European Commission

Partitioning und Transmutation: Aktueller Stand

50 YEARS
JOINT RESEARCH CENTRE

Jean-Paul Glatz
EC-JRC-ITU

Kernenergetisches Symposium
Dresden 15 Oktober 2014

ToGEther SINCE 1957

EN3S European Nuclear Safety and Security School

Joint Research Centre

transmutation options

Transmutation of minor actinides (MA) can be achieved by using:

- thermalised neutron facilities (LWRs)
- fast neutron spectrum facilities,
  - –critical reactors or
  - –sub-critical accelerator driven systems (ADS)
- ADS operates in a flexible and safe manner even with a core loading containing a high amount of MA

Comparison of thermal and fast neutron spectrum: ratio of capture σ_c / fission cross sections σ_f

	PWR UOX			FR (EFR)		
Isotope	σ_f	σ_c	$\alpha = \sigma_c / \sigma_f$	σ_f	σ_c	$\alpha = \sigma_c / \sigma_f$
^{237}Np	0.52	33	63	0.32	1.7	5.3
^{241}Am	1.1	110	100	0.27	2.0	7.4
^{243}Am	0.44	49	111	0.21	1.8	8.6
^{242}Cm	1.14	4.5	3.9	0.58	1.0	1.7
^{243}Cm	88	14	0.16	7.2	1.0	0.14
^{244}Cm	1.0	16	16	0.42	0.6	1.4
^{245}Cm	116	17	0.15	5.1	0.9	0.18
^{99}Tc	/	9	/	/	0.5	/

European transmutation projects

European Commission

- MYRRHA (SCK•CEN, Belgium)

Multi-purpose hYbrid Research Reactor for High-tech Applications

  - Started in 1998
  - Projected to be in operation by 2028

- EC 6th Framework programme EUROTRANS

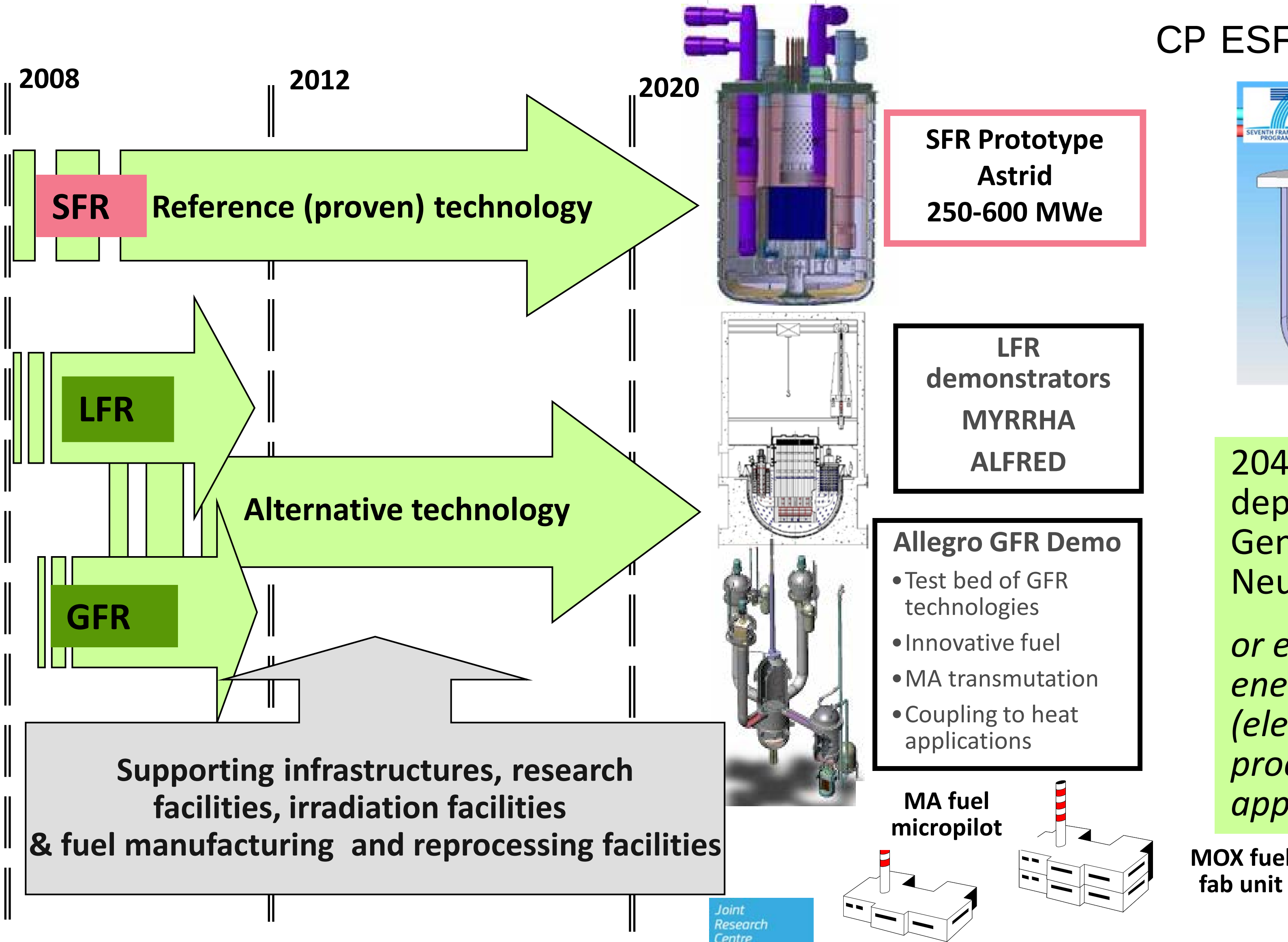
  - XT-ADS
  - EFIT_Pb
  - EFIT_Gas (back up)

EUROTRANS - EUROpean Research Programme for the TRANSmutation of High Level Nuclear Waste in an Accelerator Driven System

A fast spectrum testing facility in Europe, beyond 2015 complementary to Jules Horowitz Reactor (F).

