MSR for Management of Minor Actinides

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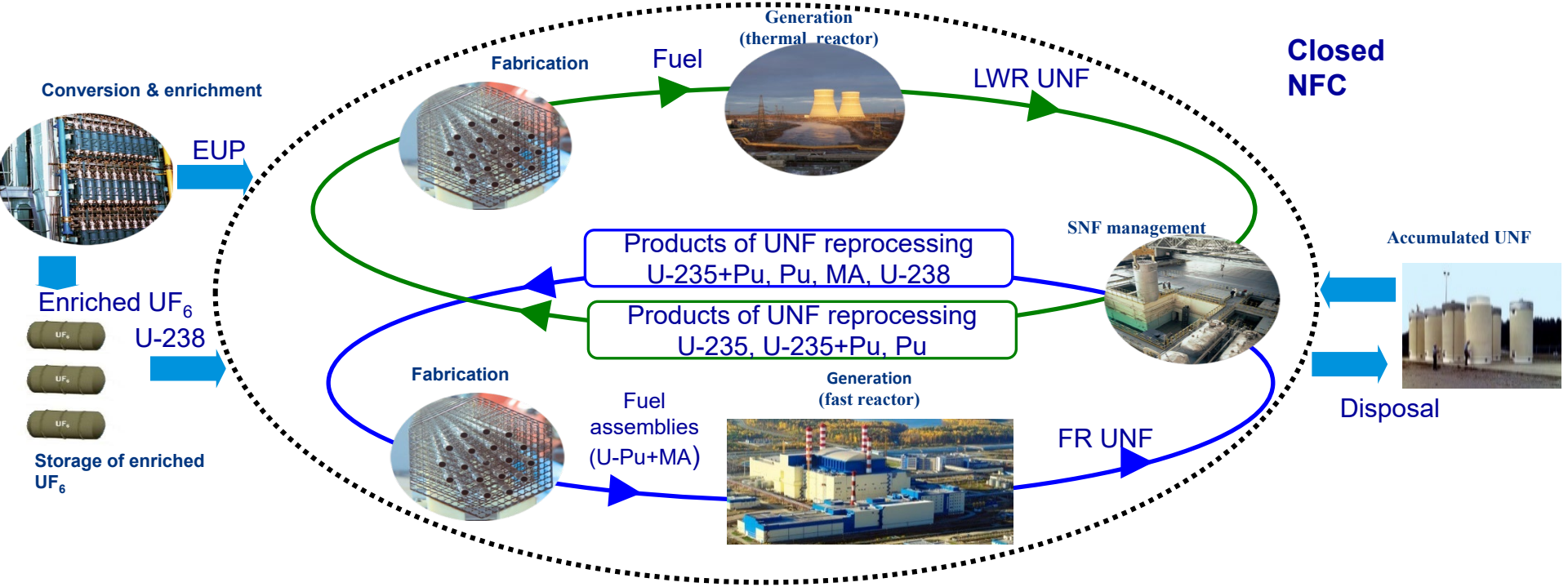
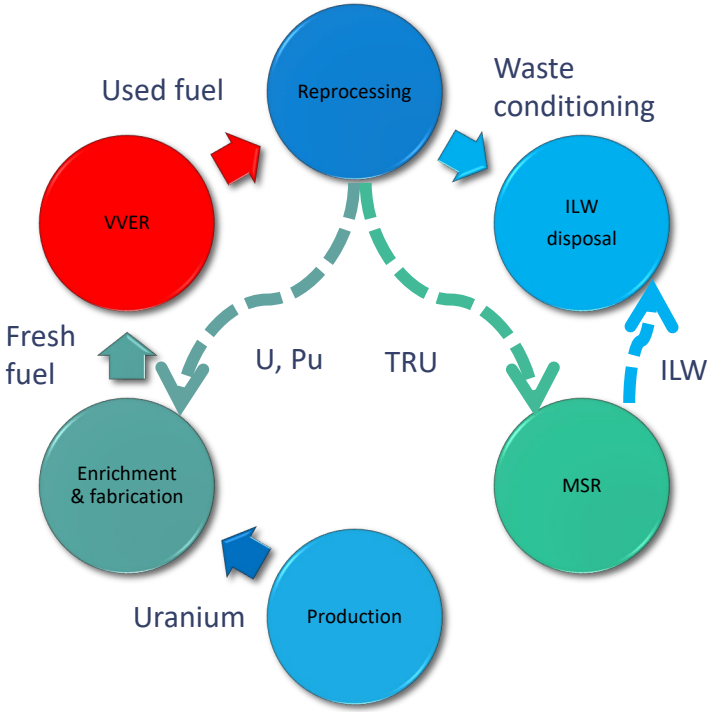
Two Component Nuclear Power System



