting of MSE An-burner

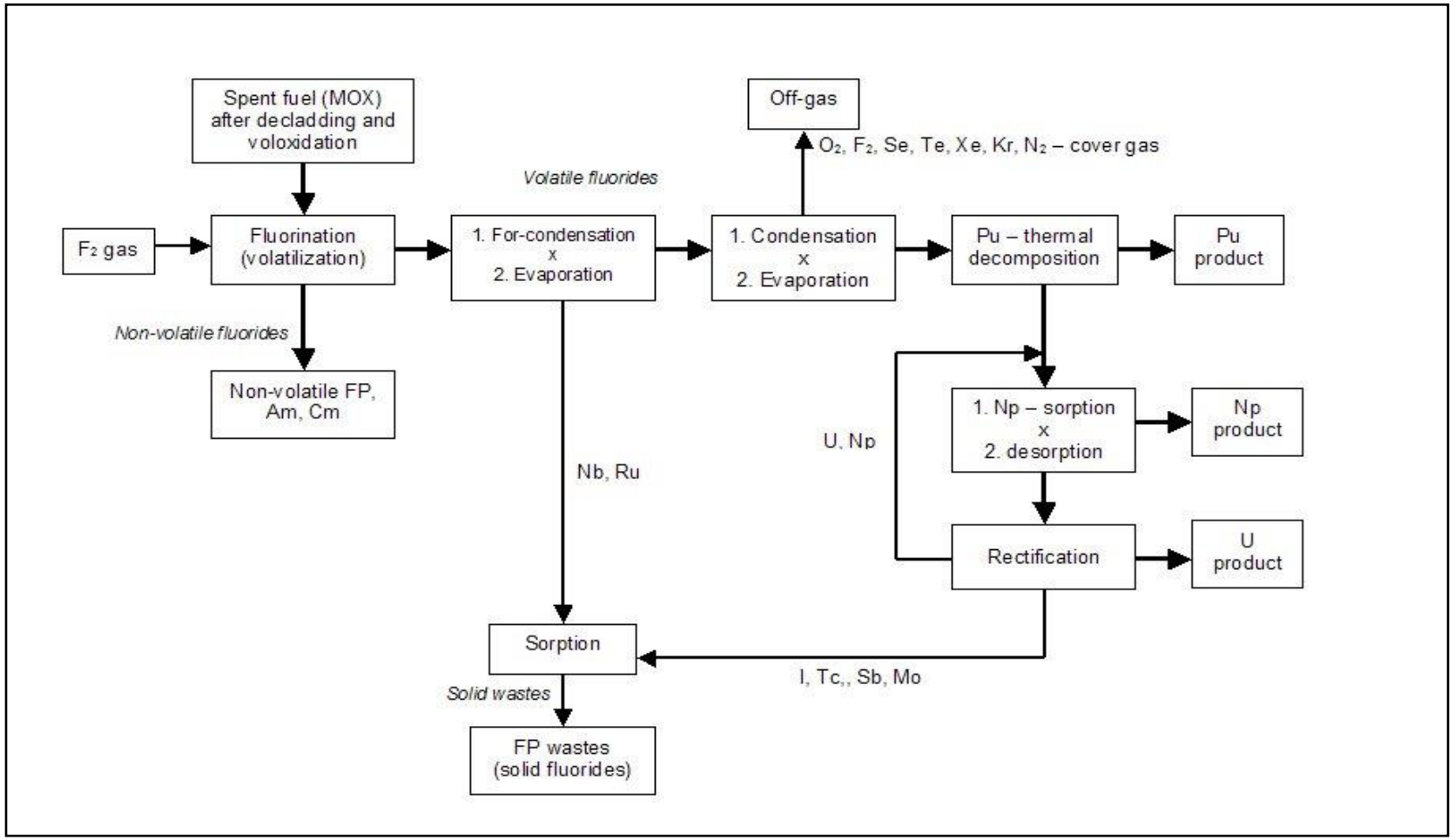
The proposals for technological schemes were based on many years of experimental research and development of dry reprocessing technology based on Fluoride Volatility Method, which was carried out at Nuclear Research Institute Řež (ÚJV Řež), and on subsequent experimental research on MSR carried out at Research Centre Řež, as well as on cooperation within European projects and bilateral cooperation with Japanese companies.