Joint Research Centre

ESNII strategy



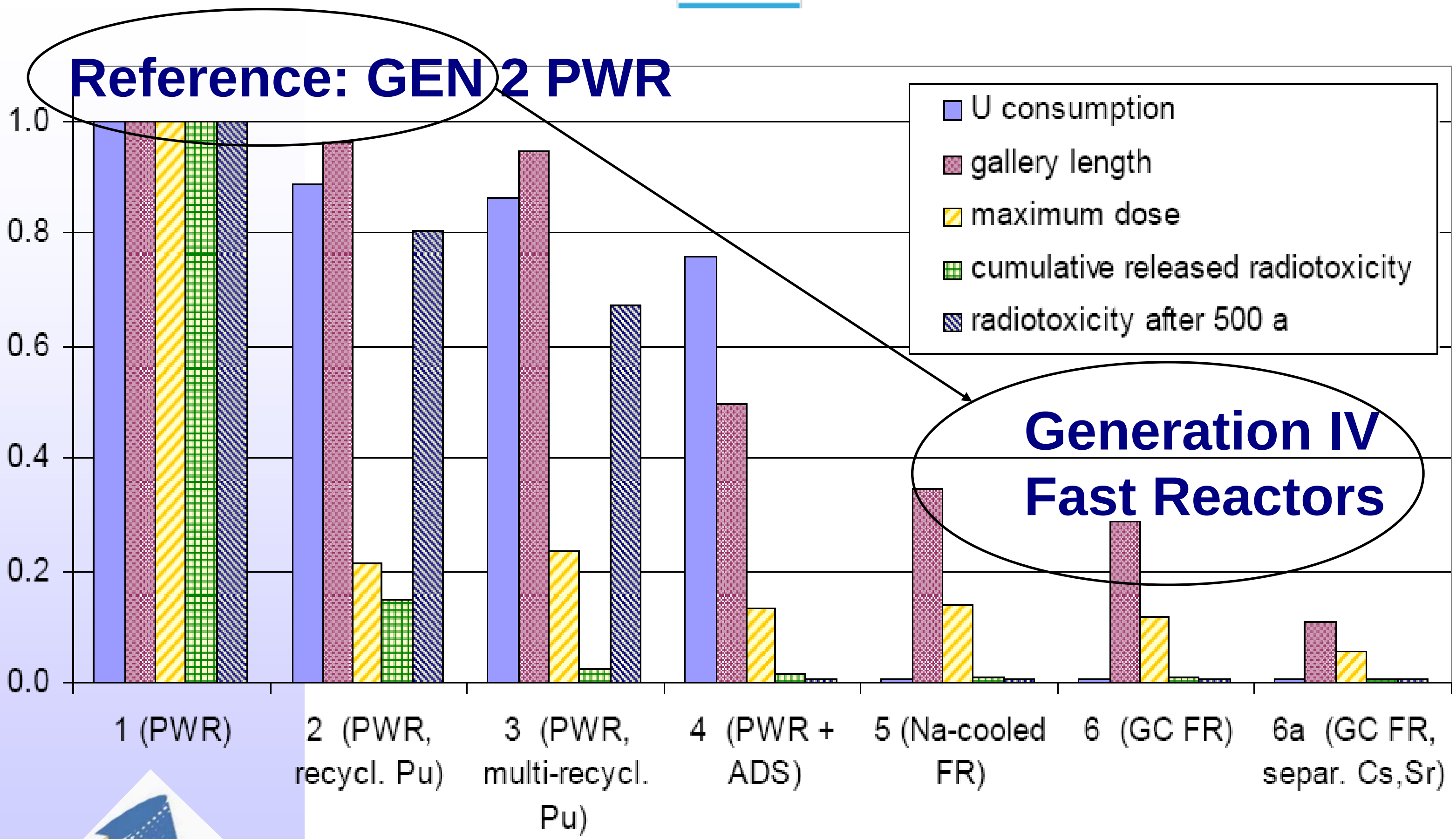
CP ESFR, ESNII+

2040: Target for deployment of Gen-IV Fast Neutron Reactors

or earlier if new energy needs (electric vehicles, process heat applications)

Sustainable fuel cycles vs open LWR cycle

European Commission



RED-IMPACT main results

GEN IV International Forum

Joint Research Centre

Why P&T

European Commission

- ✓ Improve long-term public safety (reduce radio-toxicity and future doses to man)
- ✓ Repository heat and size (footprint)
- ✓ Reduce the proliferation risk of plutonium in spent fuel
- ✓ Responsibility for own waste production
- ✓ Responsibility towards future generations

- ✓ Full actinide recycling means remote operation (additional risk for operators)

Advanced nuclear fuel cycle double strata concept

European Commission

commercial reactor
EPR, Olkiluoto, Finland

spent fuel →

← fresh fuel (MOX)

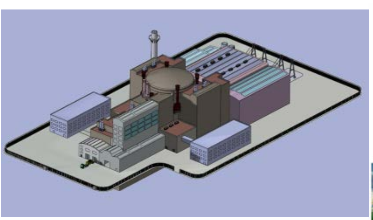
reprocessing plant
La Hague, France

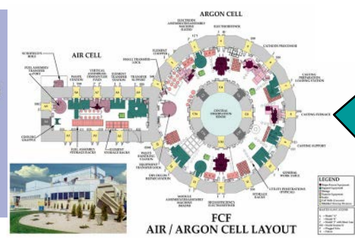
PUREX & advanced aqueous

short lived fp ↓

MYRRHA, Belgium

Integral fast reactor or ADS





← long-lived MA, Tc, I

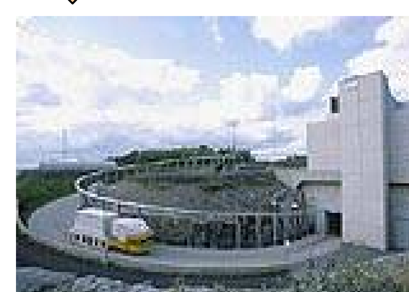
ASTRID, France

INL, US

multirecycling pyro

short lived waste →

waste repository
SFR, Forsmark, Sweden



Joint Research Centre

reasons for selecting pyro-techniques

European Commission

compact process

Integrated Fast Reactor concept, ANL

lower costs, reduced number of transports

faster recycling

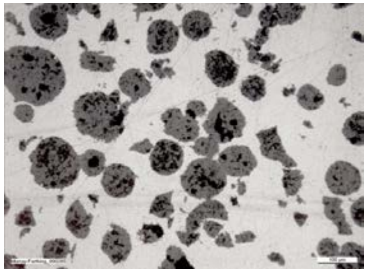
salt more radiation resistant => short fuel cooling-times

"impure" product fractions

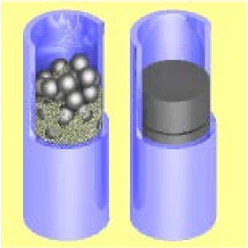
more "proliferation-resistant" process

fuel composition

- Metallic fuels, CERMET
- Inert Matrix (MgO, ZrO_2) fuels
- Th - MOX
- Nitrides eventually carbides
- Shpere Pac



Mo-$(Pu,Am)O_2$

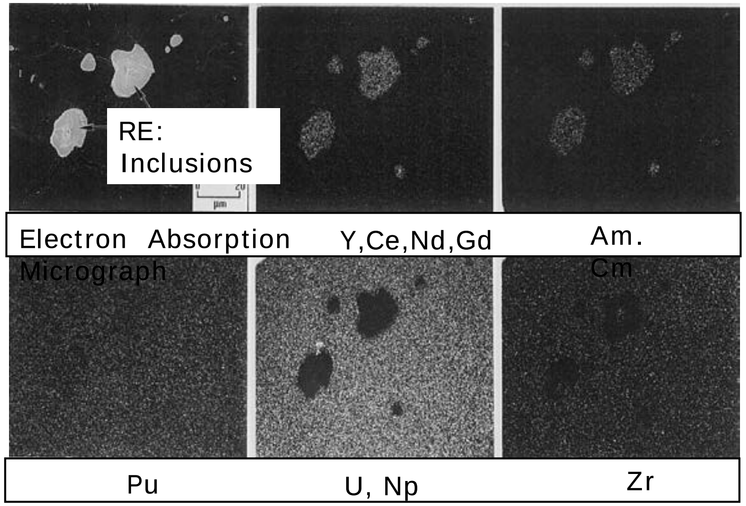


$(U,Am)O_2$

Joint Research Centre

reasons for Ln/An separation

- material burden: in spent LWR fuels, the Ln content is up to 50 times that of Am/Cm
- neutron poisoning: Ln (esp. Sm, Gd, Eu) have very high neutron capture cross sections, e.g. > 250 000 barn for Gd-157
- segregation at fuel fabrication: upon fabrication, Ln tend to form separate phases, which grow under thermal treatment; An concentrate in these phases



electron micrographs of an UPuZrMA5RE5 alloy

⇒ consequence: non-uniform heat distribution in the fuel under irradiation

French scenario

Gen. II & III ***Pu-monorecycling***

Gen. IV ***Pu-multi-recycling***

Gen. IV ***…+ MA recycling***

Pu-mono-recycling
- PWR reactors
- Pu-recycling in MOX fuel
- from PUREX to COEX™

Pu multi-recycling
- Fast-Reactors (FR)
- Pu multi-recycling
- COEX™ process

Pu+MA multi-recycling
- Fast Reactors (FR)
- Pu multi-recycling
- MA burning
- MA specific separation processes

Main incentives
- 1st step towards U resource saving
- Efficient waste conditioning

