The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1858-31

School on Physics, Technology and Applications of Accelerator Driven Systems (ADS)

19 - 30 November 2007

Partitioning.
Part II

Jean-Paul GLATZ

EU - Joint Research Centre
ITU Institute for TransUranium Elements
D-76125 Karlsruhe
Germany

Partitioning 2

Jean-Paul Glatz

School on Physics, Technology and Applications of Accelerator Driven Systems
November 19th -30th 2007
Trieste, Italy

Outline 2

- introduction
- some historical background
- basic principles and data

break

- process developments
- international networks and collaborations
- outlook

Generation IV overall objectives

- promote long-term availability of the systems and effective fuel utilization
- minimize and manage the nuclear waste produced (co-recycling of **all** actinides) and notably reduce the long term stewardship burden in the future, thereby improving protection for the public health and the environment.
- increase the assurance that systems are a very unattractive and least desirable route for diversion or theft of weapons-usable materials.

Change of philosophy

dirty fuel-clean waste instead of clean fuel-dirty waste

European partitioning projects

FP = Framework Program

SCA = Shared Cost Action project

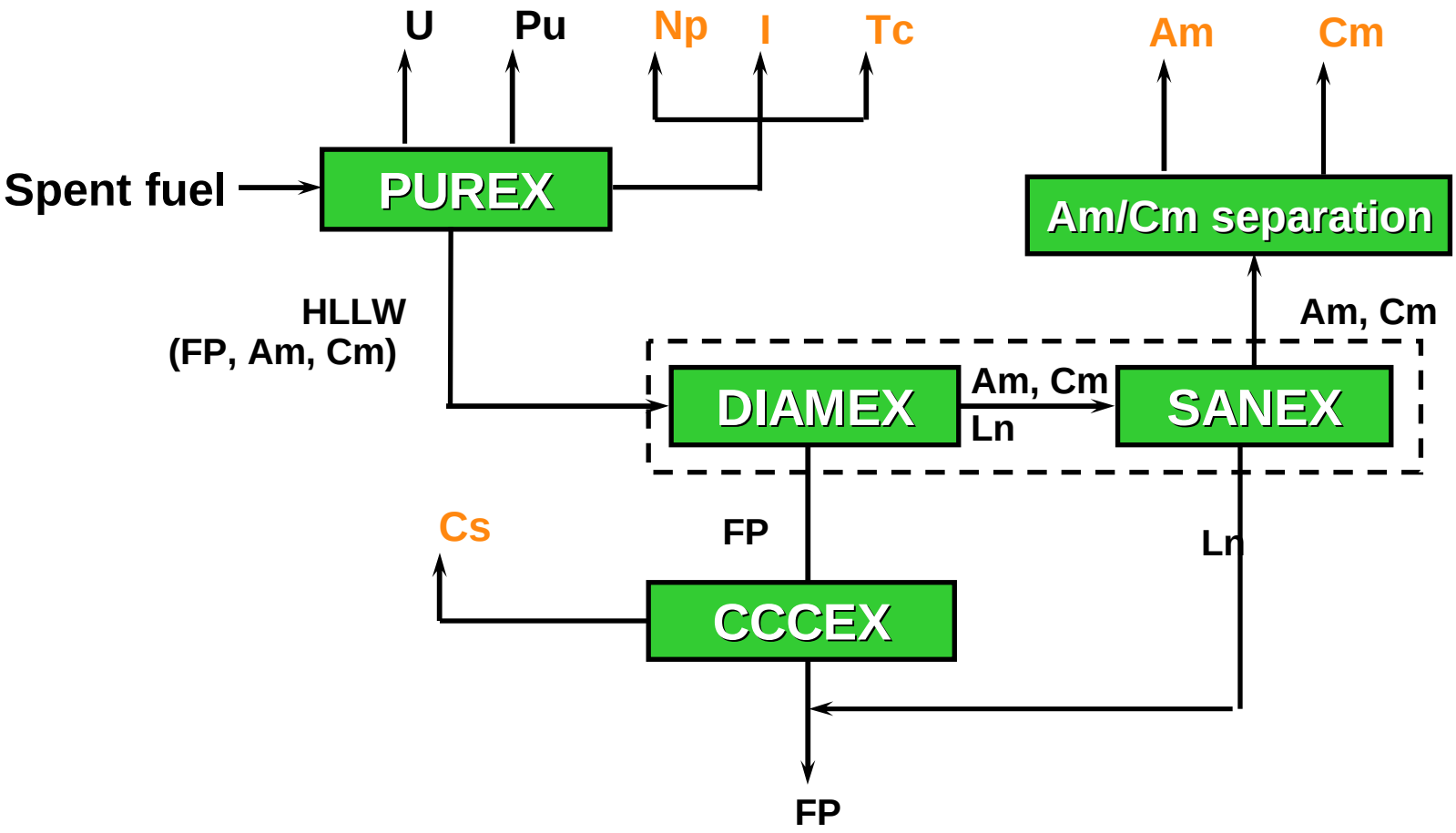
IP = Integrated project

CP = Collaboration project

SCA	FP3 1990-1994	HLLW partitioning by means of completely incinerable extractans
SCA	FP 4 1994-1998	New partitioning techniques for minor actinides, **NEWPART**
SCA	FP5 1998-2002	Pyrometallurgycal reprocessing **PYROREP** New Solvent Extraction Processes for minor actinides, **PARTNEW**
IP	FP6 2002-2006	Partitioning of minor actinides from high active wastes issuing from reprocessing of spent nuclear fuels, **EUROPART**
CP	FP7 2007-2010	Actinide recycling by separation and Transmutation **ACSEPT**

Advanced separation

french reference flowsheet



Key dates:

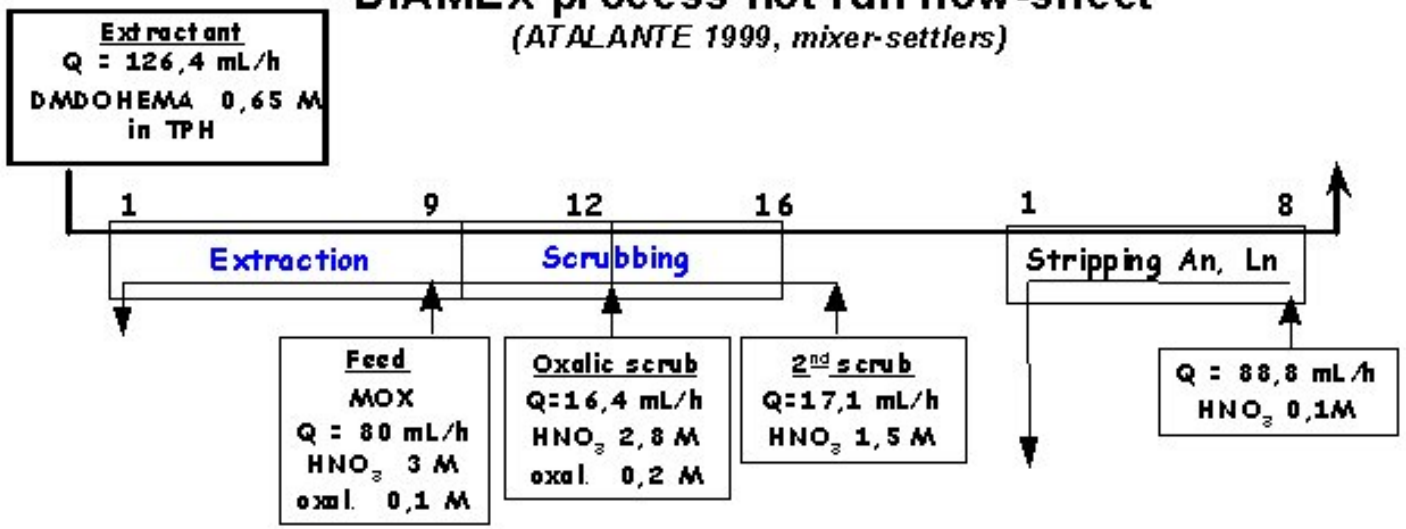
2001: Concept validation

2005: Process definition

DIAMEX process: hot runs

DIAMEX process hot run flow-sheet

(ATALANTE 1999, mixer-settlers)

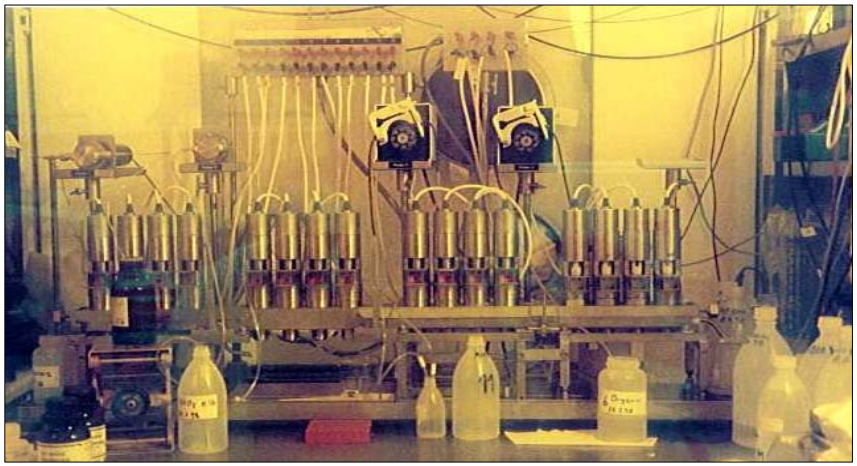


Date & place	1993 CYRANO (FAR)	1998 ITU	1998 ENEA / FZJ	1999 ATALANTE	2000 ATALANTE
Duration	16 h	4 h	11 h	45 h	38 h
Contactor	**MS**	**CC**	**MS**	**MS**	**CC**
Extractant	DMDBTDMA 0.5 M	DMDBTDMA 0.5 M	DMDBTDMA 1 M	DMDOHEMA 0.65 M	DMDOHEMA 0.65 M
Feed	**MOX**	**UOX2**	**UOX2 (sim.)**	**MOX**	**MOX**
Main results	**> 99.9 % Am** **~ 99.9 % Cm** 99.8 % Zr 97.6 % Mo ~ 33 % Ru 86 % Fe	**> 99.9 % An** ~ 85 % Pd ~ 9 % Ru ~ 18 % Y	**98.9 % Am** **98.2 % Eu** 1 % Ru	**~ 99.9 % An** **> 99 % Ln** ~ 60 % Pd ~ 10 % Ru Zr, Mo < d.l.*	*Analysis under progress*

