A closed fuel cycle option using the MSFR concept with chloride salts and the U/Pu cycle

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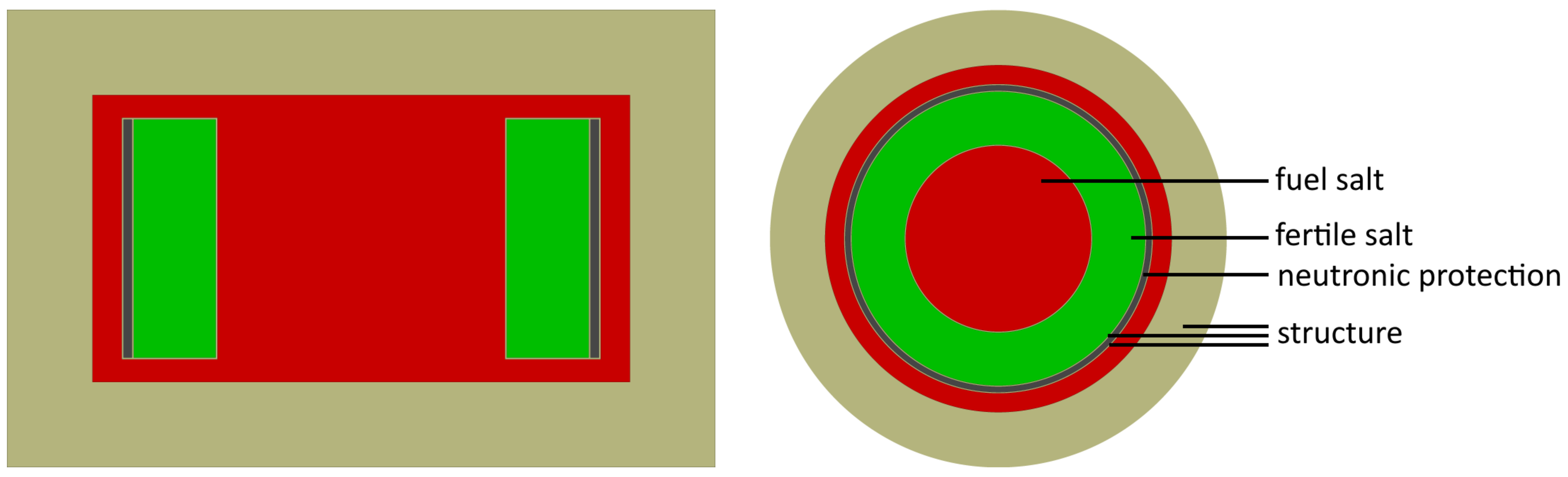
Introduction

Objective: to design and optimise a breeder Molten Salt Fast Reactor with chloride salts (MSFR-Cl) making use of transuranic elements (TRUs) of spent fuels to close the fuel cycle

Chloride MSFR presentation



Geometry for neutronic codes (Serpent2 view)