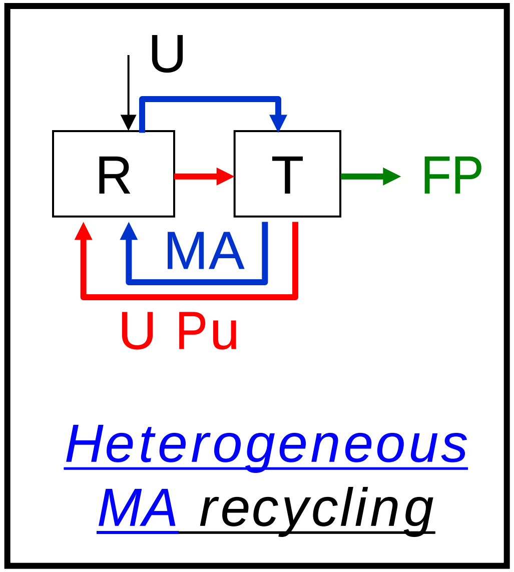
Main incentives
- Major resource saving
- Energetic independence
- Economic stability

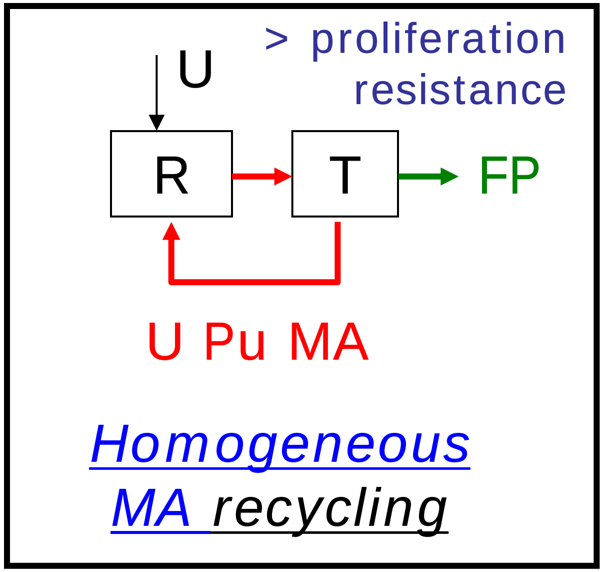
Main incentives
- Decrease of waste burden,
- Optimisation of the disposal
- Public acceptance

Advanced nuclear fuel cycle concepts

Aqueous reprocessing

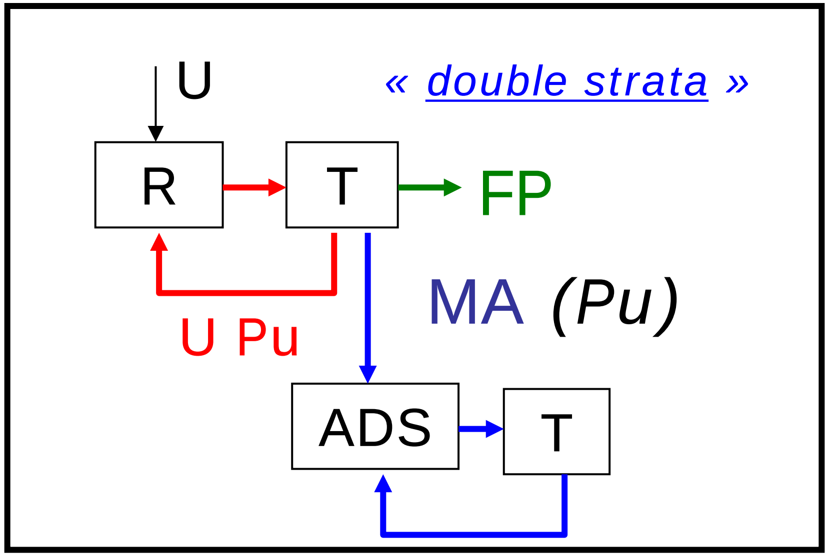
- U,Pu,Np recycled PUREX – COEX
- Heterogenous MA by DIAMEX/SANEX
- Homogenous An by GANEX





Aqueous + Pyro reprocessing

- U,Pu recycled by PUREX or COEX
- Heterogenous recycling of MA
- Pyro recycling of targets



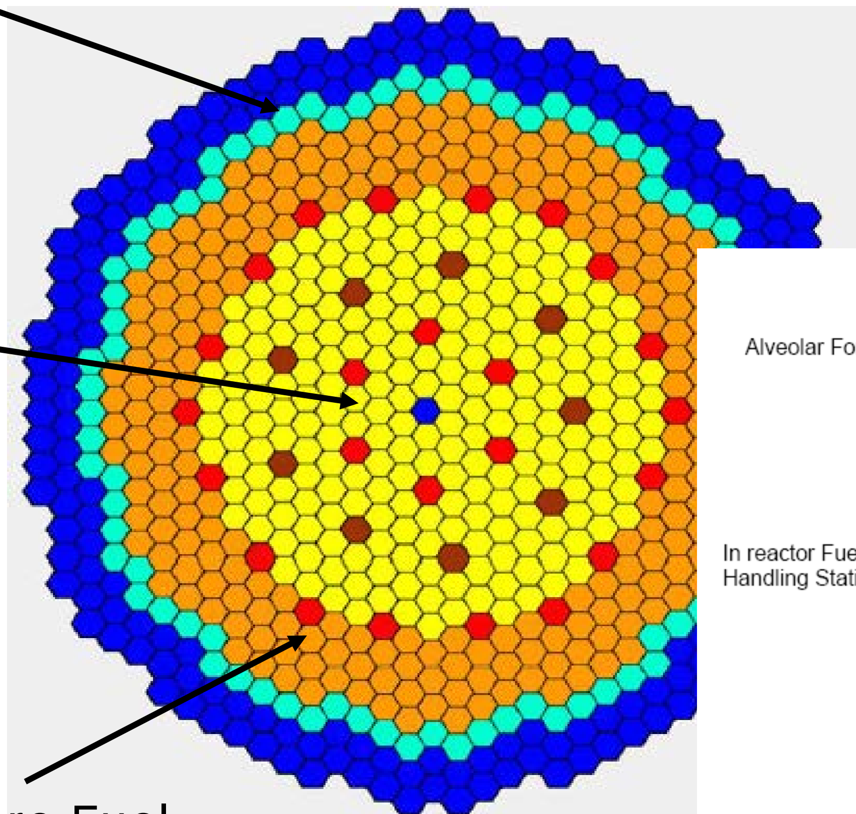
Joint Research Centre

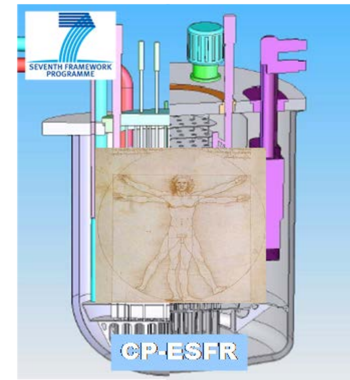
E-SFR concept GIF SFR track

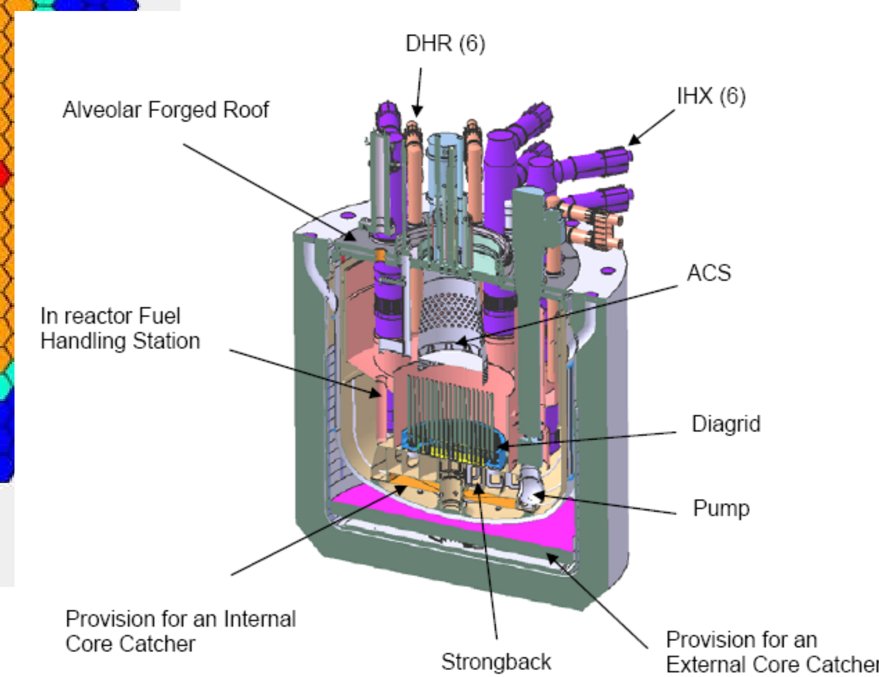
1 Row of Assemblies with Minor Actinides