Introduction of MSR into the Russian nuclear power as an integral element help to solve the problem of minor actinides

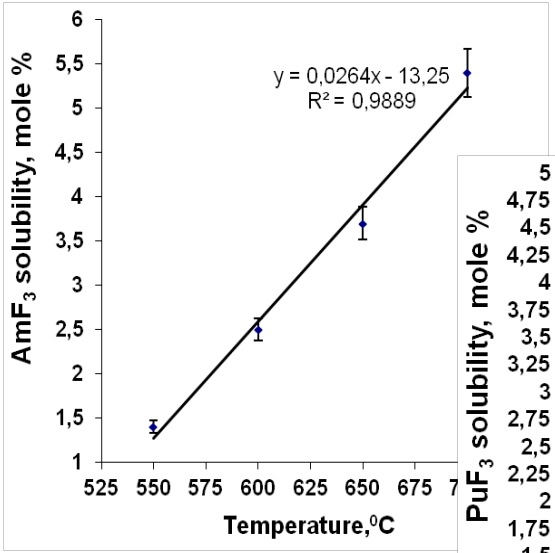


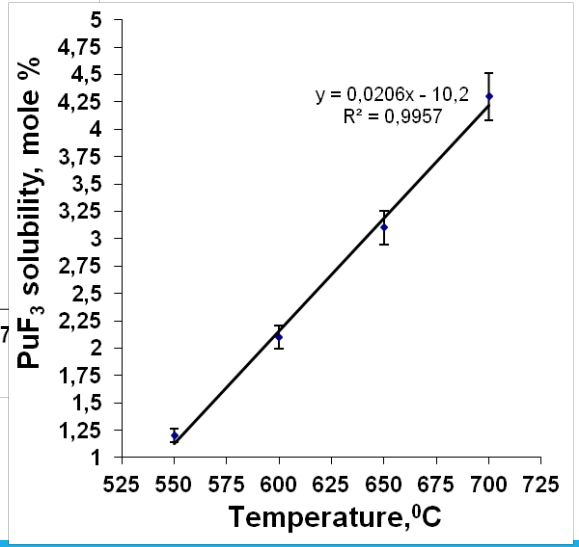
Fuel salt, mole%	$LiF-BeF_2+1TRUF_3$
Temperature, ^oC	620-720
Core radius/height, m	1.4/2.8
Core specific power, W/cm^3	130
Container material	HN80MTY alloy
Removal time for soluble FP, yr	1-3

Solvent, mole %	Feed MA/TRU	Loading (EOL), t	TRU/MA, kg/yr
$73LiF-27BeF_2$	0.1	3.9	730/73
$73LiF-27BeF_2$	0.35	13.9	730/260
$73LiF-27BeF_2$	0.45	23.2	730/330

In most cases the base-line fuel salt is lithium-beryllium fluoride salt as it has best properties

- Low neutron cross section for the solvent
- Thermal stability of the salt
- Low vapor pressure
- Radiation stability
- Adequate solubility of fuel and FP components
- Adequate transport properties
- Compatibility with construction materials
- Low fuel and processing costs





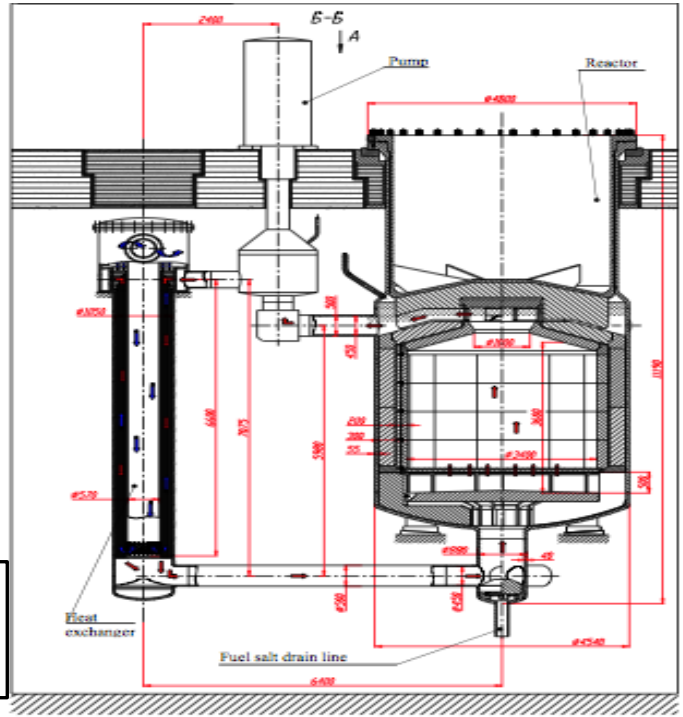
MSR design options with homogeneous core and fuel salt with high enough solubility for TRU are examined