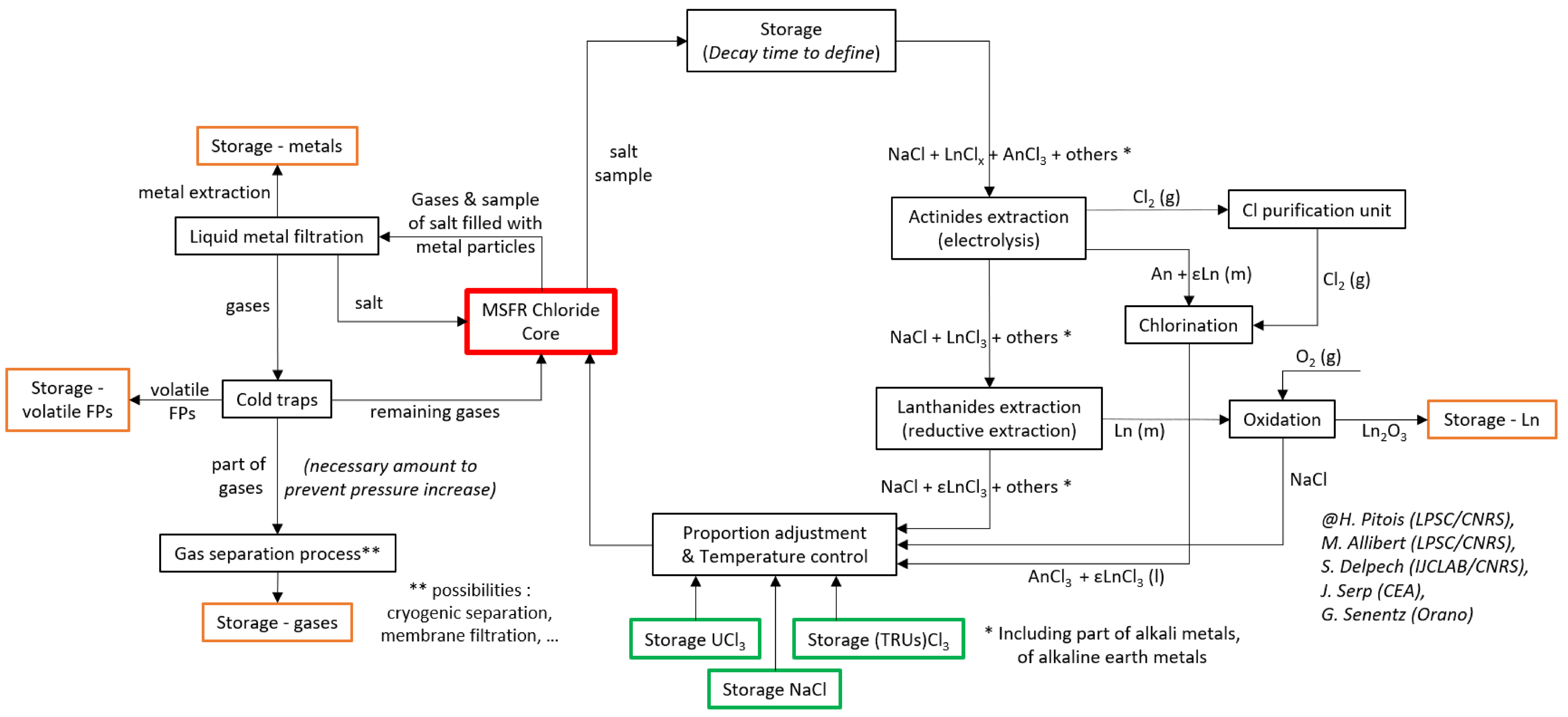
- Optimised fuel salt volume for inventory minimisation and efficient heat extraction (3GWth): 60m^3
- Optimised fertile blanket width for inventory minimisation and breeding ratio maximisation: 96cm
- Structure: Hastelloy N / Neutronic protection: B_4C
- MSFRs-Cl can be started with TRUs from spent fuels, enriched uranium, breeded plutonium ...

Initial inventory for different fuel options (masses: fuel + fertile salts)

Fuel	NaCl	UCl_3	$(TRU)Cl_3$	TRU mass	U mass	Total mass
ex-UOx (5y)	65.5%	28.0%	6.5%	16.6t + 1.6t	70.7t + 51.2t	170t + 103t
ex-MOx (15y)	65.0%	26.5%	8.5%	21.6t + 1.6t	66.7t + 51.2t	170t + 103t
^{enr}U (e=16.4%)	67.0%	33.0%	0%	0.0t + 1.6t	84.7t + 51.2t	168t + 103t
Breeded Pu	65.7%	28.6%	5.7%	14.6t + 1.6t	72.4 + 51.2t	169t + 103t

Salt processing

- Objectives:
  - Source term minimisation
  - Neutron economy increased: better regeneration
  - Prevention of corrosion induced by fission products
- Full on-site processing or partial on-site processing are possible
- Incentives for the full on-site processing:
  - Minimised enriched chlorine inventory
  - Transport of fission products in stable chemical form
- Incentives for the partial on-site reprocessing:
  - Simplified on-site unit
  - Delayed processing allows more processes including aqueous chemistry in an external factory



Full on-site processing

Depletion calculations

- Depletion calculations performed using in-house CNRS code REM to consider extractions and feedings
- Here the fuel salt is fed with the same elements it is started with but other options are possible
- Optimised processing flowrates are **100L/d** for the fuel salt and **50L/d** for the fertile salt
- Extraction efficiencies are taken equal to 100%
- Ongoing work to feed the fuel salt with the excess of Am