The overall technological scheme proposed for the incineration of plutonium and minor actinides originating from MOX-type spent fuel is as follows:



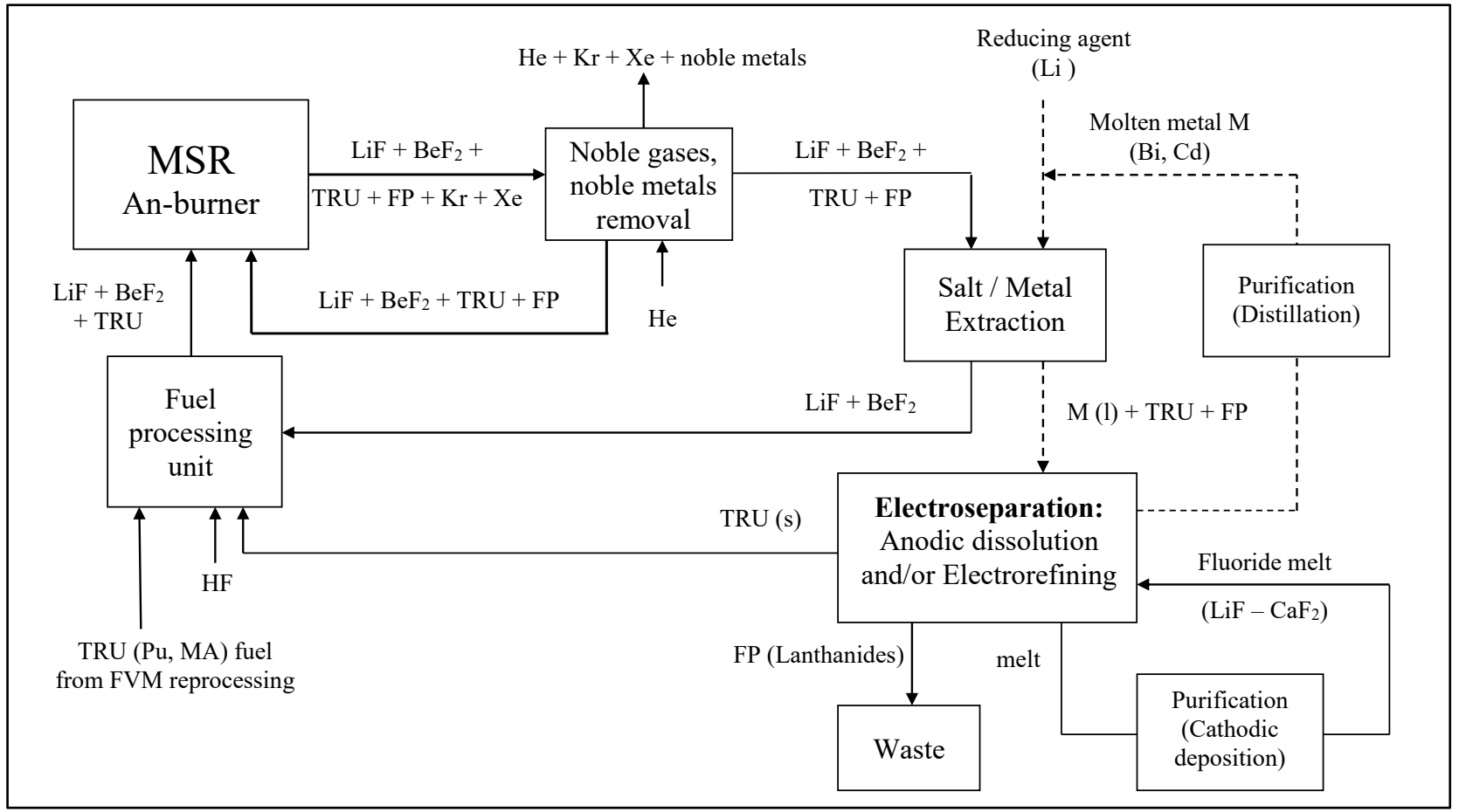
Processing of Pu and MA fuel for MSR An-burner

Fluoride Volatility Method (FVM) has been proposed for removal of uranium (and eventually also neptunium), some part of fission products and for converting the original oxide form of spent MOX fuel into fluorides.