HN80MTY
Vessel, Circuits, Heat exchangers *600 / 720° C*
Creep, Creep-fatigue, Thermal fatigue, Aging, Welds…

HN80MTY
Intermediate circuit - *455 / 620° C* Aging, Welds, Compatibility NaF-$NaBF_4$, Oxidation, Wastage…

Possibly, SiC Distribution plate- *600° C*, High irradiation

Ni Reflector *750° C*
Negligible creep



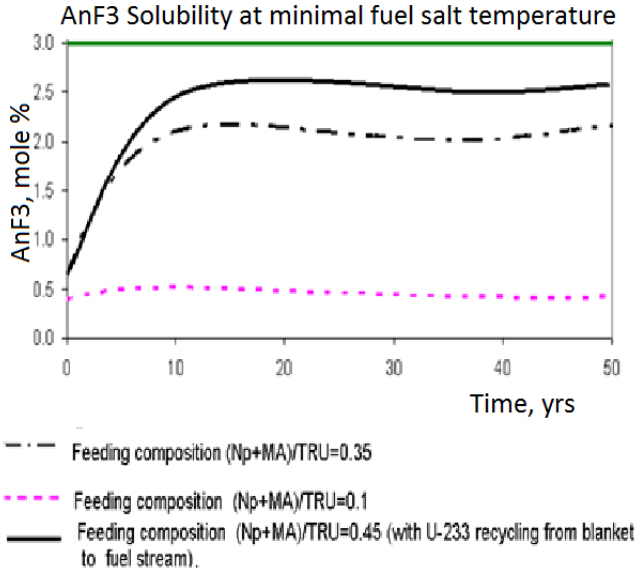
- Max temperature of the fuel salt in the primary circuit made of special Ni-Mo alloy is mainly limited by Te IGC depending on salt Redox potential

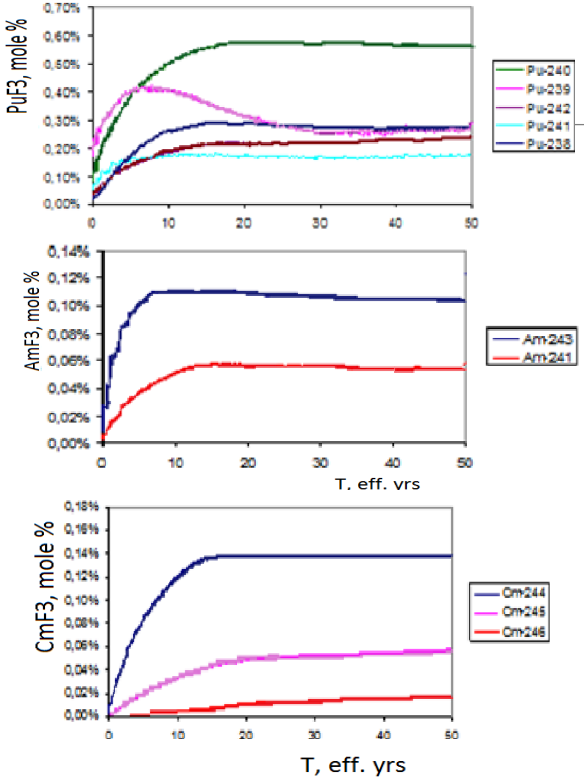
- Min temperature of fuel salt is determining not only its melting point, but also the solubility for AnF_3 in the solvent for this temperature

