Recommendations for a demonstrator of Molten Salt Fast Reactor

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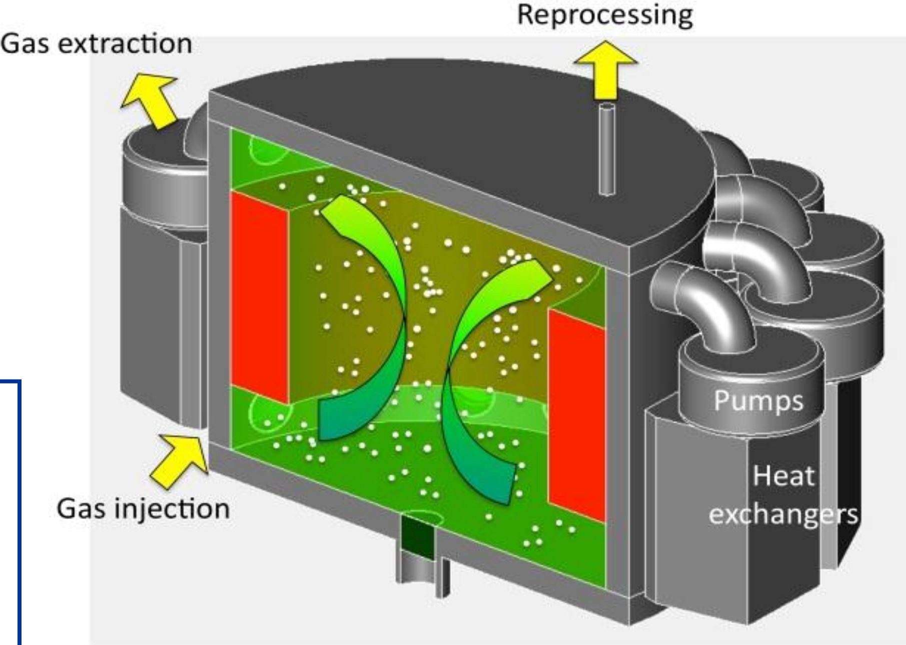
The concept of Molten Salt Fast Reactor

What is a MSFR ?

Molten Salt Reactor (molten salt = liquid fuel also used as coolant)

Based on the Thorium fuel cycle

With no solid (i.e. moderator) matter in the core ⇒ Fast neutron spectrum



Parameters of study:

Initial fissile matter (^{233}U, Pu, enriched U), salt composition, fissile inventory, reprocessing, waste management, deployment capacities, heat exchanges, structural materials, design..

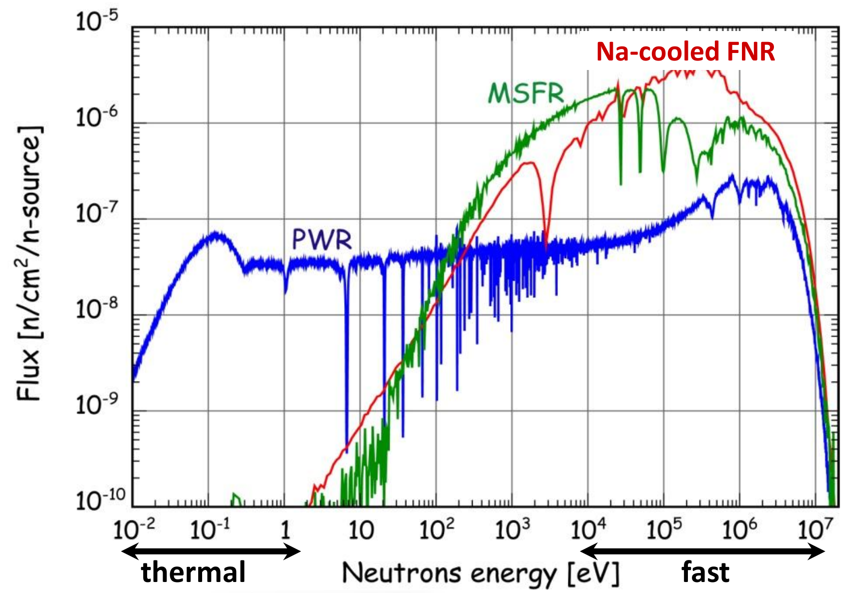
⇨ Generation IV reactors: fuel reprocessing mandatory

Neutronic core of the MSFR associated to an on-site reprocessing unit (on-line in-core bubbling and batch chemical reprocessing during reactor operation)

The concept of Molten Salt Fast Reactor

Thermal power	**3000 MWth**
Mean fuel salt temperature	**750 °C**
Fuel salt temperature rise in the core	**100 °C**
Fuel molten salt - Initial composition	**77.5% LiF and 22.5% [ThF_4+ (Fissile Matter)F_4] with Fissile Matter = ^{233}U / $^{enriched}U$ / Pu+MA**
Fuel salt melting point	**565 °C**
Fuel salt density	**4.1 g/cm^3**
Fuel salt dilation coefficient	**8.82 10^{-4} / °C**
Fertile blanket salt - Initial composition	**LiF-ThF_4 (77.5%-22.5%)**
Breeding ratio (steady-state)	**1.1**
Total feedback coefficient	**-5 pcm/K**
Core dimensions	**Diameter: 2.26 m Height: 2.26 m**
Fuel salt volume	**18 m^3 (½ in the core + ½ in the external circuits)**
Blanket salt volume	**7.3 m^3**
Total fuel salt cycle	**3.9 s**

Design of the 'reference' MSFR



R&D objectives

The renewal and diversification of interests in molten salts have led the MSR provisional SSC to shift the R&D orientations and objectives initially promoted in the original Generation IV Roadmap issued in 2002, in order to encompass in a consistent body the different applications envisioned today for fuel and coolant salts.