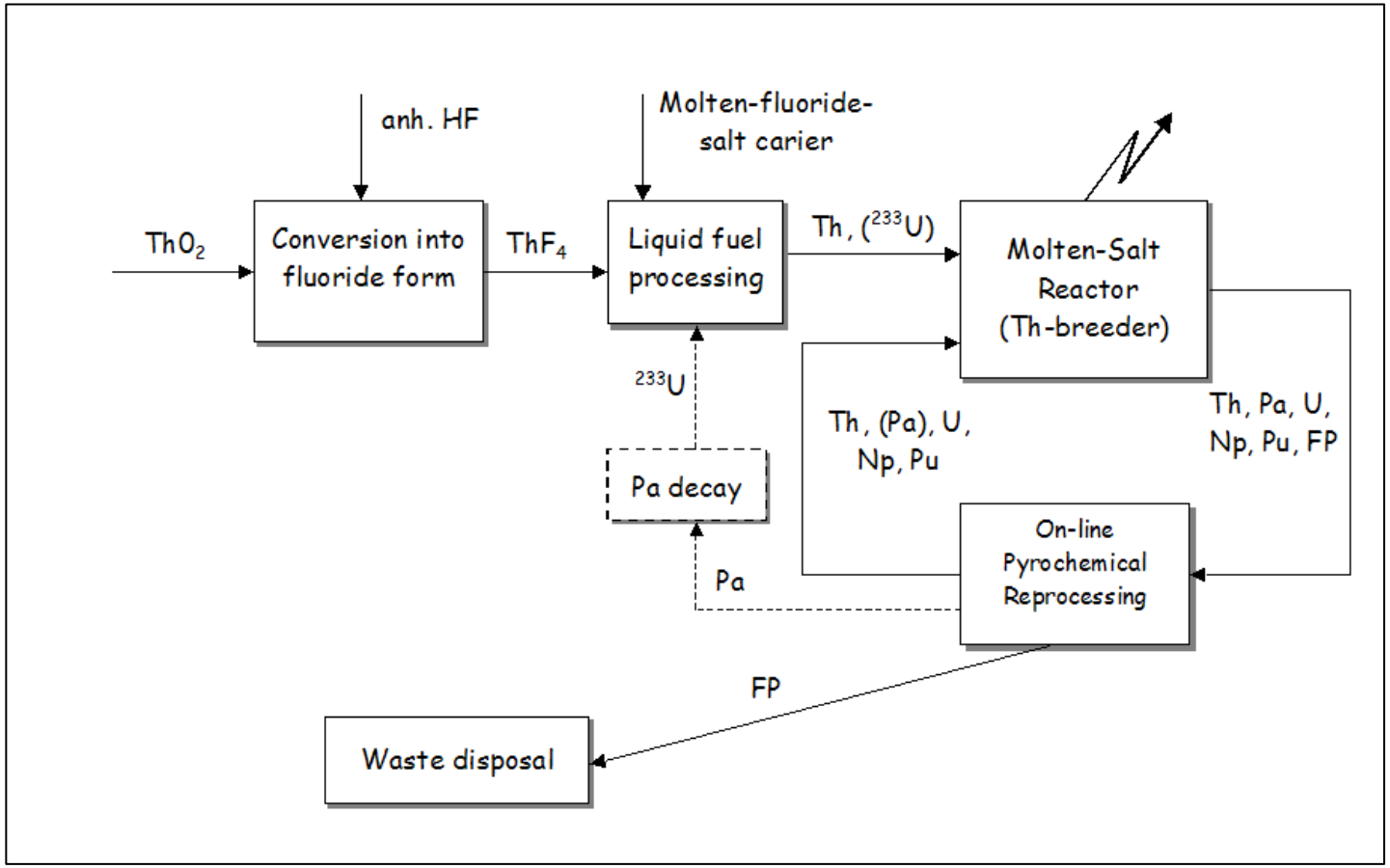
Conceptual flow-sheet of MSR An-burner

Conceptual technological flow-sheet comes on the ORNL experience with molten salt / liquid metal extraction and Nuclear Research Institute Řež experience with electrochemical separation studies realized mainly in LiF-BiF_2 and LiF-CaF_2 media. Here the reprocessing focused on FP removal is proposed either on-line or off-line.