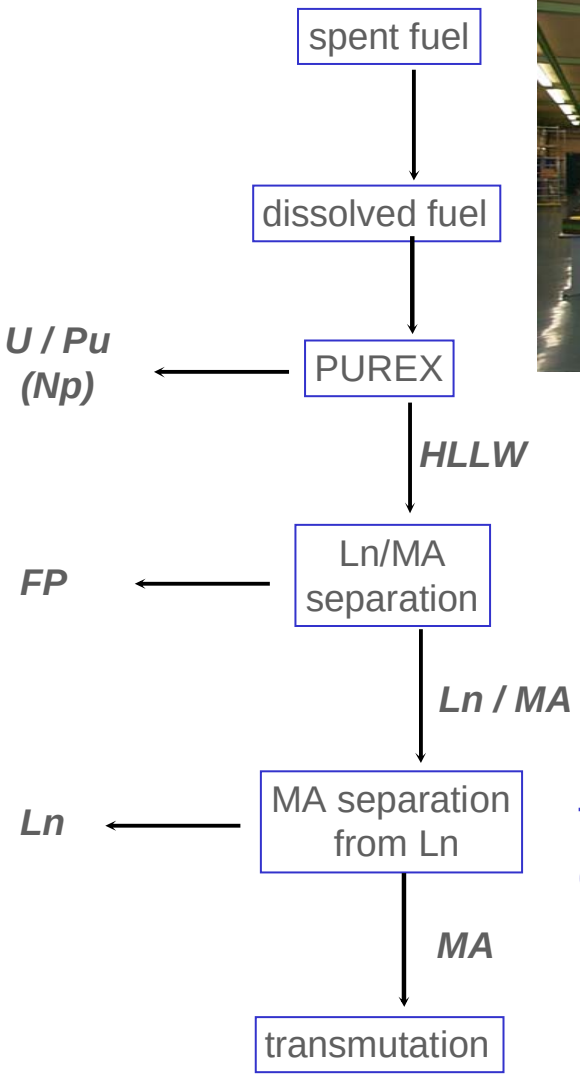
*d.l. : concentration under detection limit

MA partitioning from genuine fuel
by liquid-liquid extraction

Hot Cell Laboratory for the characterisation of spent nuclear fuel



centrifugal extractor battery for continuous counter-current extraction

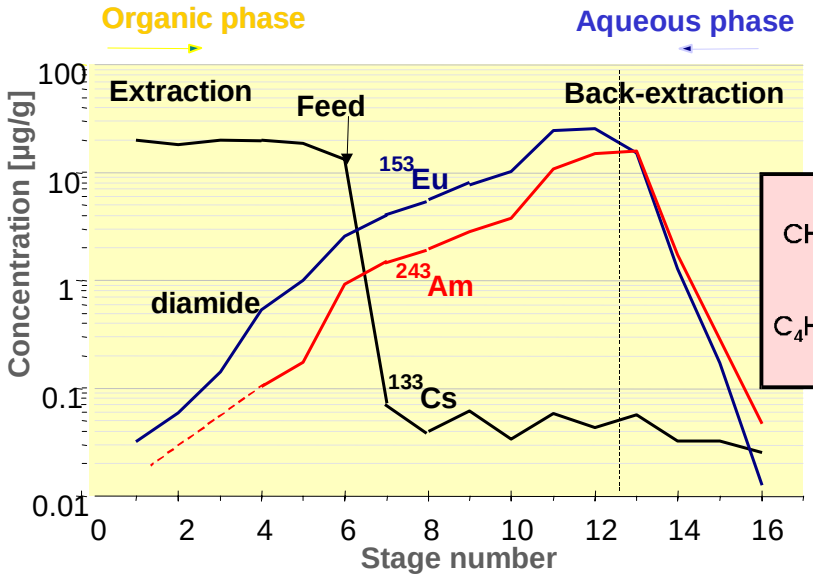


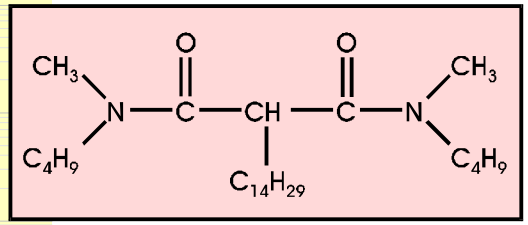
CMPO	USA
DIDPA	Japan
TRPO	China
DIAMEX	France
TODGA	Japan

DTPA	China
TPTZ	France
ClΦ DTPA	FZJ
BTP	FZK
BTBP	UK

Cm and Am recoveries ~ 99.9 %)

An partitioning from genuine HLLW



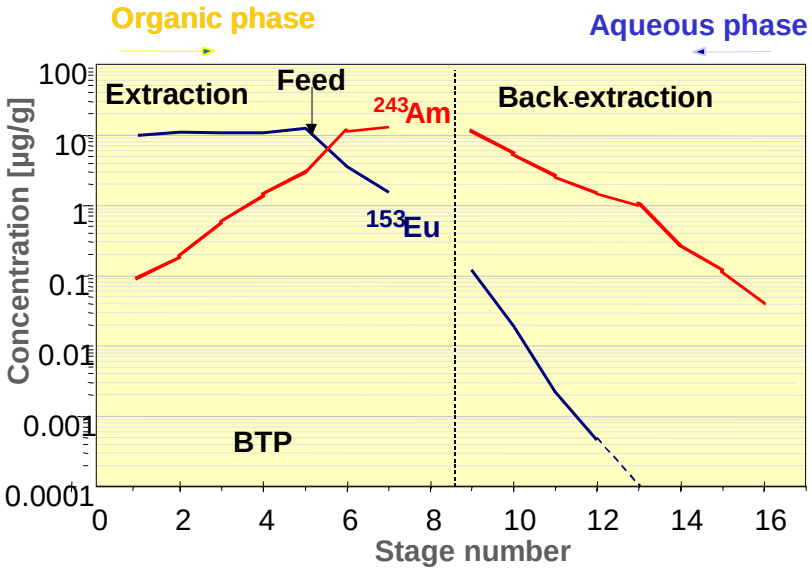


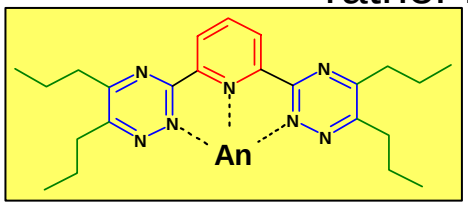
separation from non-lanthanide fission products