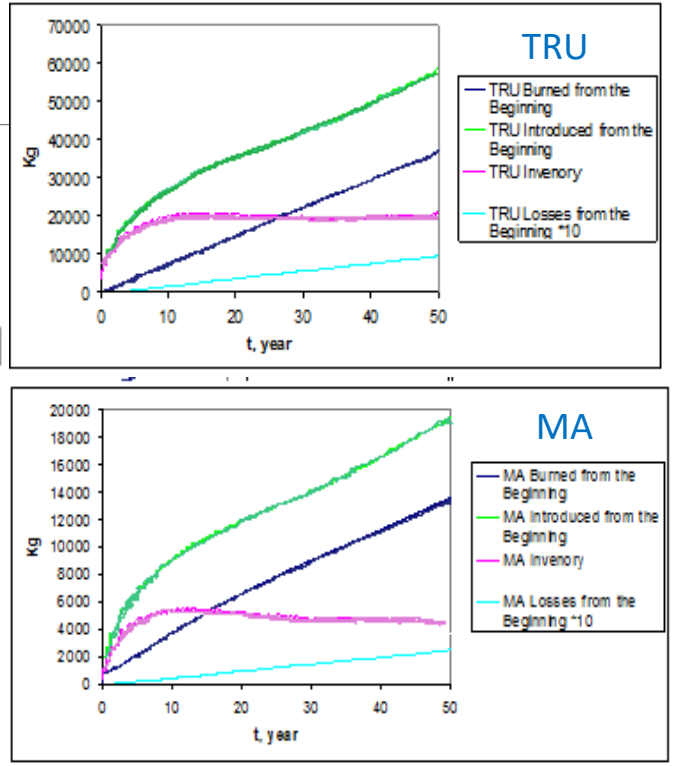
Initial loading - 11% MA+89% Pu; make up - 33,3% MA+66,7%Pu; Consume 13,6 t MA (270 kg/yr) after 50 years

Input in K_{eff}

ISOTOPE	BOL	EOL
Pu 239	0,75	0,25
Pu 241	0,25	0,41
Cm 245	-	0,28

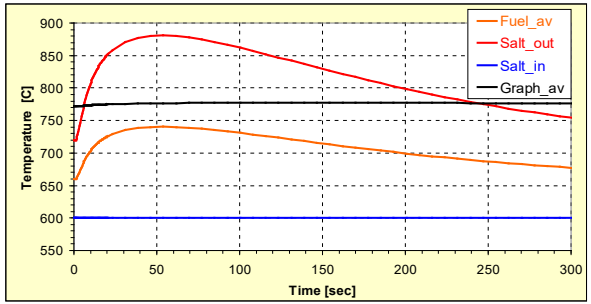




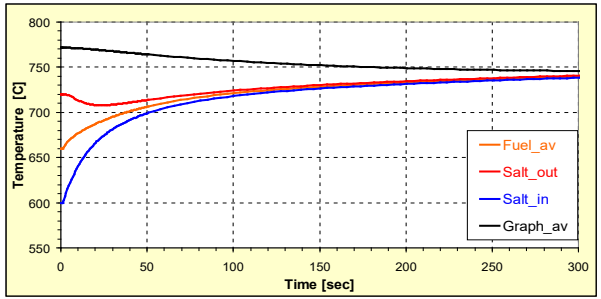


The MOSART is expected not to be seriously challenged by the major, unprotected transients such as ULOF, ULOH, overcooling, or even UTOP. The system was shown to buffer reactivity insertion of up to + 1.5$. System temperatures are expected to rise only ~300C above nominal under this severe transient conditions. The mechanical and structural integrity of the system is not expected to be impaired

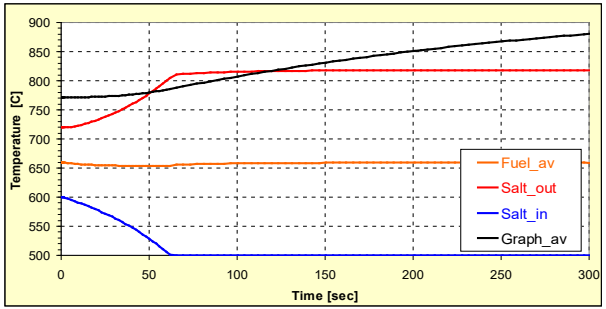
ULOF



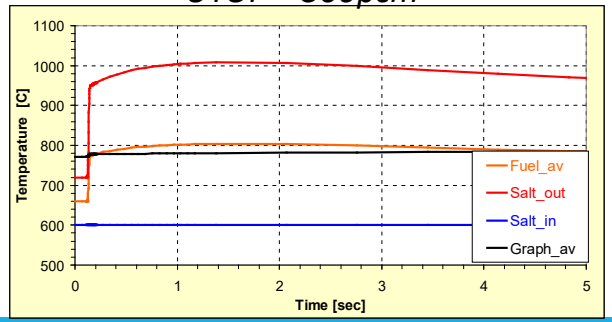
ULOH



Over-Cooling



UTOP + 500pcm



Safety Analysis In Early Stages of Development

Principal design criteria needed

Major phenomena have not been identified or ranked

Accident sequences and initiating events have not been identified in details

Qualified safety analysis tools are not yet available

- Identification of safety analysis codes (applicability of LWR and FBR tools?)
- Operational experience does not exist
- Nonprototypic (scaled) separate and integral effects tests need to be used
- Quality data and benchmarks need to be developed
- Need for test and prototype reactors (MSRE may be used for similar designs)