Flow-sheeting of MSR Th-breeder

MSR Th-breeder studies have been given greater attention at Nuclear Research Institute Řež (ÚJV Řež) and Research Centre Řež. The studies are supported by a series of experimental laboratory verifications of the possibility of electrochemical separation of uranium, thorium, and fission products from MSR carrier fluoride melts.



Selection of carrier molten fluoride salt for electrochemical separation studies

- **LiF-BeF_2 („FLiBe“)** Eutectic mixture (48 – 52 mol %) – m.p. = 365°C

  Eutectic mixture (66 – 34 mol %) proposed for MSBR – m.p. = 459 °C

  Problems with electrochemical stability – but necessary to study because carrier salt of MSBR

- LiF-NaF-KF („FLiNaK“) Eutectic mixture (46.5 – 11.5 – 42.0 mol %) – m.p. = 454 °C

  Studied because of widely used in electrochemistry of molten salts, but limited electrochemical stability

- ***LiF-CaF_2*** Eutectic mixture (79.5 – 20.5 mol %) – m.p. = 766 °C

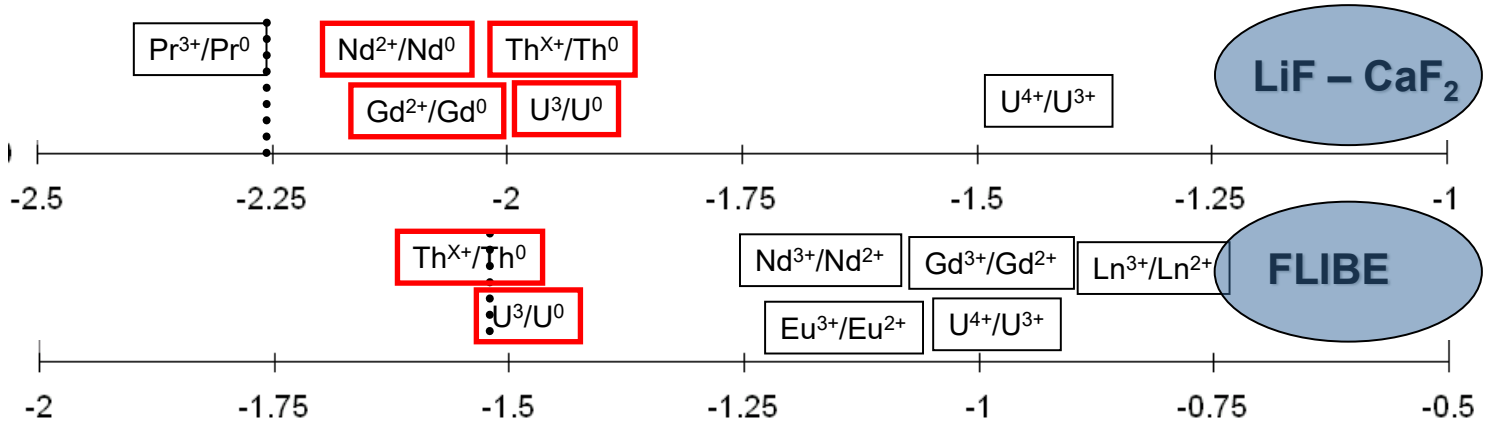
  Excellent electrochemical stability, but higher melting point

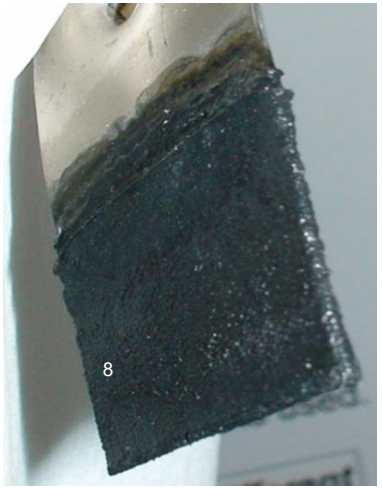
- *LiF-NaF („LiNa“)* Eutectic mixture (79.5 – 20.5 mol %) – m.p. = 649 °C