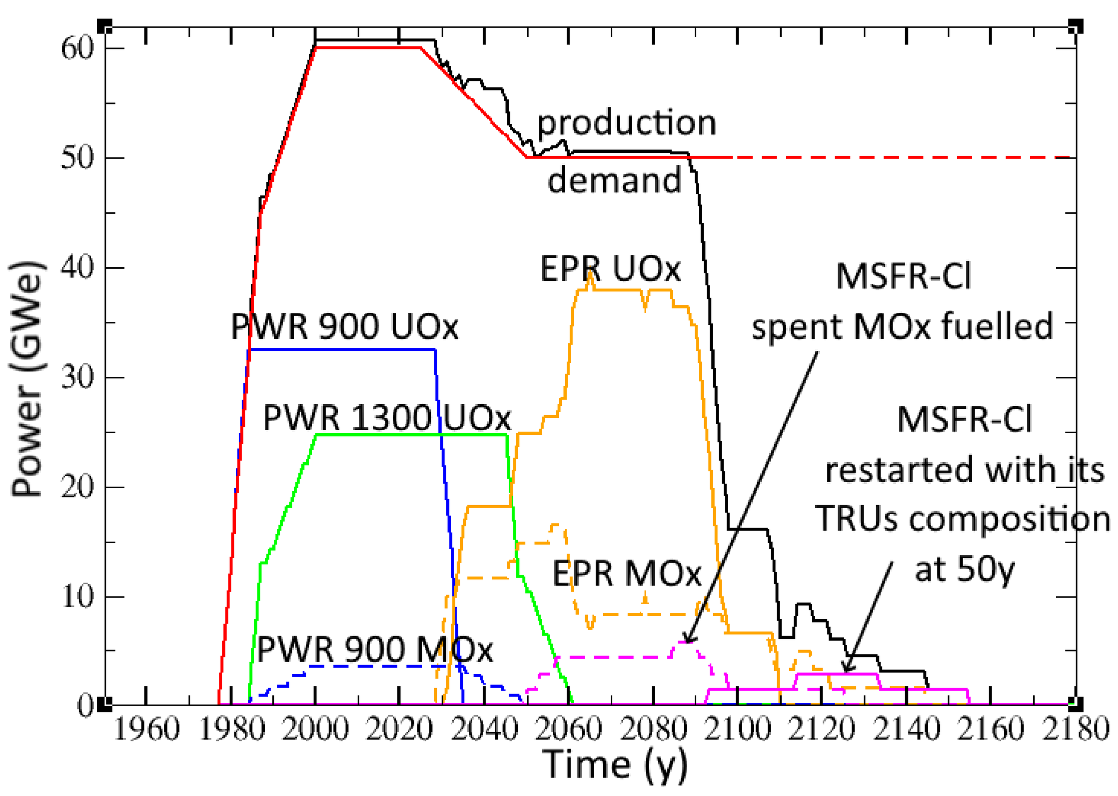
Actinide balance for spent MOx TRU fuelled MSFR-Cl

mass flow (kg/y)	U	Np	Pu	Am	Cm
core feeding	1102.05	0.02	2.59	0.42	0.07
fertile blanket feeding	361.59	0.00	478.93	0.00	0.00
fertile blanket extraction	4.29	1.34	742.87	26.39	0.06
average net output per year	-1459.35	1.32	261.34	25.97	-0.02

Deployment scenarios (example)

French case with following hypotheses:

- Start of EPRs in 2025; start of MSFRs-Cl fuelled with TRUs from spent MOx in 2050
- Priority: MSFRs, then MOx fuelled EPRs, then UOx fuelled EPRs
- End of UOx fuelled EPRs in 2100; MOx fuelled EPRs and MSFRs continue to reduce waste stockpiles