Mechanistic source term needs to be developed

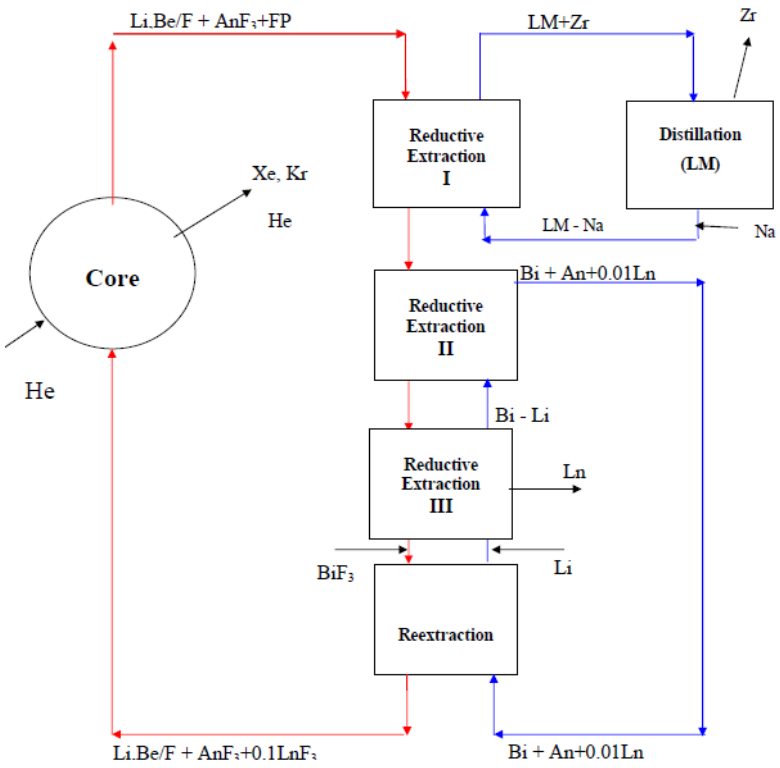
Tritium control will be necessary

Fuel qualification process needs to be defined

To achieve fuel maintenance, (1) the fuel must be delivered to and into the reactor in a proper state of purity and homogeneity, (2) the fuel must be sufficiently protected from extraneous impurities, and (3) sound procedures must exist for provision of the required redox potential in the system. They also include:

- continuous removal of Xe and Kr by the He sparging,
- addition of TRUs to replace that lost by burnup,
- recycling of all actinides,
- removal of soluble FPs (principally rare earths);
- removal of a portion of the insoluble noble and semi noble FPs.

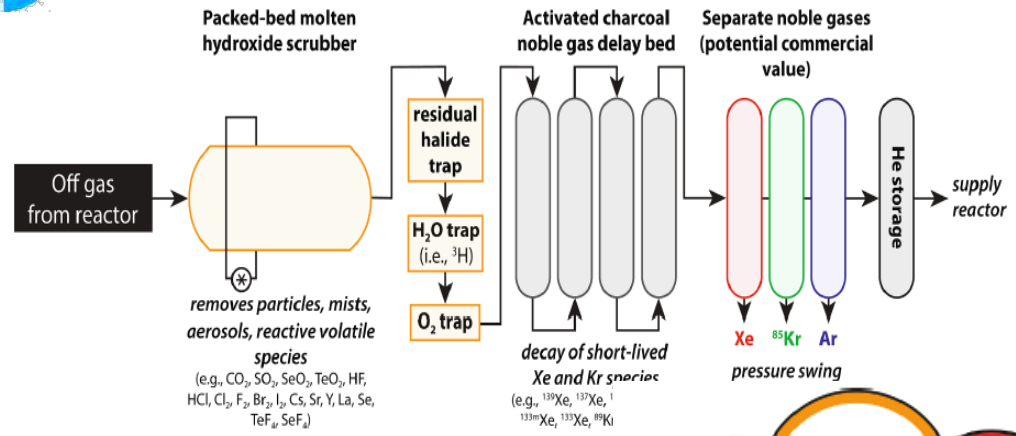
Methods for FP removal and actinides recycling in MSR