Two baseline concepts are considered which have large commonalities in basic R&D areas, particularly for liquid salt technology and materials behavior (mechanical integrity, corrosion):

- The Molten Salt Fast-neutron Reactor (MSFR) is a long-term alternative to solid-fuelled fast neutron reactors offering very negative feedback coefficients and simplified fuel cycle. Its potential has been assessed but specific technological challenges must be addressed and the safety approach has to be established.

- The AHTR is a high temperature reactor with better compactness than the VHTR and passive safety potential for medium to very high unit power.

The concept of Molten Salt Fast Reactor

Which initial load fissile for a MSFR?

- Start directly ^{233}U produced in Gen3+ or Gen4 (including MSFR) reactors

- Start directly with enriched U: enrichment required > 20%

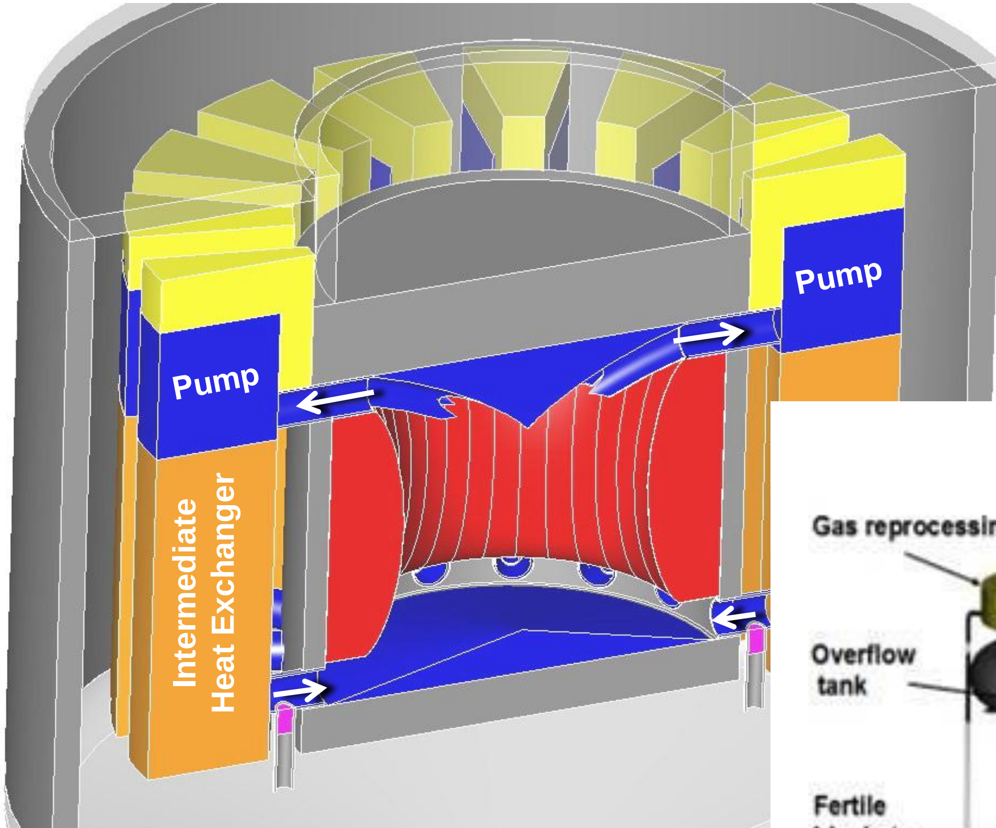
- Start with the Pu of current LWRs mixed with other TRU elements: solubility limit of valence-III elements in LiF

- Mix of these solutions: Thorium as fertile matter +

  - ^{233}U + TRU produced in LWRs
  - MOx-Th in Gen3+ / other Gen4
  - **Uranium enriched at 13% + TRU currently produced**

[kg per GWe]	^{233}U started MSFR	TRU (Pu UOx) started MSFR	Enriched U (13%) + TRU started MSFR	Th Pu-MOx started MSFR
Th 232	25 553	20 396	10 135	18 301
Pa 231				20
U 232				1
U 233	3 260			2 308
U 234				317
U 235			1 735	45
U 236				13
U 238			11 758	
Np 237		531	335	54
Pu 238		229	144	315
Pu 239		3 902	2 464	1 390
Pu 240		1 835	1 159	2 643
Pu 241		917	579	297
Pu 242		577	364	1 389
Am 241		291	184	1 423
Am 243		164	104	354
Cm 244		69	44	54
Cm 245		6	4	