  Studied on request of our reactor physicists

MSR and Th – U fuel cycle – electrochemical studies

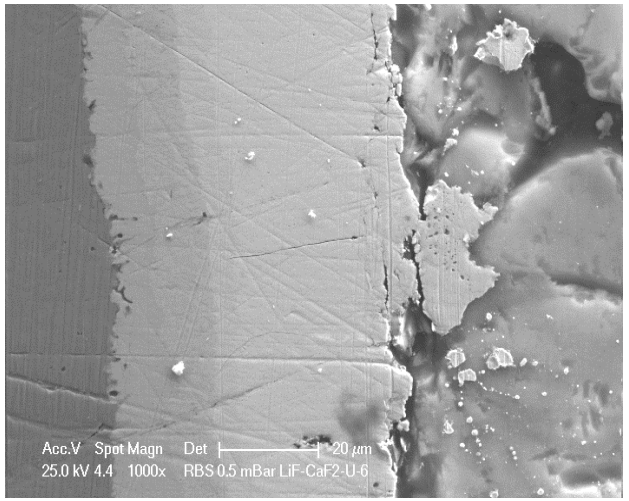
Electrochemical behavior and possibilities of the electrochemical extraction of U, Th and several Lns defined





U deposit

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



Data provided by Martin Straka and Lórant Szatmáry, ÚJV Řež

Existing results of electrochemical studies

The $LiF\text{-}CaF_2$ melt was therefore chosen as the main carrier melt to study the conditions of separation of thorium from fission products alongside FLIBE.

- The cyclic voltammetry has been the method used for studying the electrochemical properties of actinides and fission products dissolved in fluoride melt media.
- The results concerning the separation possibilities, which were evaluated by ÚJV Řež from red-ox potentials for uranium, thorium and main fission products (mainly lanthanides), are listed in the Table