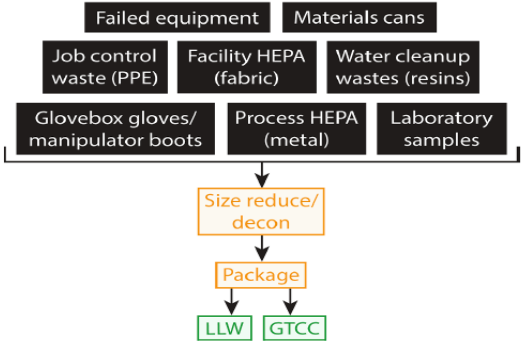


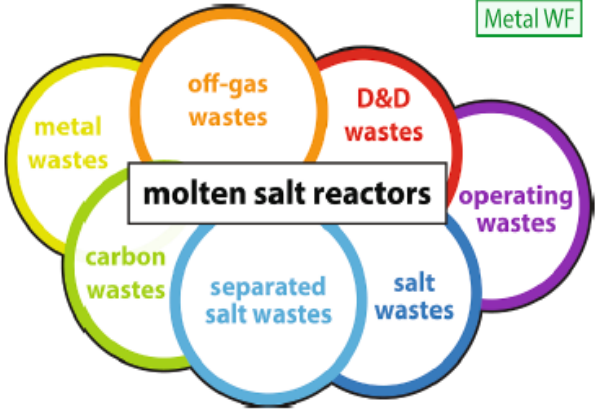
Element	Time
Kr, Xe	50 s
Zn, Ga, Ge, As, Se, Nb, Mo, Ru, Rh, Pd, Ag, Tc, Cd, In, Sn, Sb, Te	2-4 hrs
Zr	1-2 yrs
Ni, Fe, Cr	1-2 yrs
Pu, Am, Cm, Np, U	1-2 yrs
Y, La, Ce, Pr, Nd, Pm, Gd, Tb, Dy, Ho, Er	1-2 yrs
Sm, Eu	1-32yrs
Sr, Ba, Rb, Cs	5-10 yrs
Li, Be	30 yrs

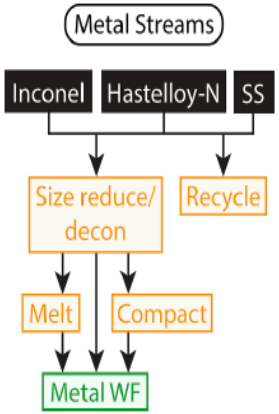
	Separation factors related to Plutonium		
	$LiF-BeF_2/Bi$	$LiF-BeF_2-ThF_4/Bi$	$LiF-NaF-BeF_2/Bi$
Pu	1	1	1
Am	-	1,5	-
Cm	6	8	-
Nd	3000	1500	100
La	25000	2300	> 300

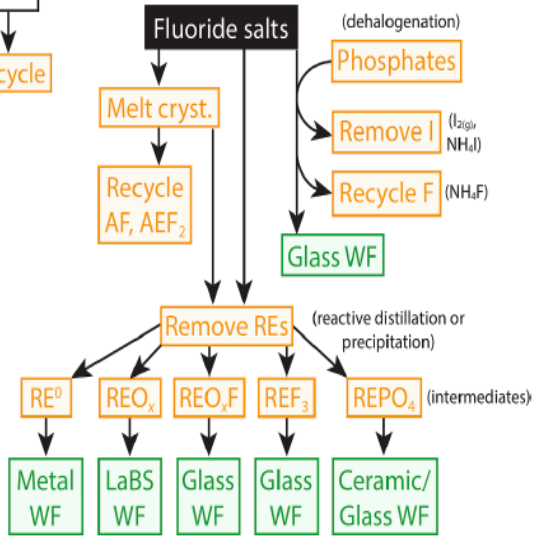
MSR waste and effluent management strategies