high decontamination factors

Tc	462
Eu	438
Am	1000
Cm	1167

Am > 99.9% Cm > 99.8%





separation from lanthanides

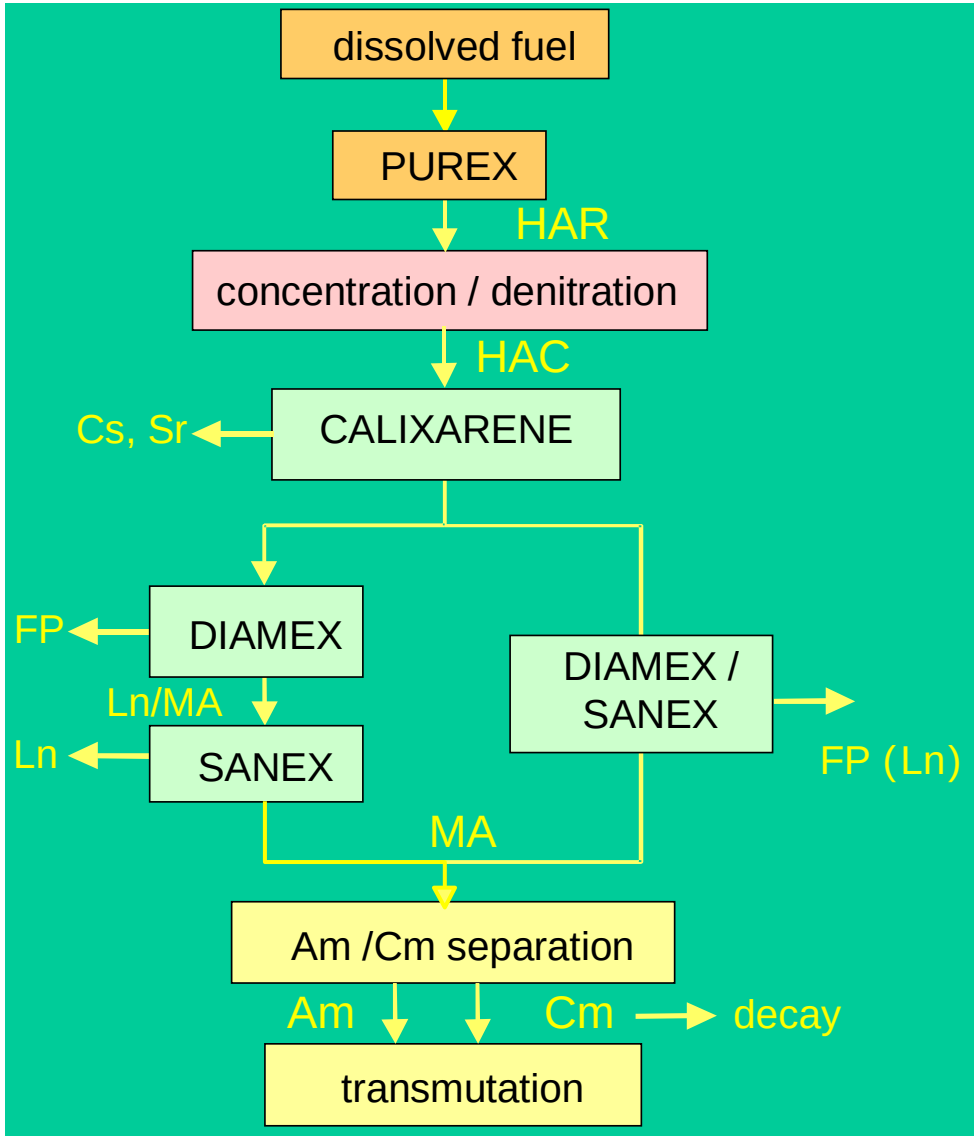
rather high decontamination factors

Eu	1
Am	60
Cm	40

high recovery rate for Am > 99%

to be improved for Cm > 97%

Advanced PUREX R&D
towards industrial application



Industrial advantages:

- *simplified PUREX*
- *low volumes of feed, waste minimisation and*
- *compact process*

Achievements at ITU:

- *demonstration of MA recovery by the DIAMEX/SANEX process combination using HAC (10x concentrated) as feed*
- *demonstration of direct MA extraction using BTP*

European programs:

PARTNEW and CALIXPART

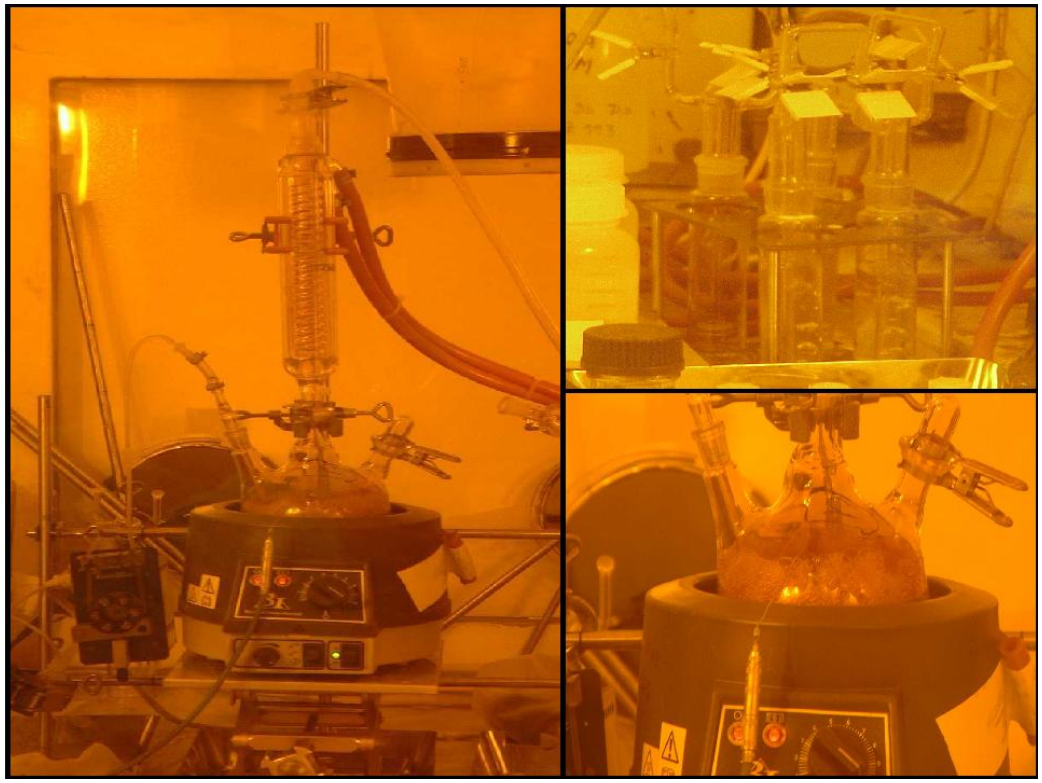
EUROPART

Production of genuine HAC

Concentration/denitration

- Concentration
  - Start volume 4 L
  - Volume reduction 10 times
  - Acidity increase (3.2 to 12 M)
- Denitration
  - formic acid (HCOOH)
  - exothermic reaction

400 mL
High Active Concentrate
(acidity 4 M)



Concentration factor 10.2
(without precipitation of MA)

DIAMEX HAC (conc. factor 10) test

Recovery

Good extraction and back-extraction properties

	Dext	Dbext
Am	>20000	>300
Cm	>10000	>2000

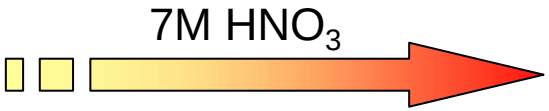
First successful DIAMEX-HAC hot test, a major event in the field of partitioning of minor actinides

	DF	Recoveries (%)	
		Raffinate fraction	An/Ln fraction
Y	85	1.2	98.8
Zr	1	> 99.99	< 0.01
Mo	1	99.3	0.6
Tc	217	< 0.01	2
Ru	1.1	92	6
Pd	1	98.8	0.9
Ln	> 5000	< 0.1	> 99.9
Np	50	2	49
Am	20000	0.005	99.7
Cm	10000	0.01	99.9