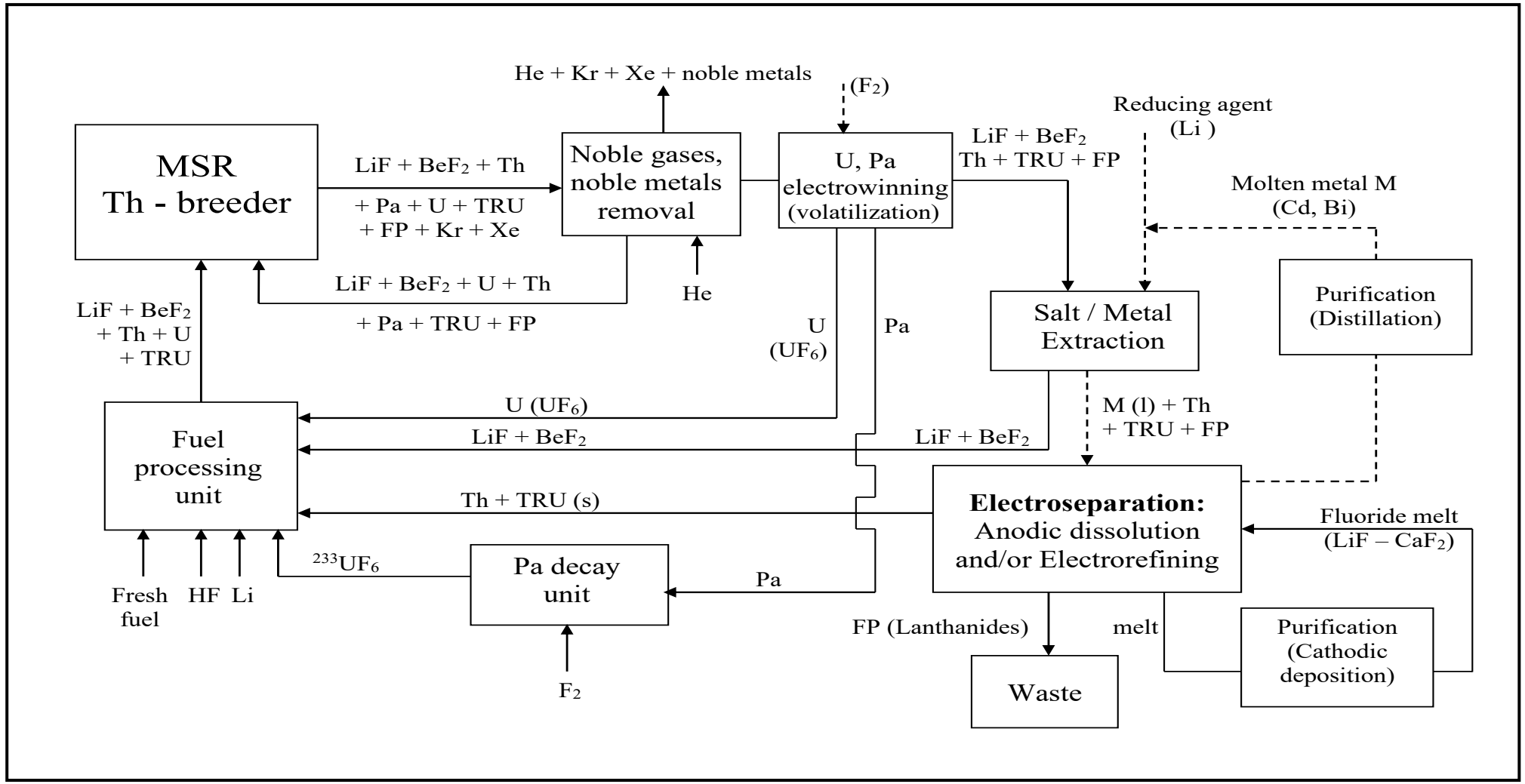
Melt	Separation presumed possible
$LiF\text{-}BeF_2$	U/Lns (Eu, Nd, Gd, Sm), U/Th
$LiF\text{-}CaF_2$	U/Lns (Eu, Nd, Gd, Sm, Pr), U/Th, Th/Lns (Eu, Nd, Gd, Sm, Pr)

From the experimental experience of ÚJV Řež and literature data, it is clear that U, Th can be directly deposited from $LiF\text{-}CaF_2$ melt on inert electrode like W, Pt, Au, Mo etc. and also on reactive electrodes.

Data provided by Martin Straka and Lórant Szatmáry, ÚJV Řež

Conceptual flow-sheet proposed for MSR Th-breeder on-line reprocessing

Based on the above-mentioned studies, this conceptual technological flow sheet has been proposed.