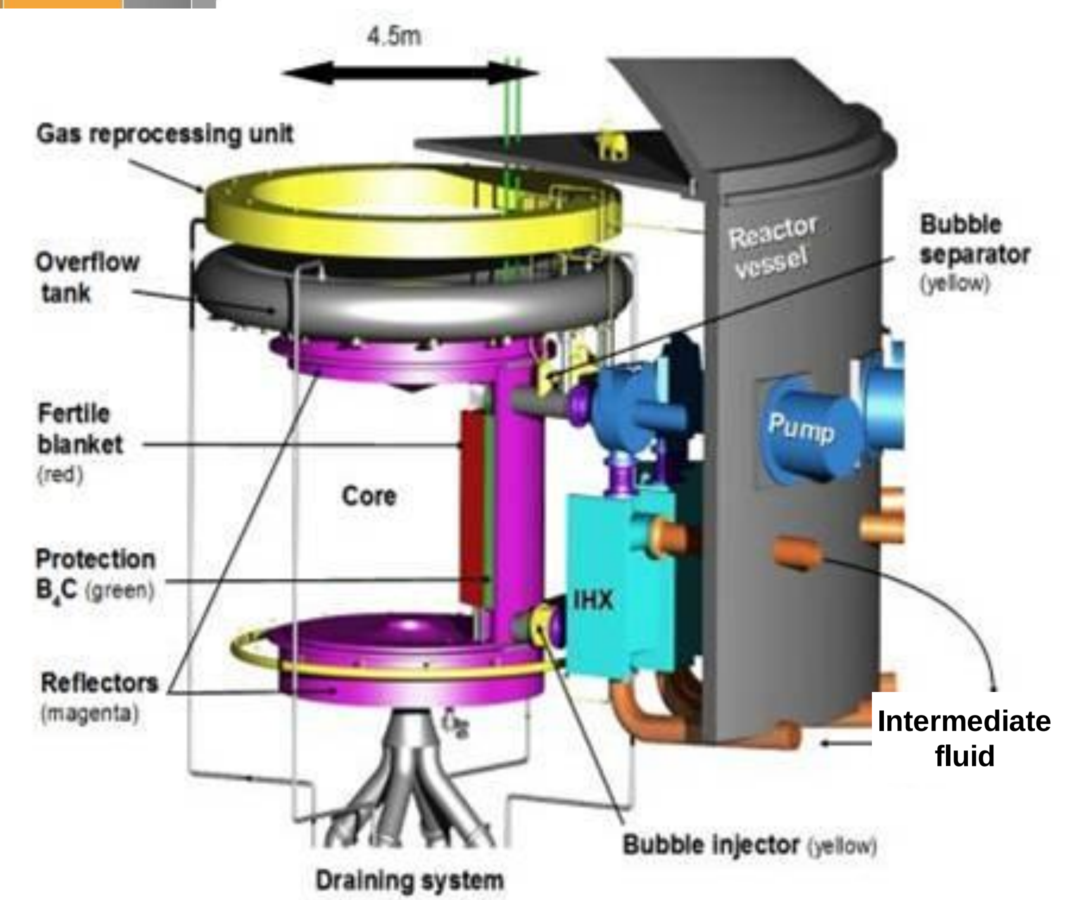
The concept of Molten Salt Fast Reactor



Core:

No inside structure

Outside structure: Upper and lower Reflectors, Fertile Blanket Wall



+ 16 external modules:

- Pipes (cold and hot region)
- Bubble Separator
- Pump
- Heat Exchanger
- Bubble Injection

Demonstration and Demonstrator of MSFR

Sizing of the facilities:

Small size: ~1liter - chemistry and corrosion – off-line processing

Pyrochemistry: basic chemical data, processing, monitoring

Medium size: ~100 liters – hydrodynamics, noble FP extraction, heat exchanges

Process analysis, modeling, technology tests

Full size experiment: ~1 m^3 salt / loop – validation at loop scale

Validation of technology integration and hydrodynamics models

3 levels of radio protection:

✓ Inactive simulant salt ⇨ Standard laboratory

Hydrodynamics, material, measurements, model validation

✓ Low activity level (Th, depleted U) ⇨ Standard lab + radio protect

Pyrochemistry, corrosion, chemical monitoring

✓ High activity level (^{enriched}U, ^{233}U, Pu, MA) ⇨ Nuclear facility

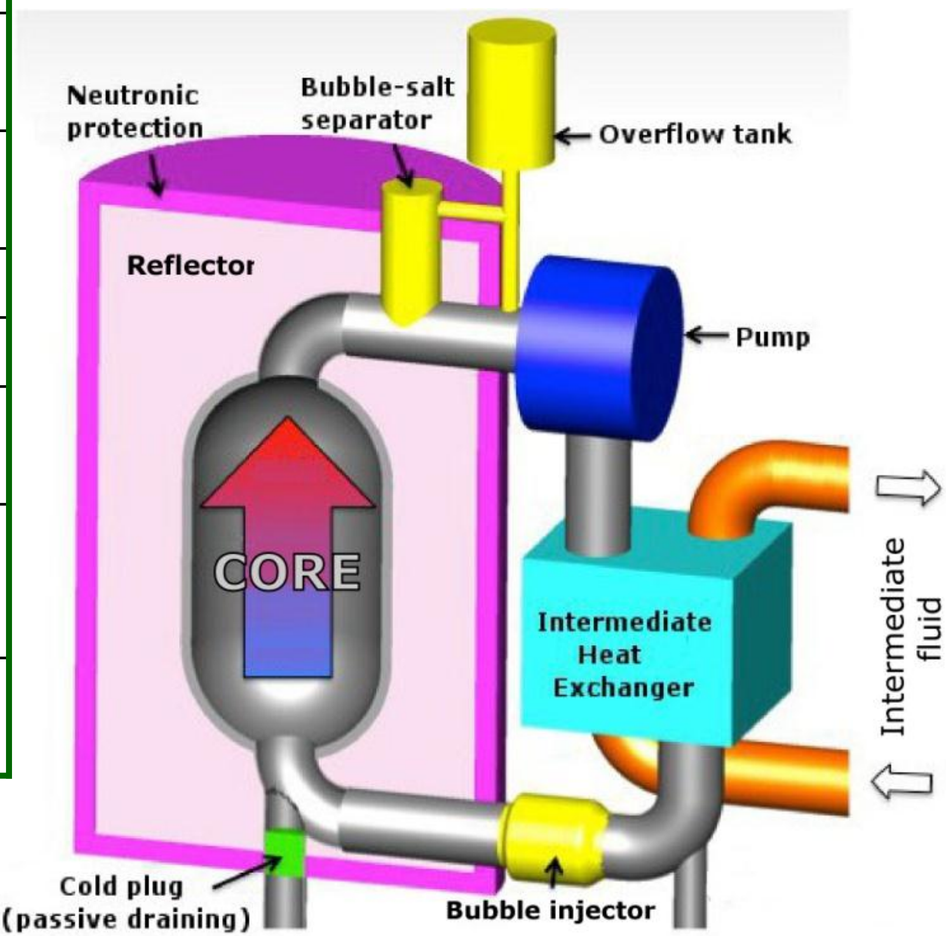
Fuel salt processing: Pyrochemistry, , Actinides recycling