Inner core Fuel Assemblies

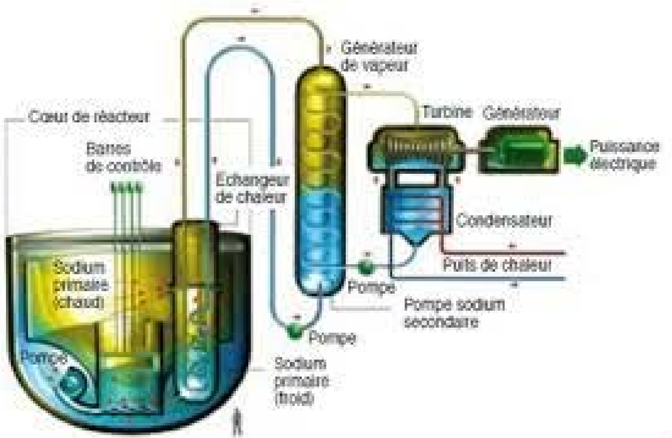
Outer core Fuel Assemblies

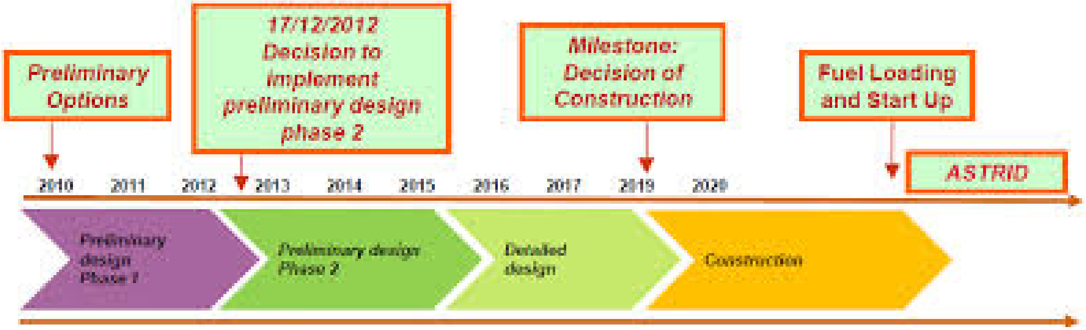


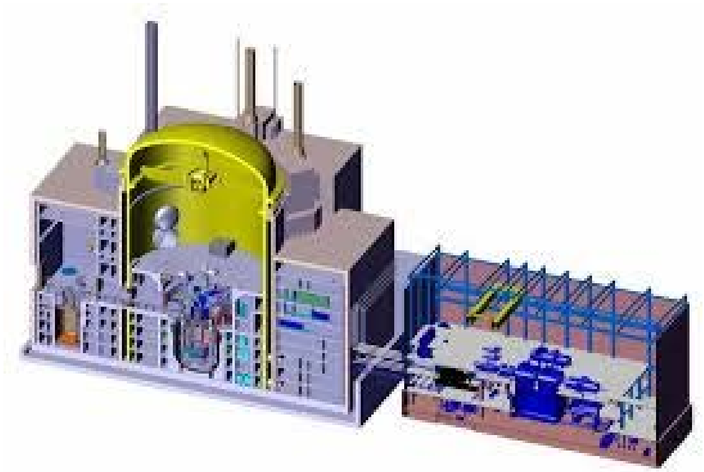




French Astrid project







minor actinide transmutation on an industrial scale:

- Homogeneous concept : 2% of Am in a standard fuel
- Heterogeneous concept : 10% on UO2 in the radial blanket

Several experimental phases in ASTRID to implement different transmutation scenarios

P&T requirements

1) Overall P&T efficiency, 99.9%
2) Transmutation efficiency, 10% - 20%

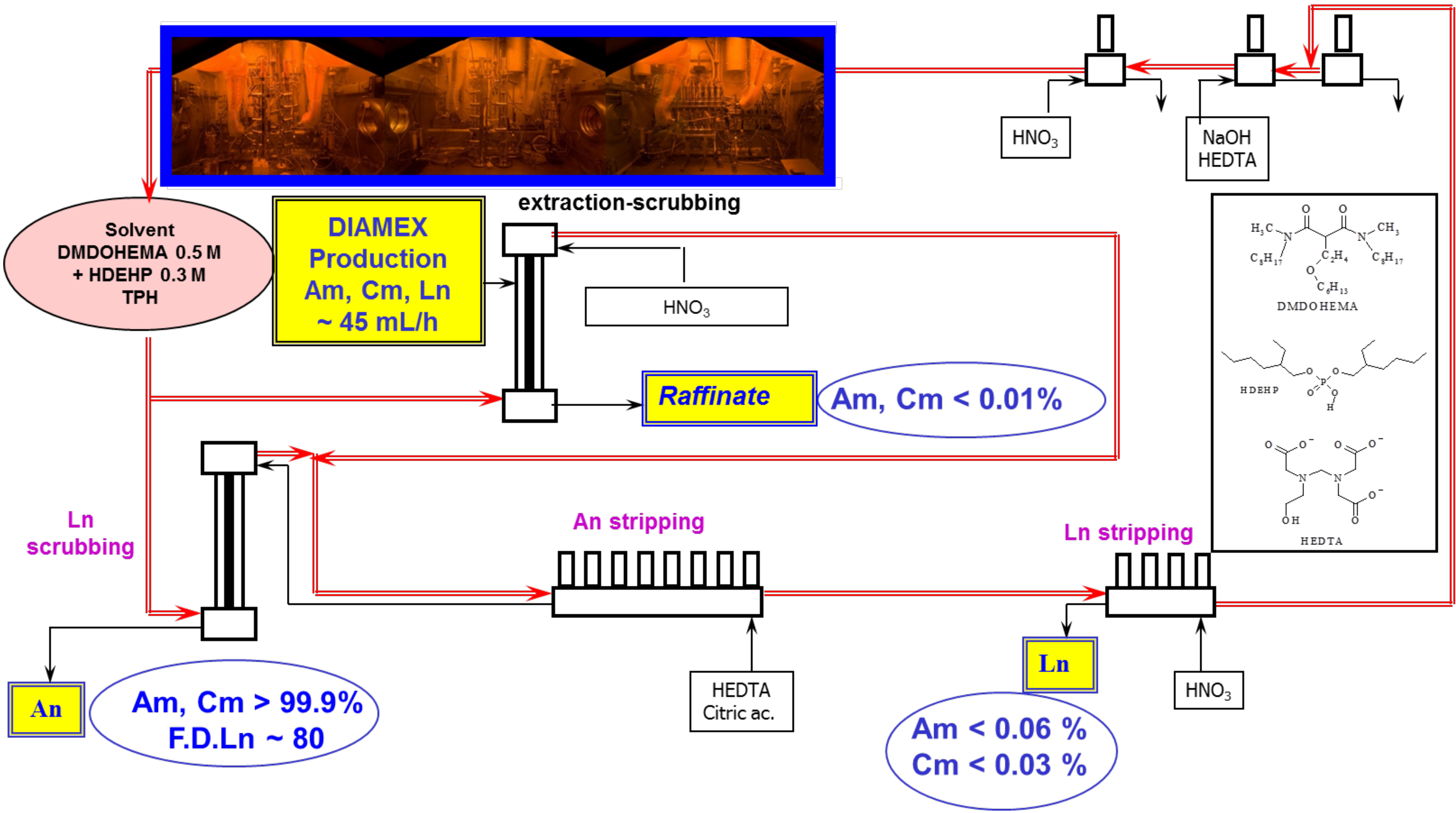
→ multi-recycling required

→ Partitioning efficiency > 99.9%

< 0.1% losses

Decontamination factor > 1 000

SANEX demonstrative hot run
CEA Marcoule 2005



European partitioning projects

European Commission

FP3 1990-1994 — *HLLW partitioning by means of completely incinerable extractants*