Evolution of the fleet with MSFRs-Cl

Final stockpiles

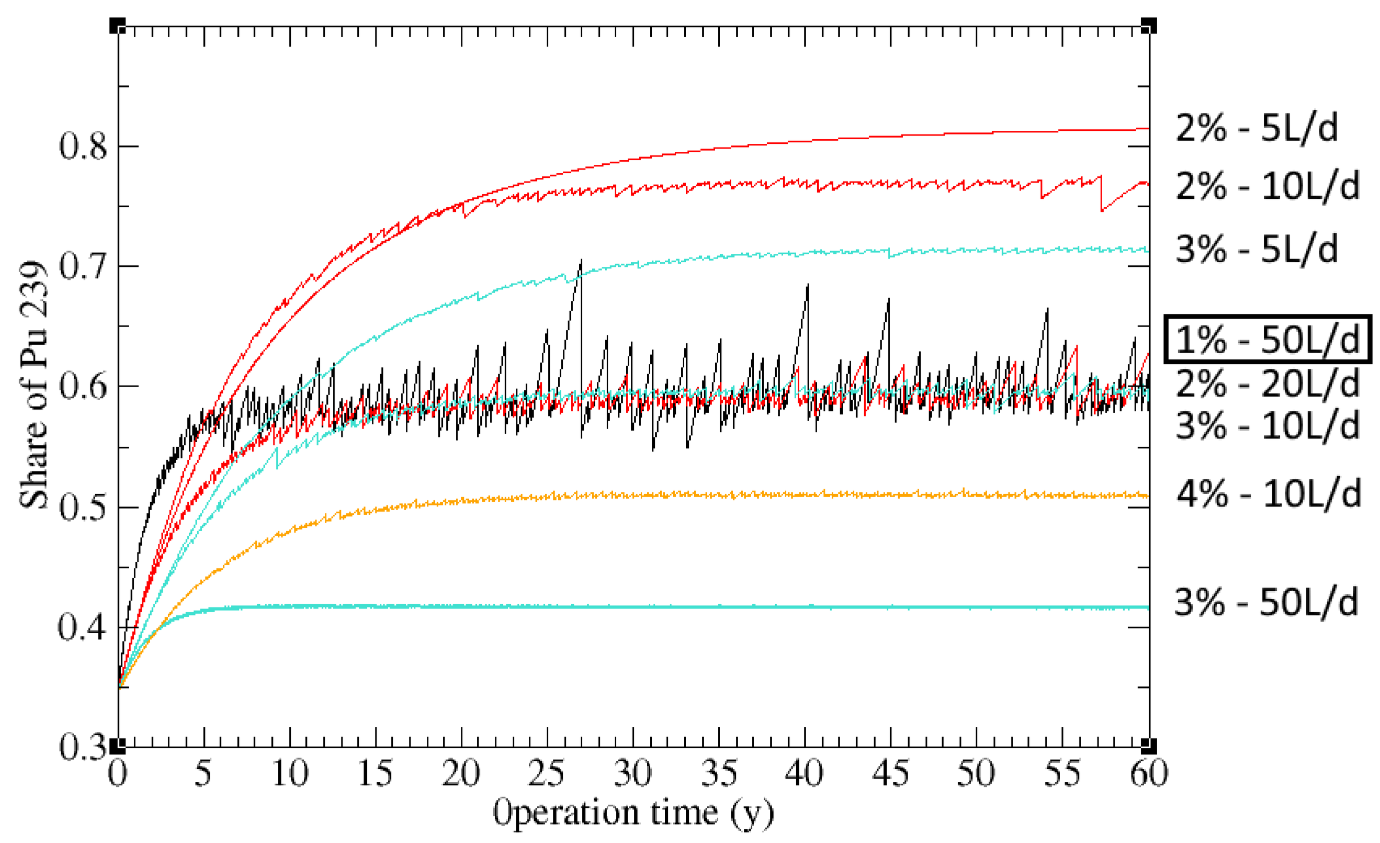
	Final masses	
	EPRs only	With MSFR-Cl
^{nat}U used	687 kt	659 kt
Spent UOx TRUs	Practically eliminated	Practically eliminated
Spent MOx TRUs	**225 t**	**25 t (Am & Cm)**
TRUs from MSFRs	/	110 t *

* 47t of breeded Pu
\+ 63t of TRUs from MSFRs

- Spent MOx TRUs stockpile is greatly reduced, Am & Cm could be used in MSFR fuel (ongoing work)
- Less ^{nat}U consumption; final wastes could be burnt in alternative MSFR configurations: burners

Proliferation resistance

- Several options are possible, spent MOx Pu addition in the fertile salt is considered here
- **Synergy with EPRs** by regeneration of Pu vector (aim: 60% of ^{239}Pu ~ Pu in spent UOx)
- Pu vector is chosen by the amount of Pu maintained and the processing rate of the fertile salt
- Current choice: **1% of $PuCl_3$ + 50L/d** for the processing rate in the fertile blanket



Evolution of ^{239}Pu share in fertile salt

Review & perspectives

- Chloride MSFR designed to use TRUs from spent fuels to close the fuel cycle
- Geometry optimisation:
  - Optimised volume of fuel salt: 60m^3
  - Optimised fertile blanket width: 96cm
  - Neutronic protection is being optimised
- Design of new fuel processing units
- Synergy with EPRs is possible, with the improvement of the Pu vector
- Ongoing deployment studies to assess the interest of MSFRs-Cl and adjust the design, for French deployment or worldwide deployment
- Alternative versions of the reactor (smaller power, configuration without fertile blanket) will be studied later on