Power Demonstrator of the MSFR

Thermal power	100 MWth
Mean fuel salt temperature	725 °C
Fuel salt temperature rise in the core	30 °C
Fuel Molten salt initial composition	77.55% LiF-ThF_4-$^{233}UF_4$ or LiF-ThF_4-(^{enriched}U+MOx-Th)F_3
Fuel salt melting point	565 °C
Fuel salt density	4.1 g/cm^3
Core dimensions	Diameter: 1.112 m Height: 1.112 m
Fuel Salt Volume	1.8 m^3 1.08 in core 0.72 in external circuits
Total fuel salt cycle in the fuel circuit	3.5 s

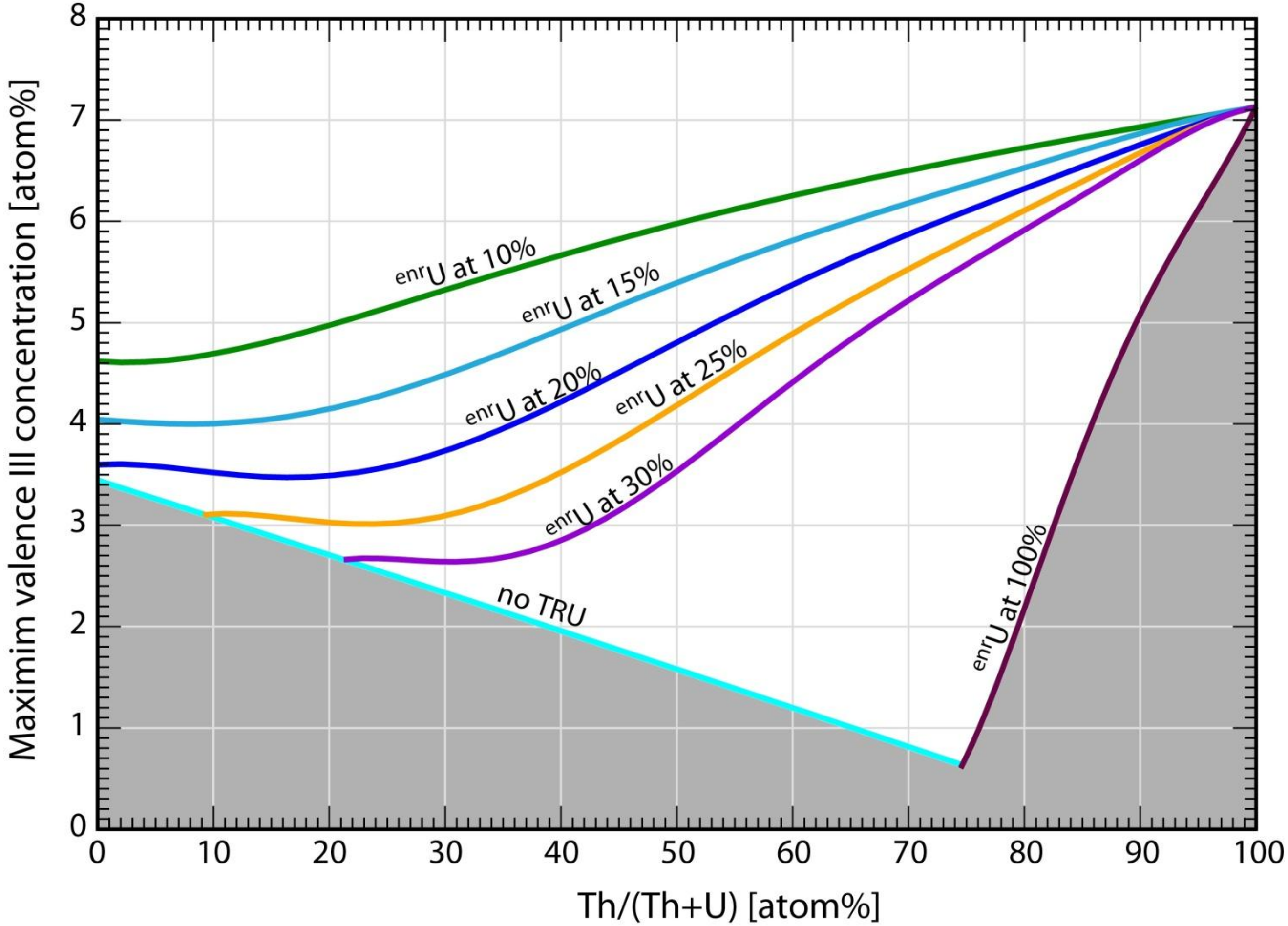
Demonstrator characteristics representative of the MSFR