FP 4 1994-1998 — *New partitioning techniques for minor actinides, NEWPART*

FP5 1998-2002 — *Pyrometallurgical reprocessing PYROREP*
New Solvent Extraction Processes for minor actinides, PARTNEW

FP6 2002-2006 — *Partitioning of MA from high active wastes, EUROPART*

EuroPart
Sixth Framework Programme

FP7 2007-2013 — *Actinide recycling by separation and Transmutation ACSEPT*

SEVENTH FRAMEWORK PROGRAMME

ACSEPT
innovative solutions for sustainable nuclear energy

Since 2013 — *Safety of ACtinide Separation proceSSes SACSESS*

SACSESS
Safety of actinide separation processes

Joint Research Centre

TODGA/BTBP experiment

1.5 kg of commercial LWR fuel (60 GWd/tHM)

PUREX process: co-extraction of U, Pu and Np

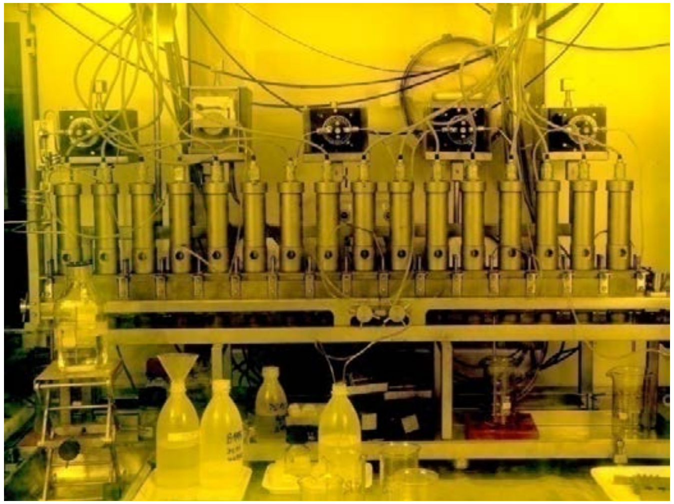
Denitration and concentration of feed (10x)

- No losses of actinides in precipitate

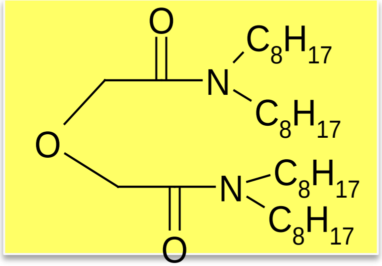
Co-extraction of An and Ln by TODGA/TBP demonstration process from concentrated Purex raffinate

First successful BTBP demonstration process using the genuine TODGA/TBP product as feed

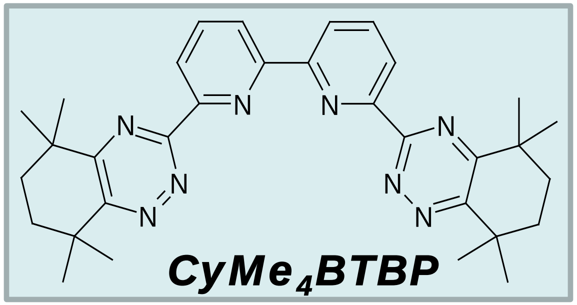
Overall recoveries of all the An ~99.9 %



centrifugal contactor battery



TODGA



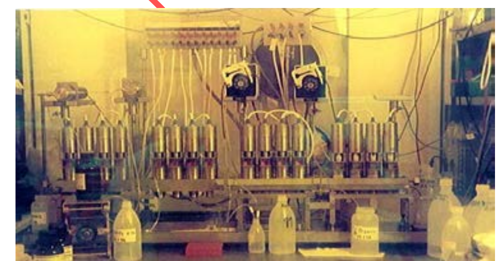
SUPERFACT
Fuel Cycle Closure

European Commission

fuel characterization

fuel fabrication

separated actinides (Np, Am, Cm)



reprocessing

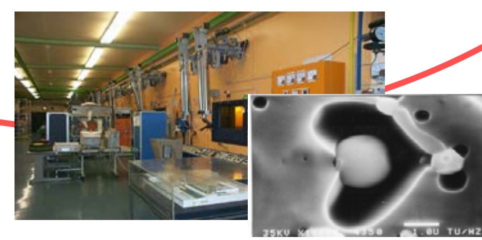
$(U,Pu,Np,Am)O_2$
Np: 2-45%, Am: 2-20%

DE LA RECHERCHE À L'INDUSTRIE
cea

50 YEARS
itu
JOINT RESEARCH CENTRE

irradiation (PHENIX)
360 EFPD

post irradiation examination



transmutation rate ~ 30%

Joint Research Centre

GANEX demonstration
ITU 2012

genuine fast reactor fuel

Feed characterisation and adjustment

IC-ICP-MS, TIMS, ICP-MS, titration

Flow-sheet calculations (CEA and NNL)

GANEX 1

Extraction of U leaving other An in raffinate
Feed ~ 150 – 175 g/L U
2 stage process,
16 stages extraction and scrubbing
16 stages back extraction
DEHiBA (monoamide)

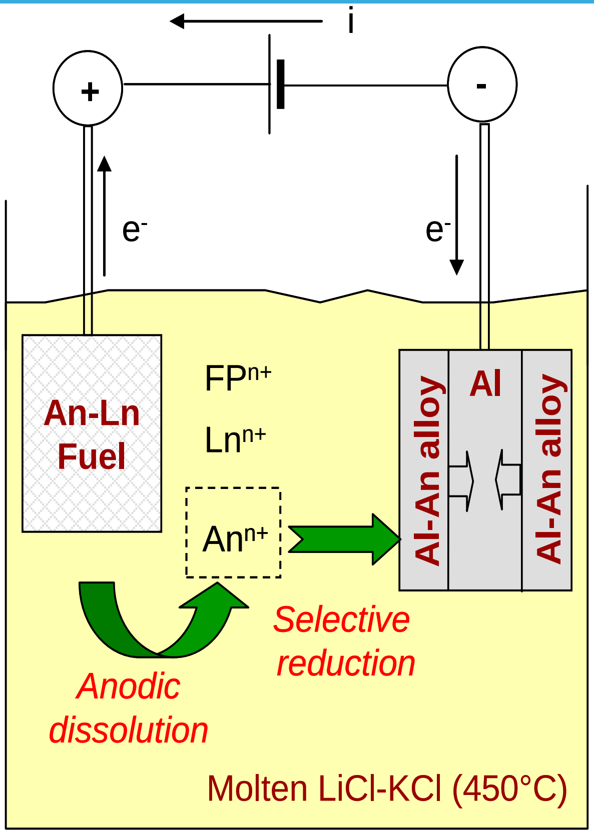
U recovery >99.9%

GANEX 2

Pu, Np and MA extraction and separation
feed of ~ 15 g/L Pu
2 stage process
16 stages extraction and scrub
16 stages backextraction
TODGA + DMDOHEMA

grouped TRU recovery close to 99.9%

Electrorefining on solid aluminium cathode



- **Efficiency**

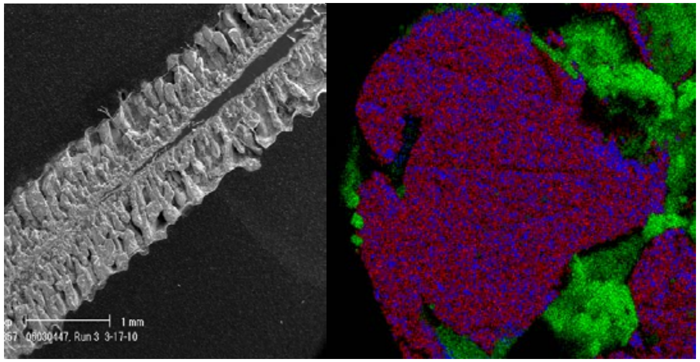
  High efficient grouped separation of all actinides using Al cathode and un-irradiated and irradiated METAPHIX fuel: $U_{61}Pu_{22}Zr_{10}Am_{2}Nd_{3.5}Gd_{0.5}Y_{0.5}Ce_{0.5}$