Preparing feed for a TODGA-BTBP processes

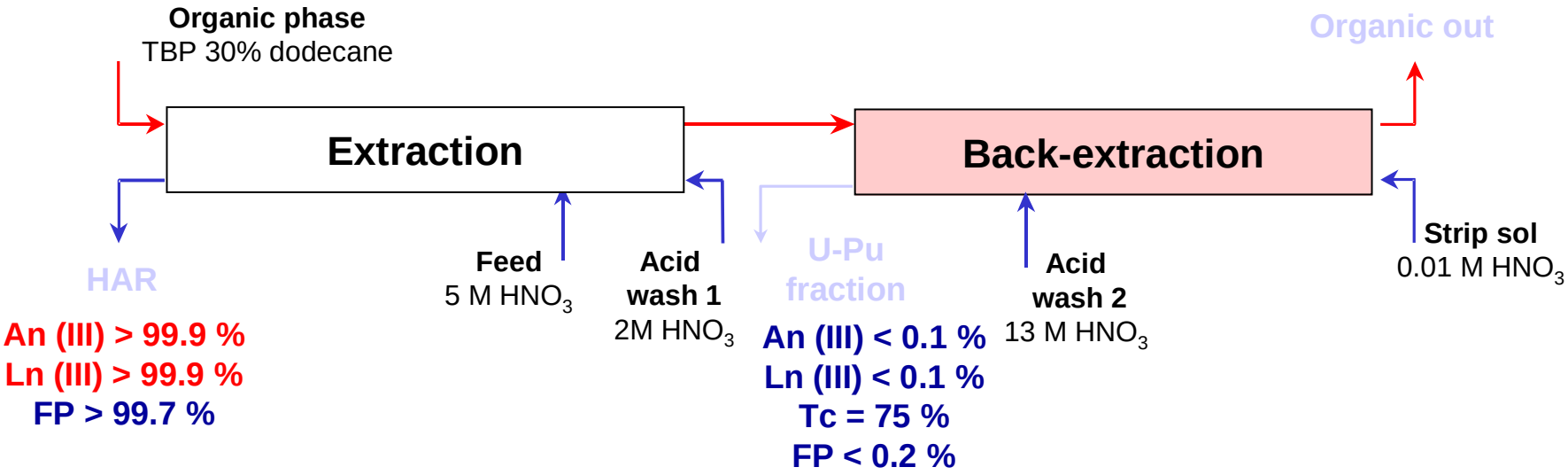
- **Spent fuel dissolution**

0.65 Kg of UOX fuel
(69 GWd/tM)



2.9 L of spent fuel solution

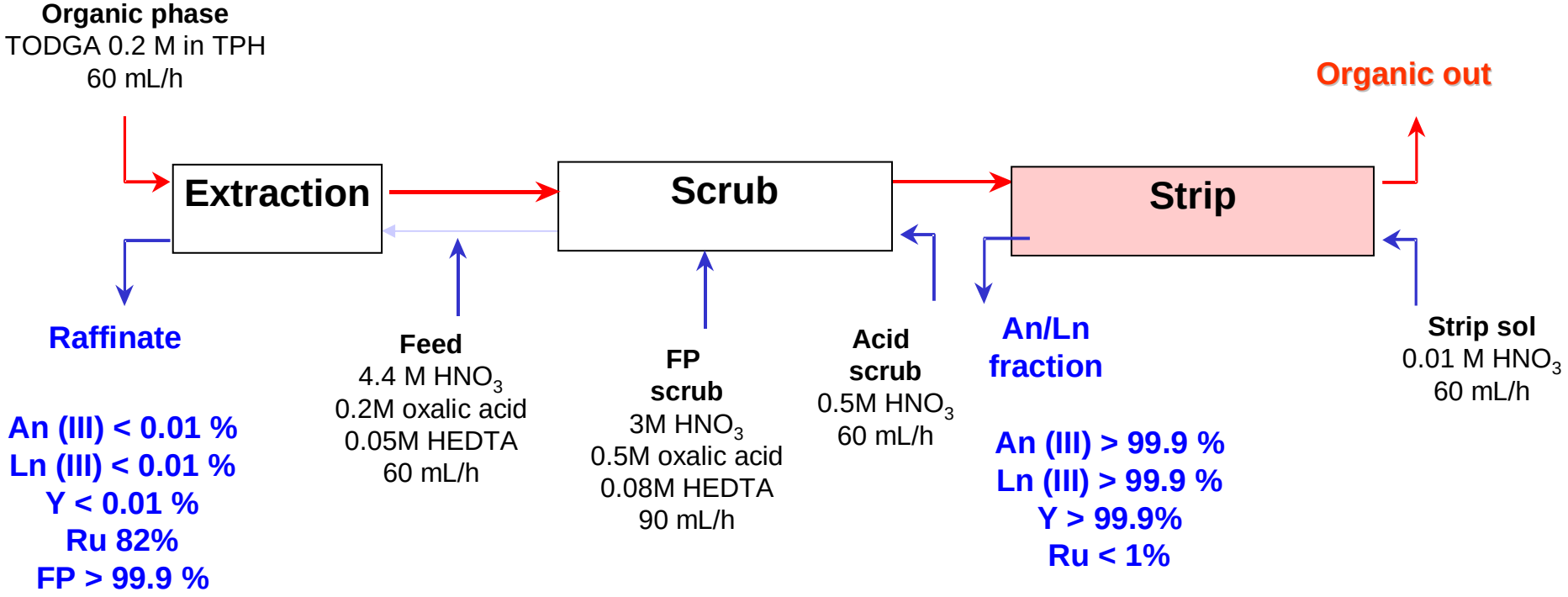
- **PUREX processing**



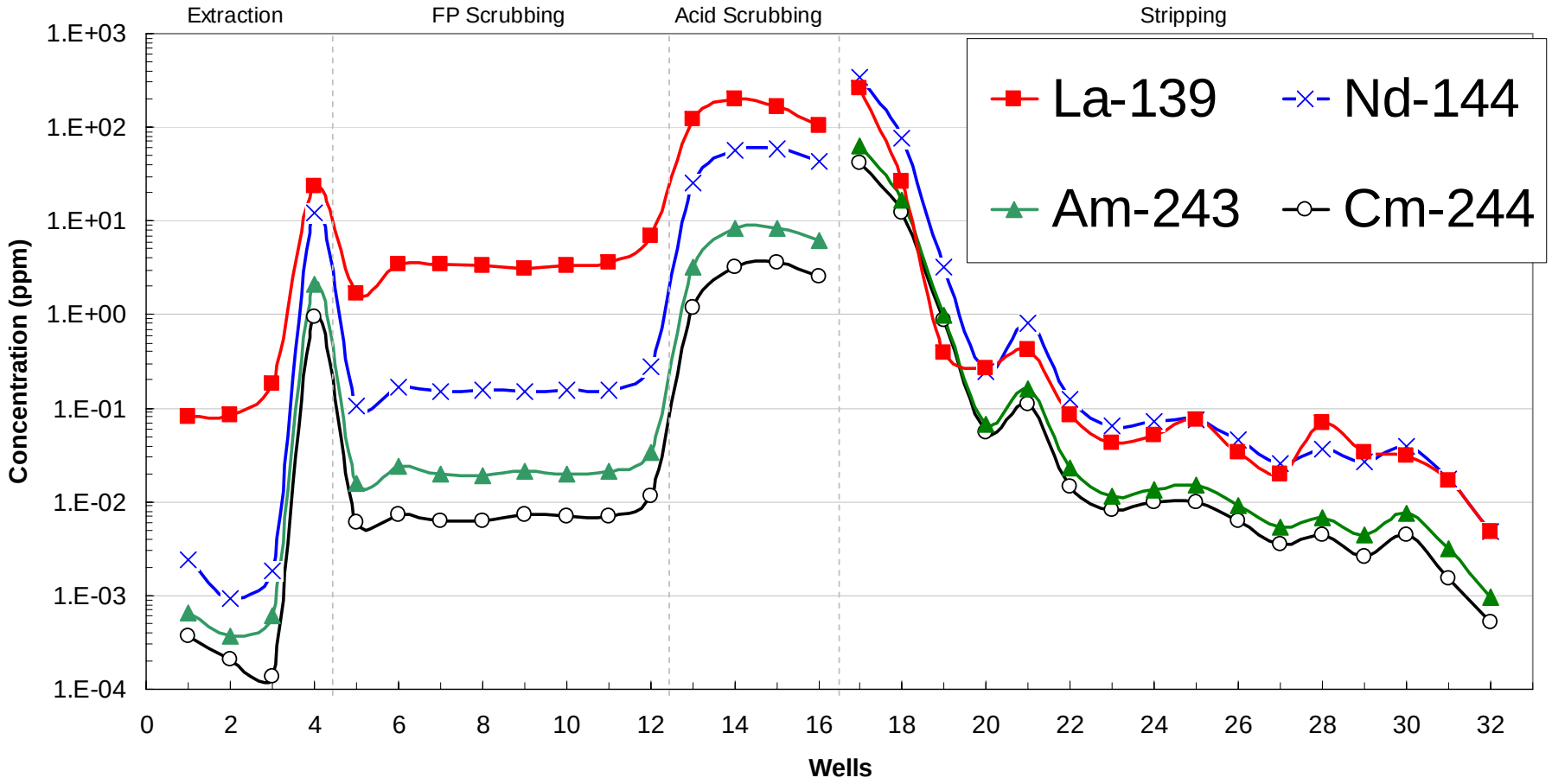
2.5 L of HAR solution !!!