From the power reactor to the demonstrator:
Power / 30 and Volume / 10

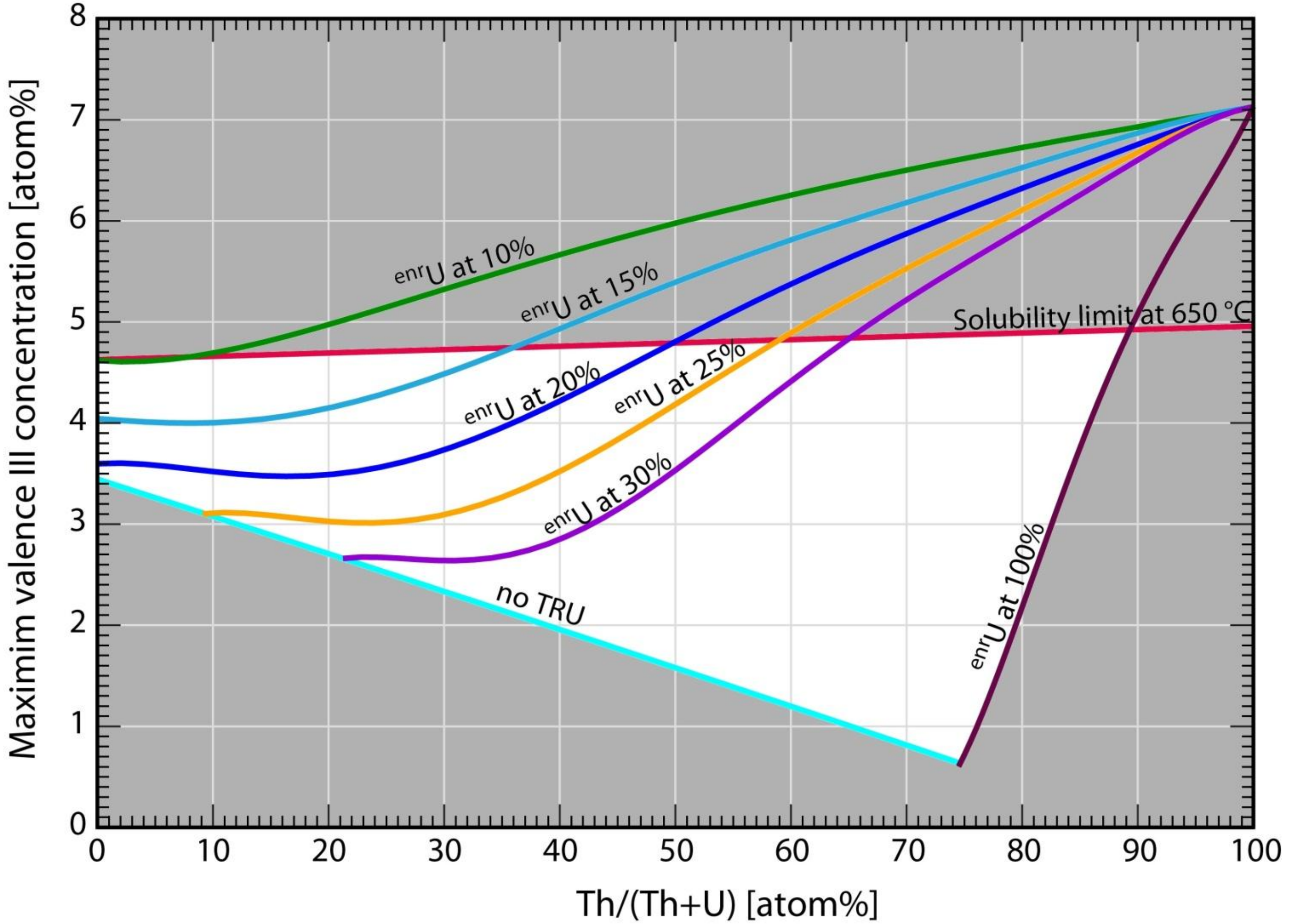


6 external loops

Power Demonstrator of the MSFR: initial fissile load

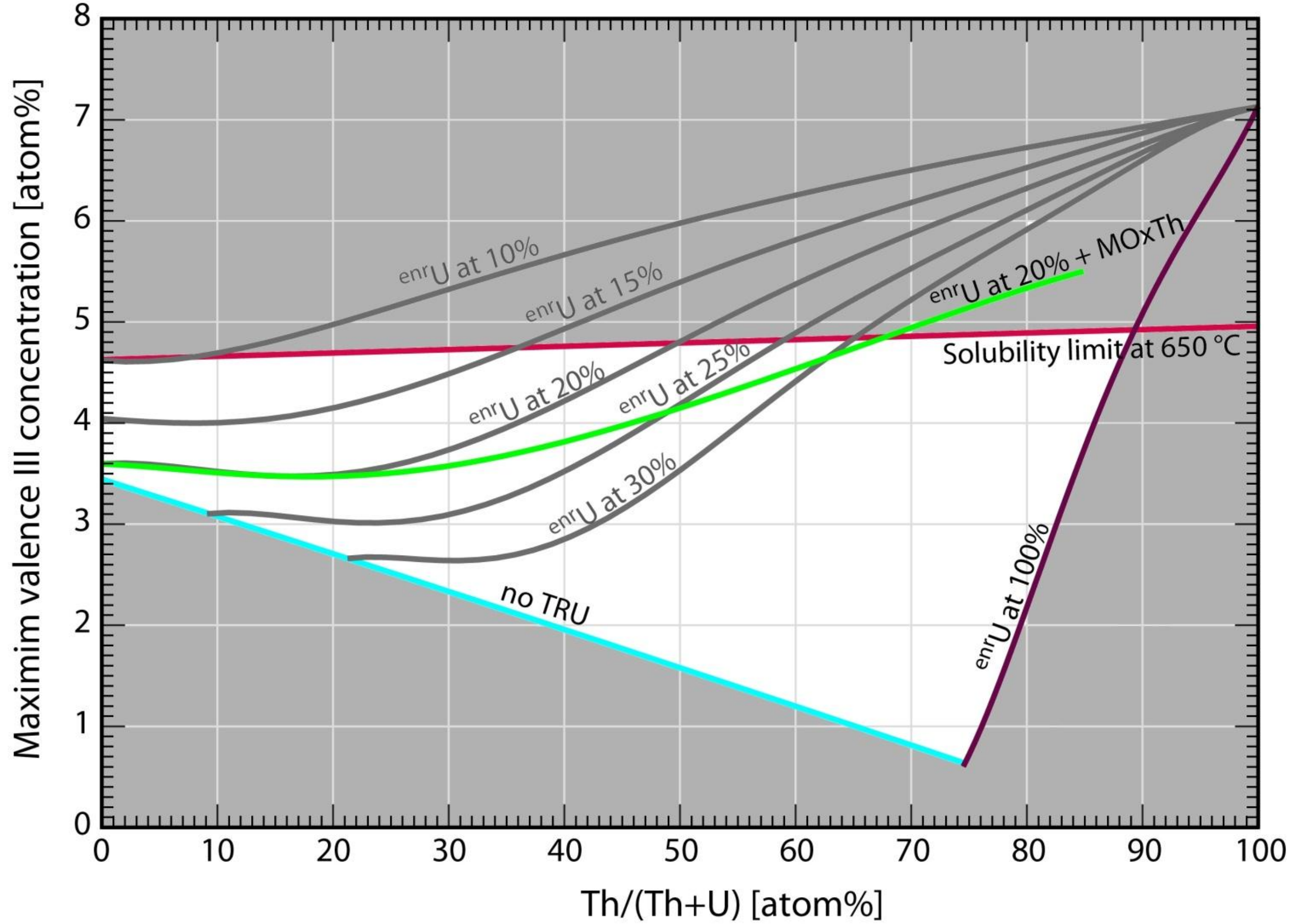


Power Demonstrator of the MSFR: initial fissile load



✓ enriched U mixed with transuranic elements possible with U enrichment of 15% - 20%

Power Demonstrator of the MSFR: initial fissile load



- ✓ enrichedU mixed with transuranic elements possible with U enrichment of 15% - 20%
- ✓ Uranium enriched at 20% mixed with irradiated MOx-Th with a ratio of Th/(Th+U) = 20 to 65%

From Power Demonstrator of the MSFR to SMR

	No radial blanket and H/D=1	No radial blanket and H/D=1
Power [MW_{th}]	**100**	**200**
Initial ^{233}U load [kg]	654	654
Fuel reprocessing of 1l/day		
Feeding in ^{233}U [kg/an]	**11.38**	**23.38**
Breeding ratio	-29.83%	-30.64%
Total ^{233}U needed [kg]	**1013.87**	**1388.37**

Around 650kg of ^{233}U to start

Under-breeder reactor

Fuel reprocessing of 4l/day		
Feeding in ^{233}U [kg/an]	**11.20**	**22.58**