- **Deposits characterisation**

  Solid, compact deposits composed of An-Al alloys (mainly $AnAl_3$, $AnAl_4$)

- **Capacity of Al to take-up An:**

  Very high capacity of solid Al demonstrated: More than 2 g of An in 1 g Al



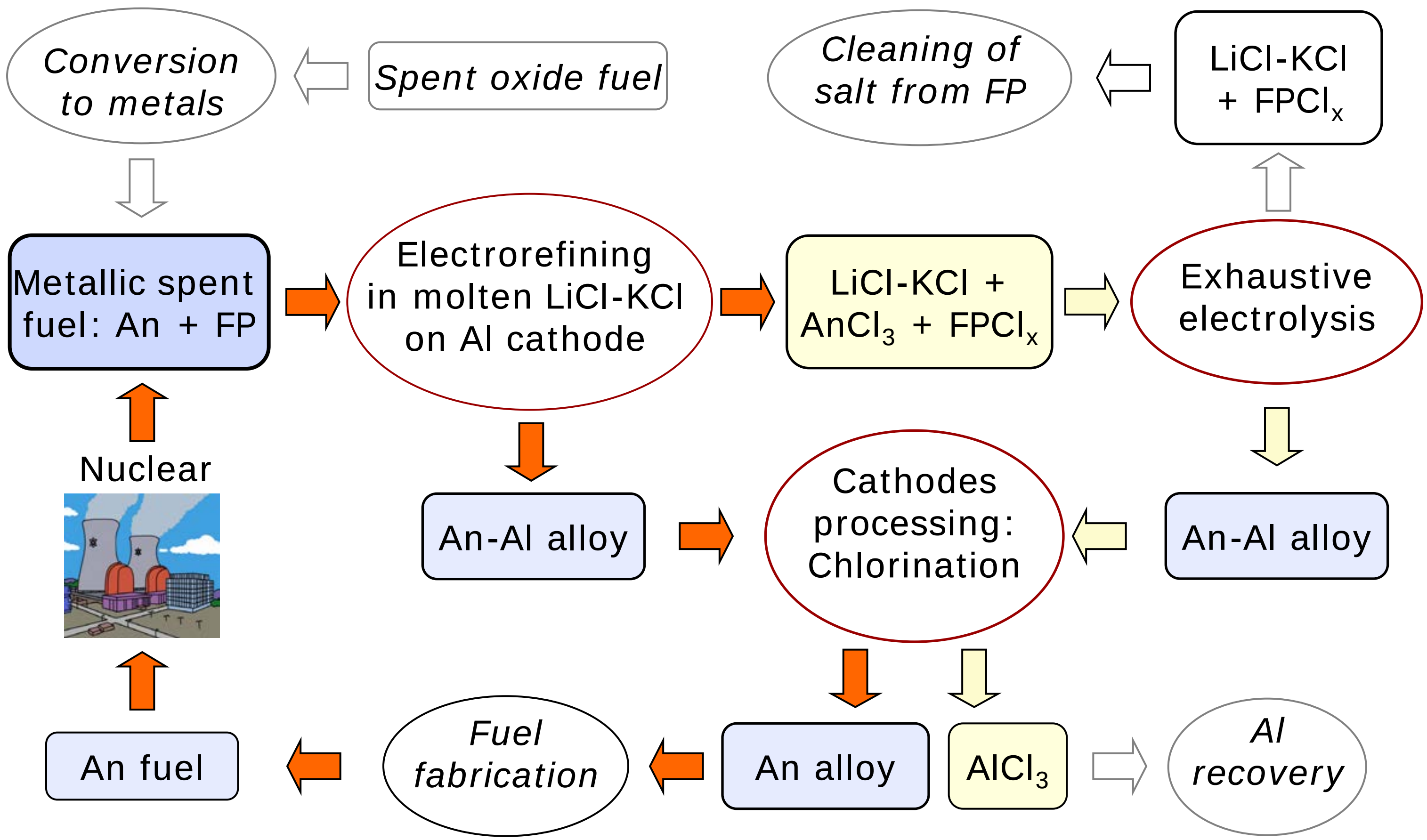
- **Selectivity**

  less than 2% lanthanides contained in the actinide deposit

- **Recovery**

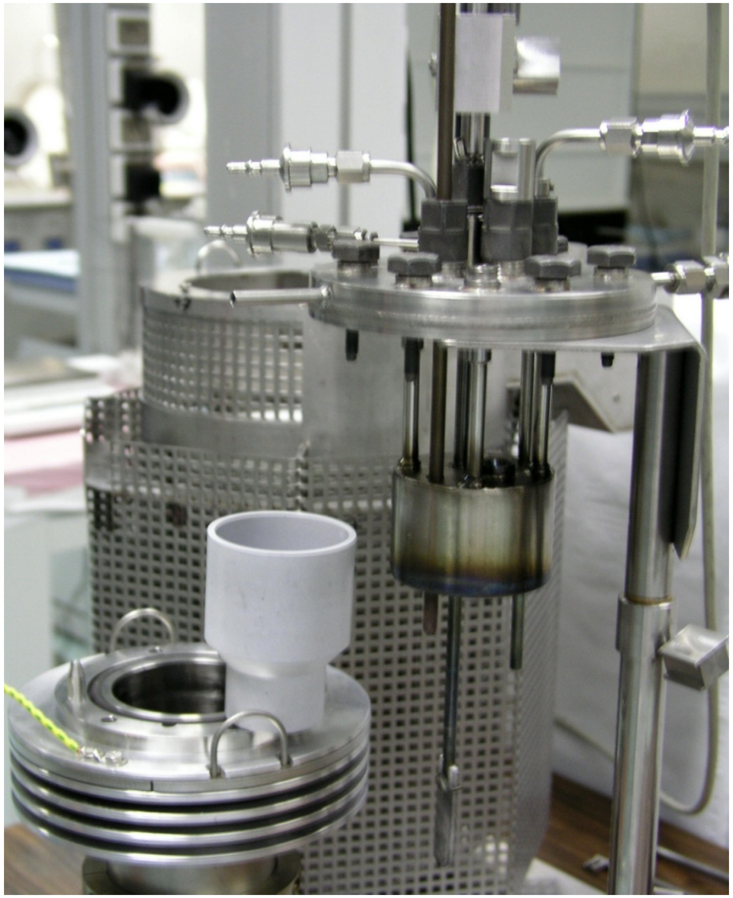
  > 99.9% actinide recovery

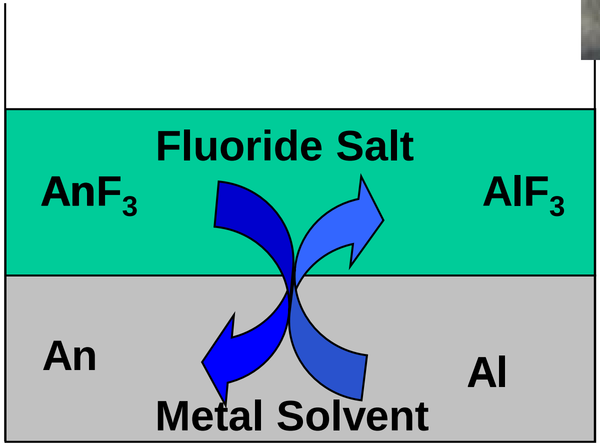
Pyrochemical Advanced Nuclear Fuel Cycle