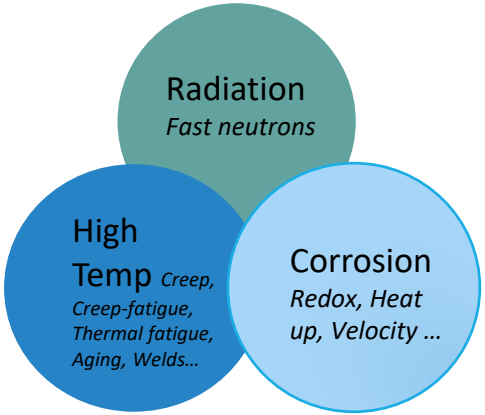


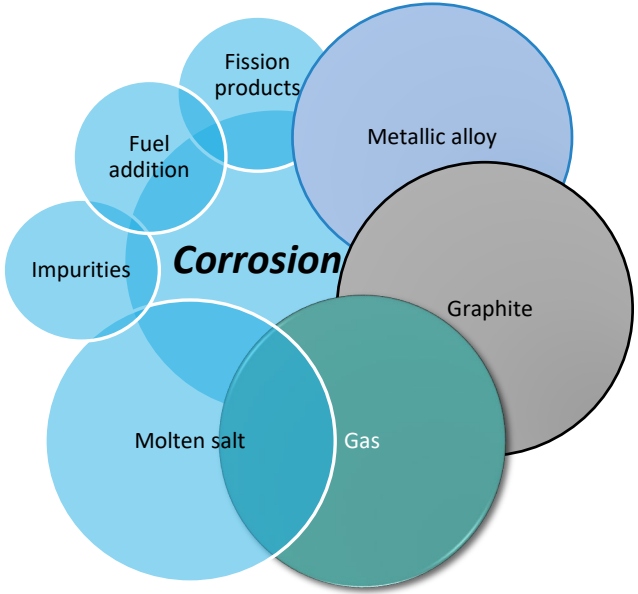


Gen IV MSR Container Materials

The success of MSR is strongly dependent on the compatibility of the container materials with the molten salts used in primary and secondary circuits

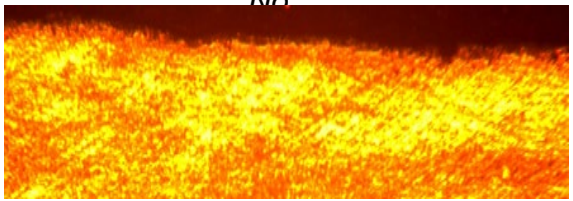
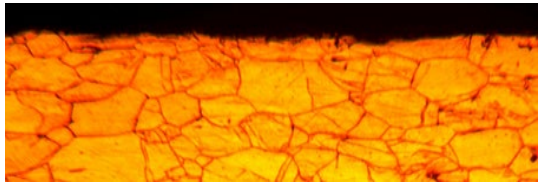
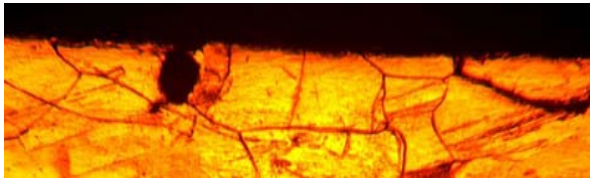
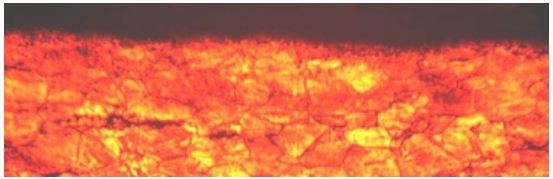
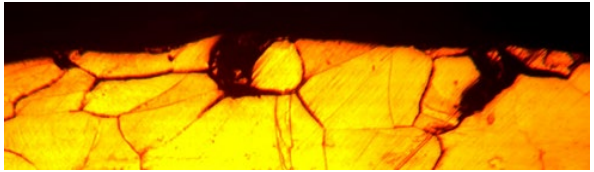
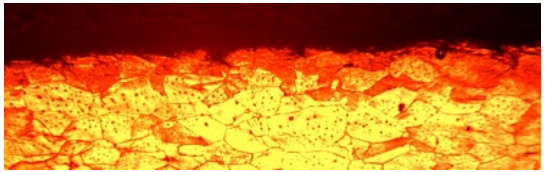
Combined environments





Because the products of oxidation of metals by fluoride melts are quite soluble in corroding media, passivation is precluded, and the corrosion rate depends on other factors, including: <u>Oxidants, Thermal gradients, Salt flow rate, Galvanic coupling</u>

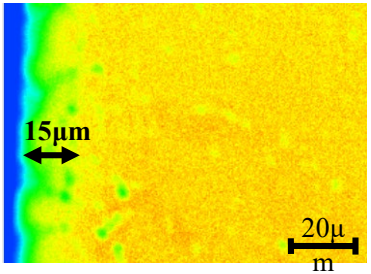
N-alloy Compatibility With Li,Be,U/F Depends on Redox Potential

U(IV)/(UIII)	EM-721, enlargement ×160	HN80MTY, enlargement ×610
30 without loading at 760°C	*No* 	*No* 
60 without loading at 760°C	*K = 3380pc ×μm/cm ; l = 117μm* 	*No* 
90 without loading at 800°C	*K = 5830pc ×μm/cm ; l = 286μm* 	*K = 530pc ×μm/cm ; l = 26μm* 

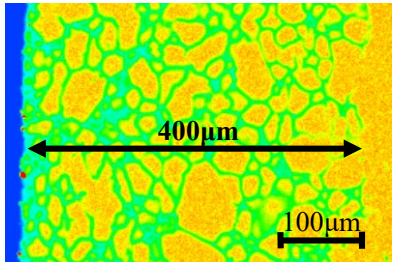
N-Alloy compatibility with Li,Na,K/F salt mixture