Breeding ratio	-29.37%	-29.59%
Total ^{233}U needed [kg]	**1001.86**	**1353.13**

Low impact of the chemical reprocessing rate (not mandatory for the demonstrator)

From Power Demonstrator of the MSFR to SMR

	No radial blanket and H/D=1	No radial blanket and H/D=1	Radial blanket and H/D=1	Radial blanket and H/D=1
Power [MW_{th}]	**100**	**200**	**100**	**200**
Initial ^{233}U load [kg]	654	654	667	667
Fuel reprocessing of 1l/day				
Feeding in ^{233}U [kg/an]	11.38	23.38	1.72	4.70
Breeding ratio	**-29.83%**	**-30.64%**	**-4.52%**	**-6.16%**
Total ^{233}U needed [kg]	1013.87	1388.37	738.83	835.16
Breeding ratio (radial + axial fertile blankets)			***1.81%***	***-0.04%***
Fuel reprocessing of 4l/day				
Feeding in ^{233}U [kg/an]	11.20	22.58	1. 48	3.58
Breeding ratio	**-29.37%**	**-29.59%**	**-3.88%**	**-4.69%**
Total ^{233}U needed [kg]	1001.86	1353.13	722.50	794.21
Breeding ratio (radial + axial fertile blankets)			***2.49%***	***1.54%***

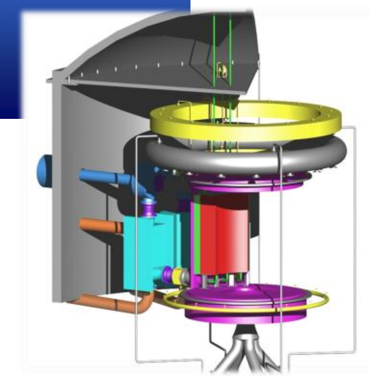
Addition of axial + radial fertile blankets ⇨ small modular breeder MSFR