TODGA-BTBP process

Flowsheet



TODGA–BTBP process



Ln-An profiles

TODGA–BTBP process

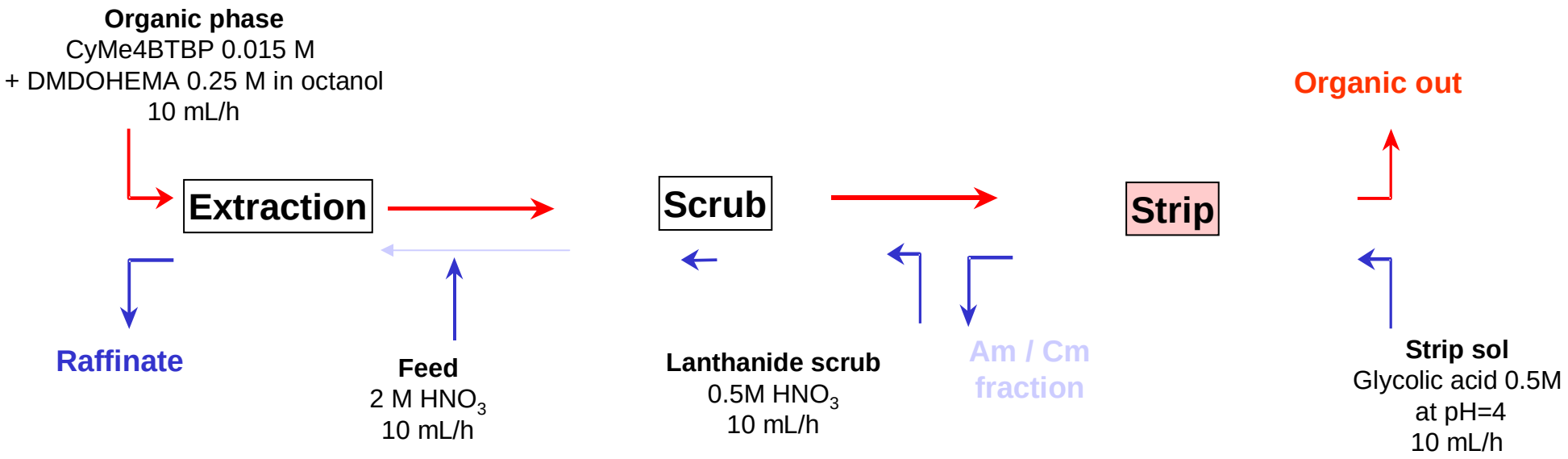
Recovery of key elements show

Good extraction and back-extraction properties

	DF	Recoveries (%)	
		Raffinate fraction	An/Ln fraction
Y	1500	< 0.1	> 99.9
Zr	1	> 99.9	< 0.1
Mo	1	> 99.9	< 0.1
Sr	1	> 99.9	< 0.1
Ru	1.2	82	1
Pd	1	> 99.9	< 0.1
Ln	> 1000	< 0.1	> 99.9
Am	40000	< 0.01	99.99
Cm	40000	< 0.01	99.99