An - actinides, FP - fission products, Al - aluminium

CEA liquid metal/molten salt extraction process





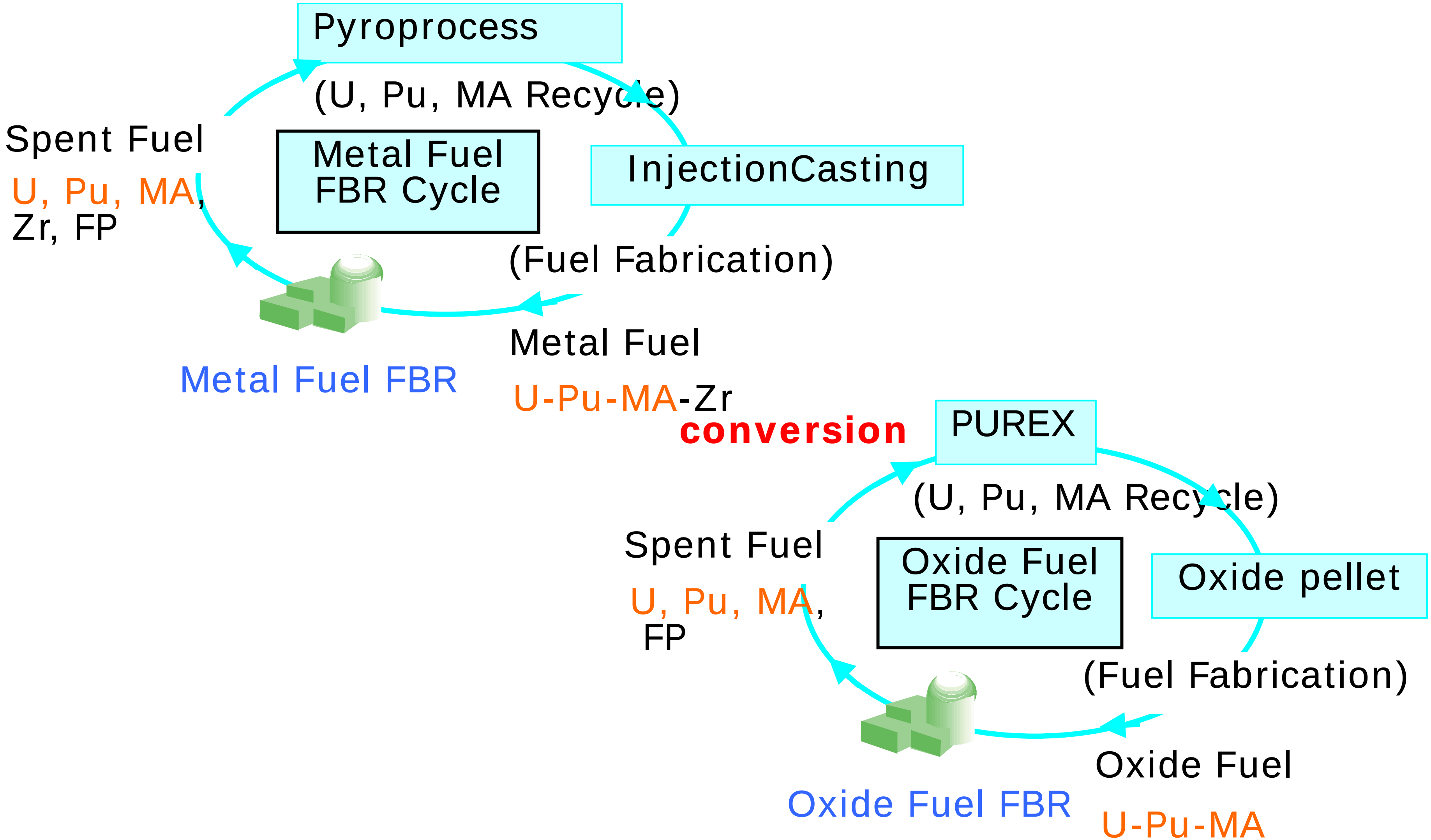
Salt before extraction

Salt after extraction

Actinide distribution coefficients > 100

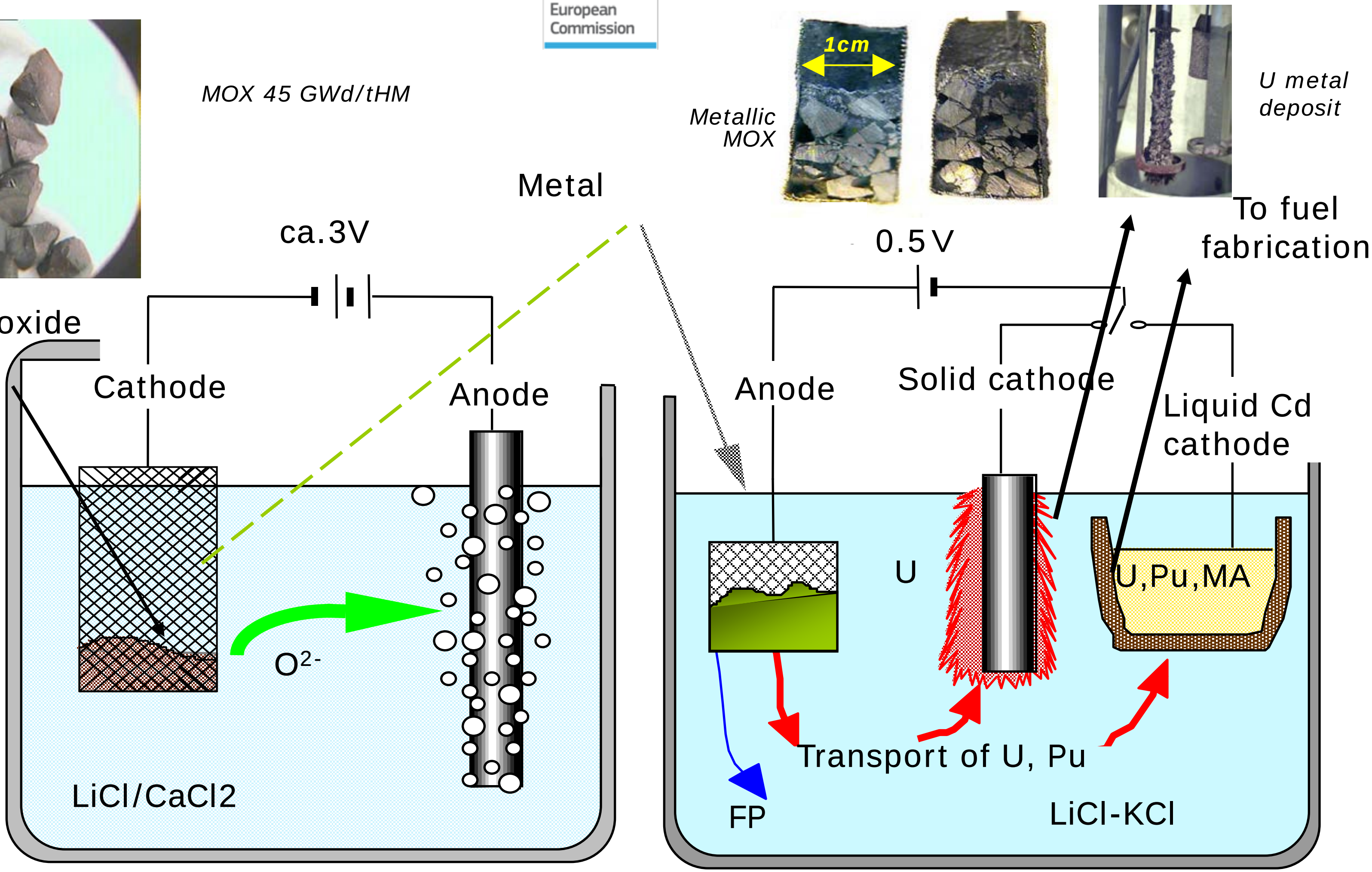
An/Ln separation factors > 1000

Fuel Conversion



oxide fuel treatment by pyro-process

Decladded oxide fuel



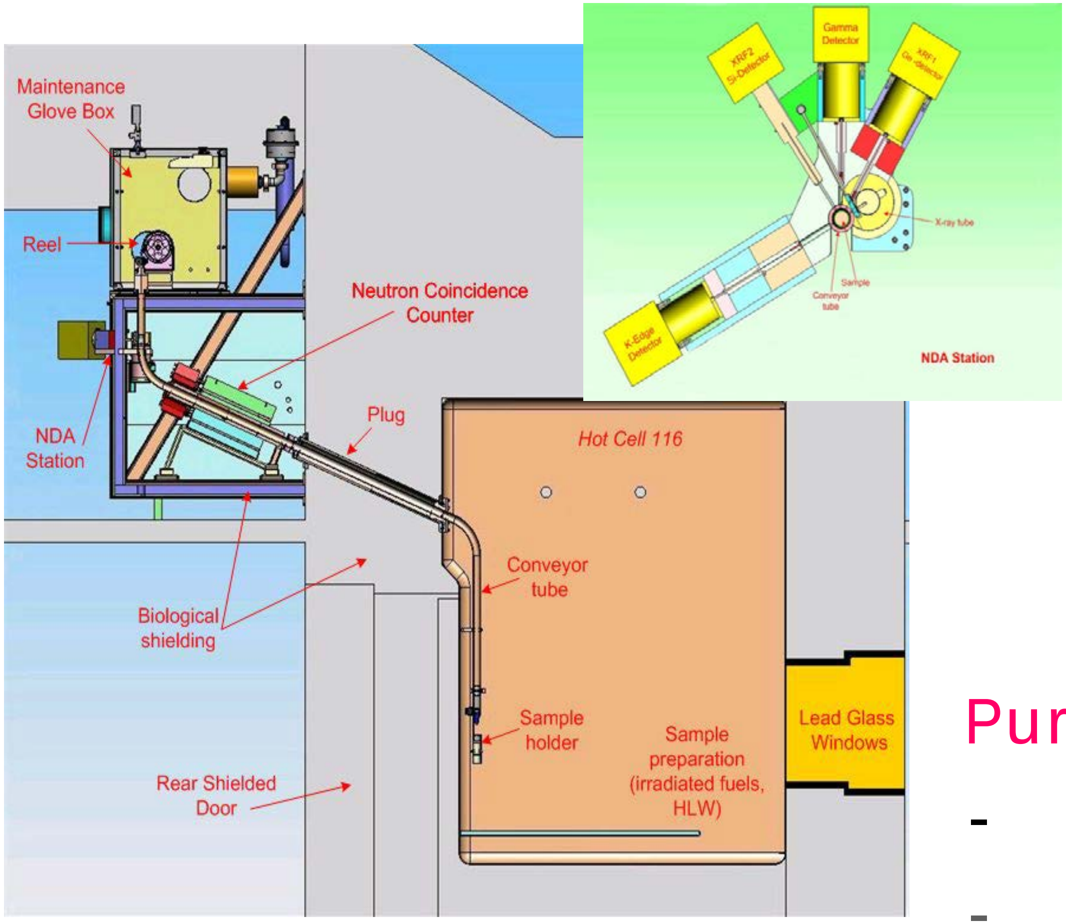
Oxide to metal conversion

U,PU,MA refining
(FP removal)

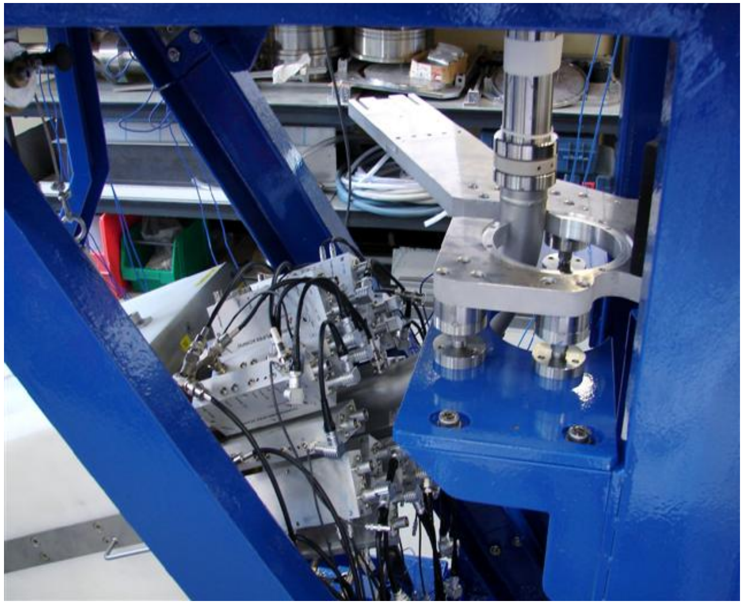
Safeguarding the pyroprocess

European Commission

NDA assay system for a direct non-destructive assay on irradiated samples



Advanced NDA assay system



Testing of equipment

Purpose

- Process evaluation
- Establish a safeguard scheme

Joint Research Centre

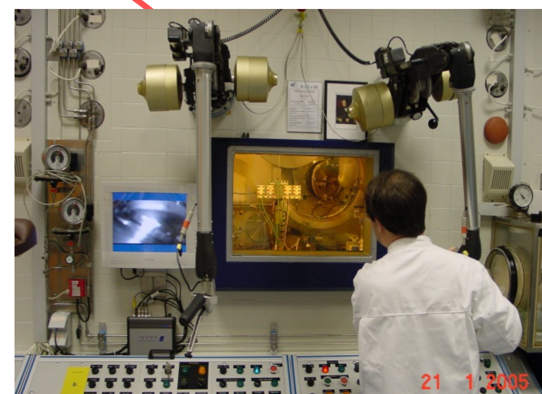
METAPHIX
Fuel Cycle Closure

European Commission

fuel characterization