From Power Demonstrator of the MSFR to SMR

	No radial blanket and H/D=1	No radial blanket and H/D=1	Radial blanket and H/D=1	Radial blanket and H/D=1	Radial blanket and H/D=1.5	Radial blanket and H/D=1.5
Power [MW_{th}]	**100**	**200**	**100**	**200**	**100**	**200**
Initial ^{233}U load [kg]	654	654	667	667	677	677
Fuel reprocessing of 1l/day						
Feeding in ^{233}U [kg/an]	11.38	23.38	1.72	4.70	-0.07	0.98
Breeding ratio	**-29.83%**	**-30.64%**	**-4.52%**	**-6.16%**	***0.18%***	**-1.29%**
Total ^{233}U needed [kg]	1013.87	1388.37	738.83	835.16	715.05	754.25
Breeding ratio (radial + axial fertile blankets)			***1.81%***	***-0.04%***		
Fuel reprocessing of 4l/day						
Feeding in ^{233}U [kg/an]	11.20	22.58	1. 48	3.58	-0.38	-0.26
Breeding ratio	**-29.37%**	**-29.59%**	**-3.88%**	**-4.69%**	***1.00%***	***0.34%***
Total ^{233}U needed [kg]	1001.86	1353.13	722.50	794.21	709.74	723.03
Breeding ratio (radial + axial fertile blankets)			***2.49%***	***1.54%***		

Addition of a radial fertile blanket + Elongated core ⇨ small modular breeder MSFR

European 'EVOL' (Evaluation and Viability Of Liquid fuel fast reactor systems) Project (7th PCRD) - *EURATOM/ROSATOM cooperation*



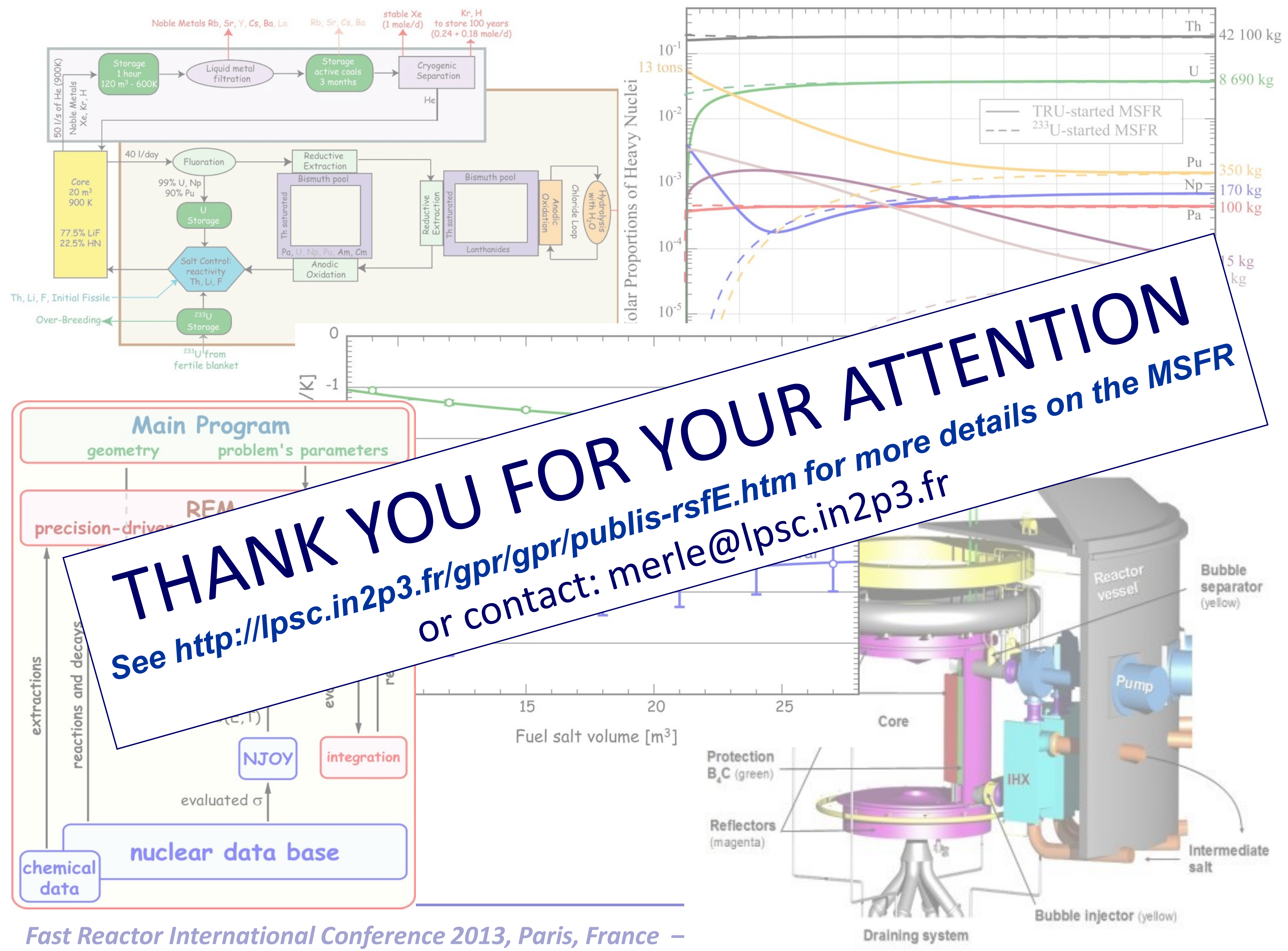
EVOL objective: to propose a design of MSFR by 2014 given the best system configuration issued from physical, chemical and material studies