Cr depletion on material surface as result of uniform corrosion

FLiNaK

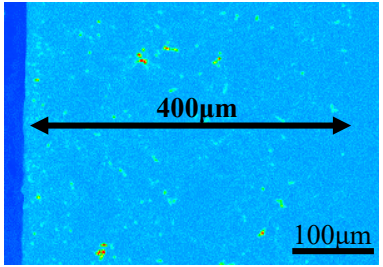


FLiNaK + 10mg/cm^2 Te

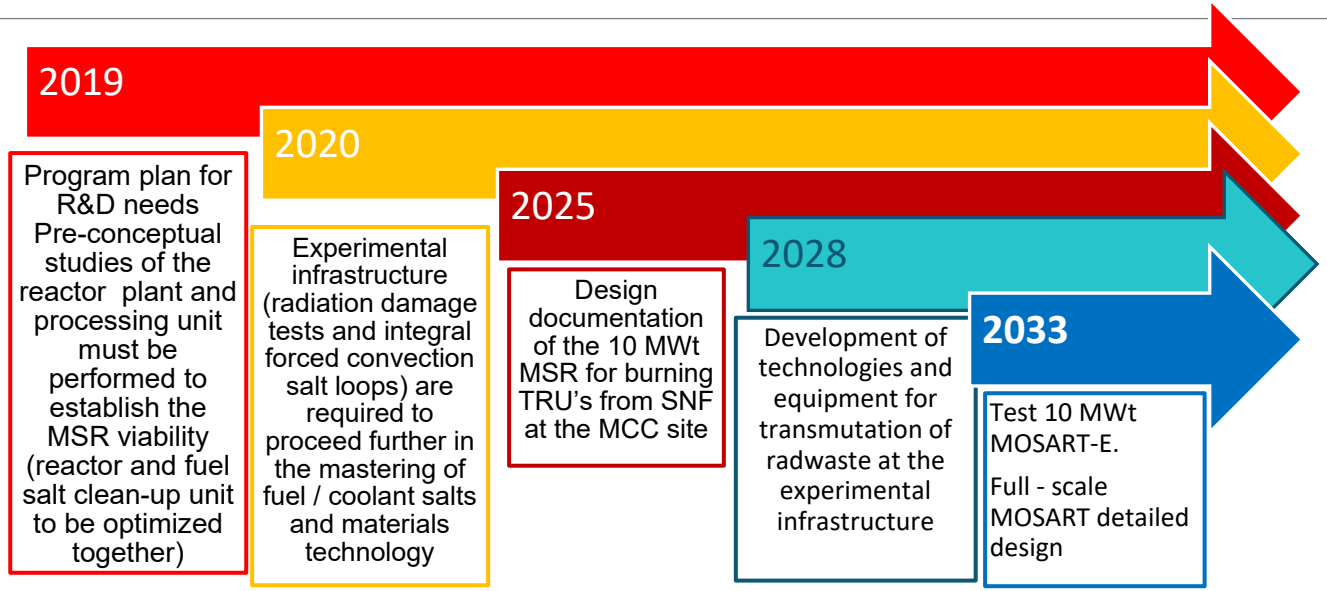


FLiNaK + 10mg/cm^2 Te after 200 hrs exposure

Te distribution



The construction of a large power MSR is proposed to be preceded by the construction of 10 MWt test MSR unit to demonstrate the control of the reactor and fuel salt management with its volatile and fission products with different TRU loadings for start up, transition to equilibrium, drain-out, shut down etc.



There are opportunities to further improve the efficiency of burning minor actinides in MSR, which will be justified by the results of the experimental setup

Summary

- MSR concepts offer alternative options for the long lived waste incineration with the added value of liquid fuel (fuel cycle flexibility, intrinsic safety features, simplified fuel processing, in-service inspection, no fuel transportation and refabrication required).
- Significant progress has been made on the resolution (or cancellation) of critical viability issues (material compatibility, salt physical & chemical properties, fuel salt processing feasibility, intrinsic safety).
- Pre-conceptual studies of the whole reactor and processing unit must be performed to establish the MSR viability (reactor and fuel salt clean-up unit to be optimized together).
- Experimental infrastructures (analytical and integral salt loops with real fuel salts) are required to proceed further in the mastering of MSR technologies (e.g. tritium control) and components (long shaft pump, heat exchanger, etc.) testing.
- MSRs will require a significant change in current regulations and guidance