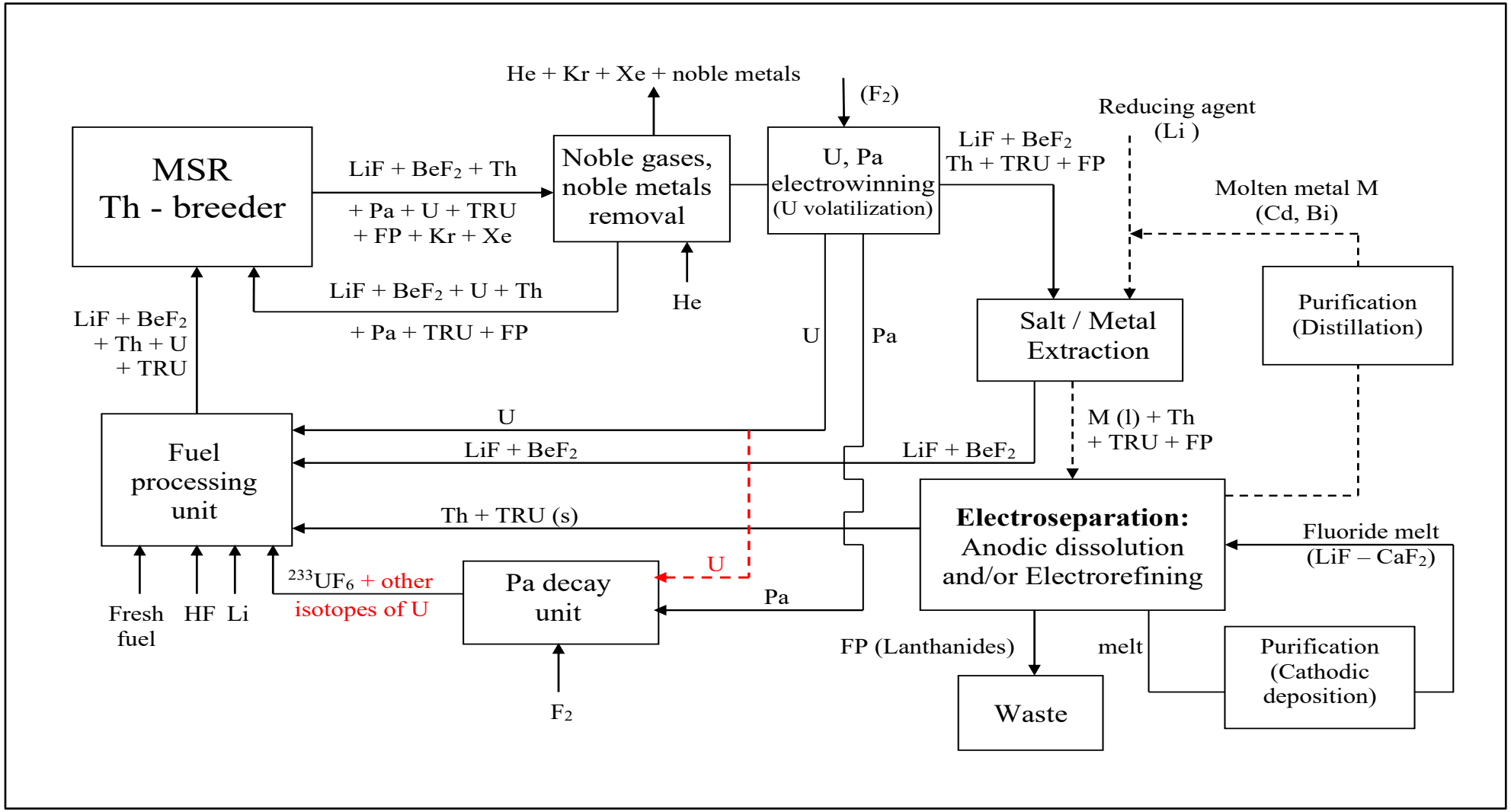


Flow-sheeting studies and non-proliferation aspects

- If the MSR is operated in the pure Th-U fuel cycle (MSR Th-breeder) in which ^{233}U is the only fissile material, then the use of MSR on-line reprocessing technology is necessary. This technology will then make it possible to reach a breeding factor higher than 1. In this case, the principle, how to separate the bred uranium ^{233}U is to extract protactinium ^{233}Pa from the MSR fuel circuit as quickly as possible and then wait for it to convert to uranium ^{233}U. The reason for the rapid removal of protactinium ^{233}Pa (with the half-life of 27 days) is to prevent its conversion into undesirable ^{234}Pa. In the proposed conceptual flow-sheet the principle how to obtain the fresh uranium ^{233}U is to separate the protactinium and store it in a decay unit until the ^{233}Pa is converted into uranium ^{233}U. By fluorination of the melt containing protactinium and the newly formed uranium ^{233}U, the uranium in the form of hexafluoride is separated, while the as yet unconverted protactinium remains dissolved in the melt.

- **The separation of protactinium and uranium represents a sensitive point in the MSR fuel cycle from a nonproliferation issue. However, if we want to operate the MSR as a Th-breeder, i.e., to ensure a breeding factor higher than 1, this step is necessary. In order to significantly reduce the risk of fissile material being diverted for military or terrorist purposes, there is the possibility to significantly increase the physical protection of the technology by feeding part of the uranium from the MSR fuel cycle into the Pa decay unit. This uranium will contain, in addition to ^{233}U, other isotopes of uranium including ^{232}U whose decay products will provide physical protection of the system by their high radioactivity.**

NPPP issues: Conceptual flow-sheet of MSR Th-breeder on-line reprocessing with increased physical protection



Thank you for your attention

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