fuel fabrication

grouped actinide separation (U, Pu, Np, Am, Cm)

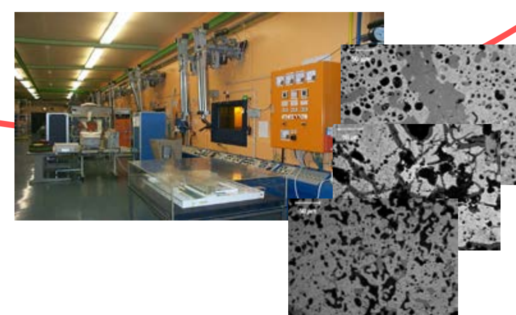


pyro-reprocessing

U,Pu,Zr,Ln,MA
Ln, MA 0-5%

irradiation (PHENIX)
2, 7, 11 at% burn-up

post irradiation examination



transmutation rate ~ 10–45% depending on burn-up

CRIEPI

50 YEARS itu JOINT RESEARCH CENTRE

DE LA RECHERCHE À L'INDUSTRIE cea

Joint Research Centre

Summary

- In the SNE-TP the ESNII initiatitive supports a reference (SFR) and two alternative (LFR and GFR) routes as GENIV reactors systems
- Advanced closed fuel cycle demonstrated for oxide (SUPERFACT) and metallic (METAPHIX) fuel
- Transmutation in fast reactors (ASTRID) and ADS (MYRRHA) ongoing
- Homogeneous and heterogeneous minor actinide recycling options
- grouped recycling feasible for aqueous (GANEX) and dry reprocessing implies remote refabrication
- focus on a safe implementation of all of these processes