- **Recommendations for the design of the core and fuel heat exchangers**
- **Definition of a safety approach dedicated to liquid-fuel reactors - Transposition of the defence in depth principle - Development of dedicated tools for transient simulations of molten salt reactors**
- **Determination of the salt composition - Determination of Pu solubility in LiF-ThF4 - Control of salt potential by introducing Th metal**
- **Evaluation of the reprocessing efficiency (based on experimental data) – FFFER project**
- **Recommendations for the composition of structural materials around the core**

WP2: Design and Safety
WP3: Fuel Salt Chemistry and Reprocessing
WP4: Structural Materials

European participants to EVOL: France (CNRS: Coordinator, Aubert&Duval, INOPRO, Grenoble INP), EU (JRC – Institute for TransU Elements), Netherlands (Delft University of Technology), Germany (KIT-G, FZD), Italy (Politecnico di Torino), United Kingdom (Oxford University), Czech Republic (Energovyzkum Ltd), Hungary (Budapest University of Technology) + 2 observers (Politecnico di Milano, Italy and Paul Scherrer Institute, Switzerland)

+ Coupled to the ROSATOM project MARS (Minor Actinides Recycling in Molten Salt)

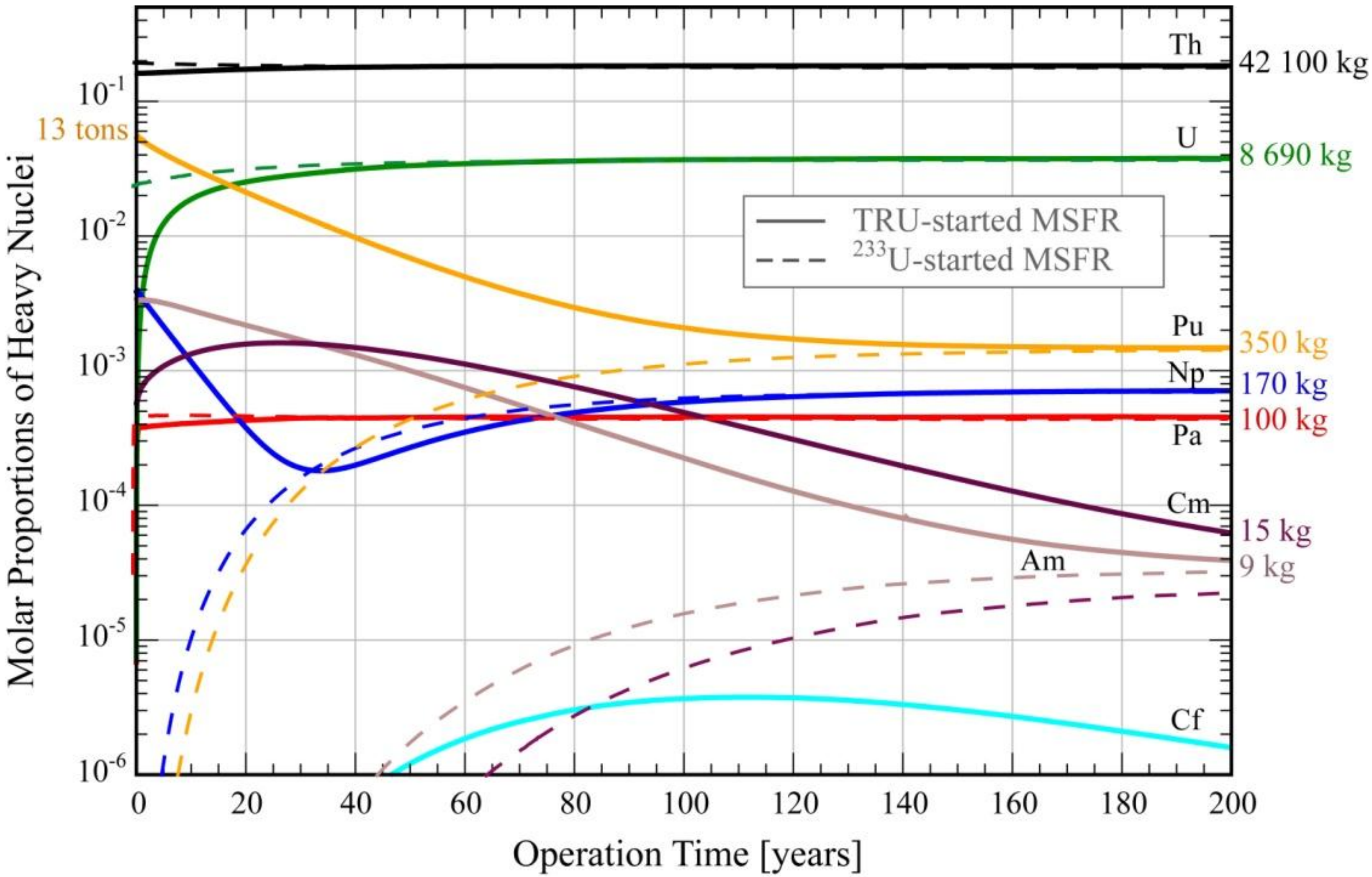


THANK YOU FOR YOUR ATTENTION

See http://lpsc.in2p3.fr/gpr/gpr/publis-rsfE.htm for more details on the MSFR

or contact: merle@lpsc.in2p3.fr

MSFR: Starting Modes / Initial Heavy Nuclei Inventory



MSFR: Starting Modes / Initial Heavy Nuclei Inventory