TODGA-BTBP process

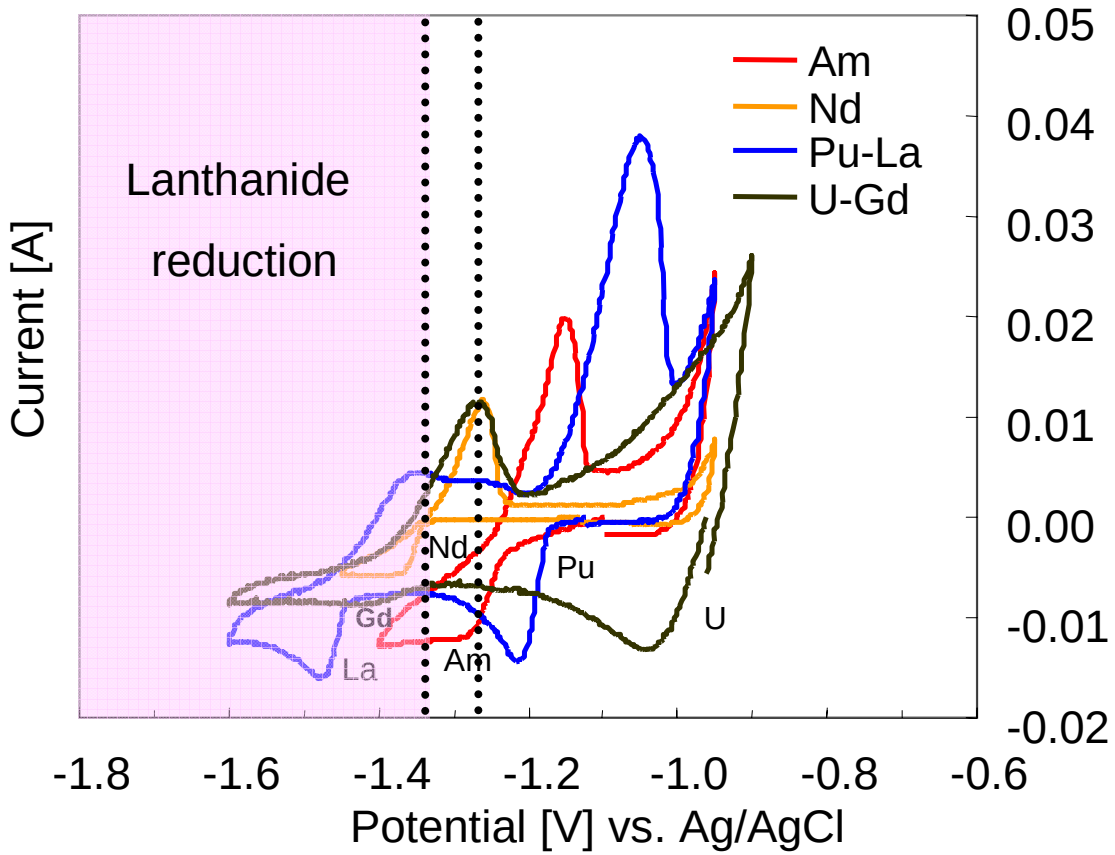
Flowsheet



Major problems

- **Low kinetics**
- **Low solubility**
- **Radiolysis**

Cyclic voltammetry on solid aluminium

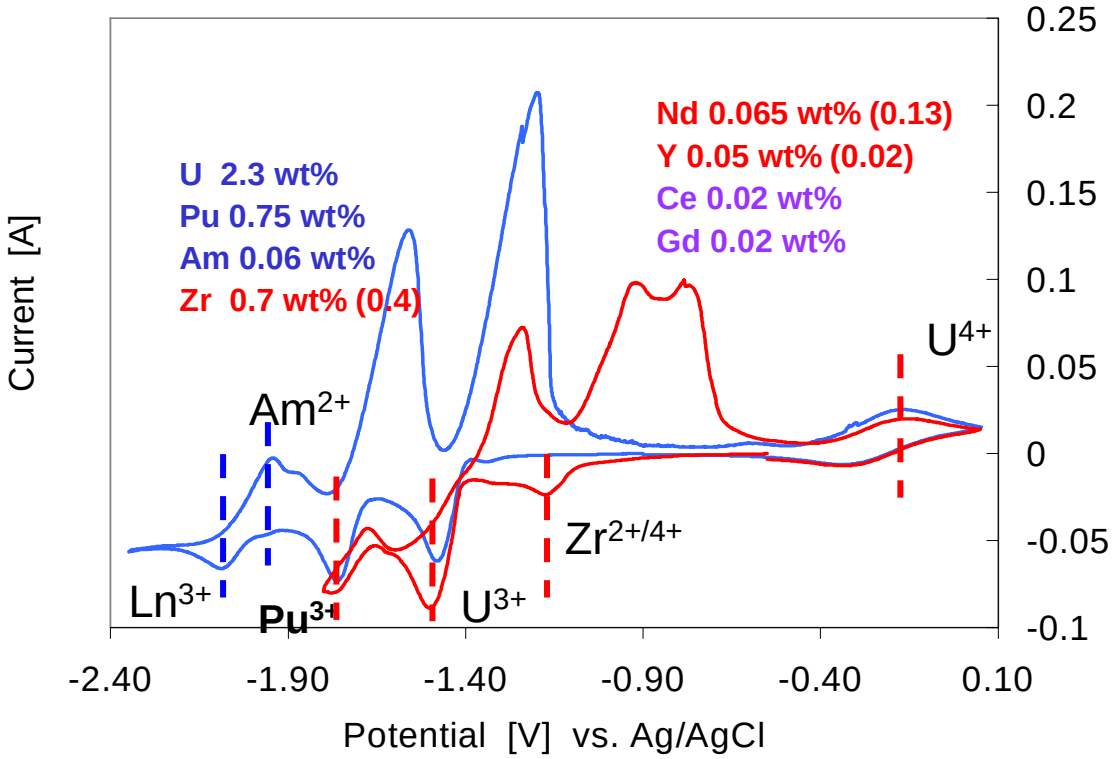


- ✓The difference between MA and Ln reduction is 100 mV.
- ✓ An electrolysis performed at a cathodic potential equal or greater than-1.3 V allows to separate An from Ln
- ✓ Separation factor of Am from Nd on Al foam

$$SF = \frac{\frac{[Nd]_{salt}}{[Am]_{salt}}}{\frac{[Nd]_{Al}}{[Am]_{Al}}} = \frac{[Am]_{Al}\,[Nd]_{salt}}{[Am]_{salt}\,[Nd]_{Al}}$$

	Nd wt % in salt	Am wt % in salt	Nd mg in Al	Am mg in Al	SF
Before 1 st electrolysis	0.247	0.45			
After 1st electrolysis	0.247	0.12	2.1	125	**120**
Before 2nd electrolysis	0.249	0.13			
After 2nd electrolysis	0.244	0.03	35	130	**40**

Cyclic voltammetry of UPuZrAnLn alloy



LiCl-KCl, T = 460°C, v = 100 mV/s, Reference electrode : Ag/AgCl 1 wt%, Working electrode area : ~ 0.2 cm².

Cyclic voltammetry on W in a solution of $An^{3+}/Ln^{3+}/Zr^{x+}$ in LiClKCl obtained from $U_{61}Pu_{22}Zr_{10}Am_2Nd_{3.5}Y_{0.5}Ce_{0.5}Gd_{0.5}$ alloy,

Interpretation of $Zr^{+,2+/4+}$ signal is difficult due to possible multiple valency of Zr,

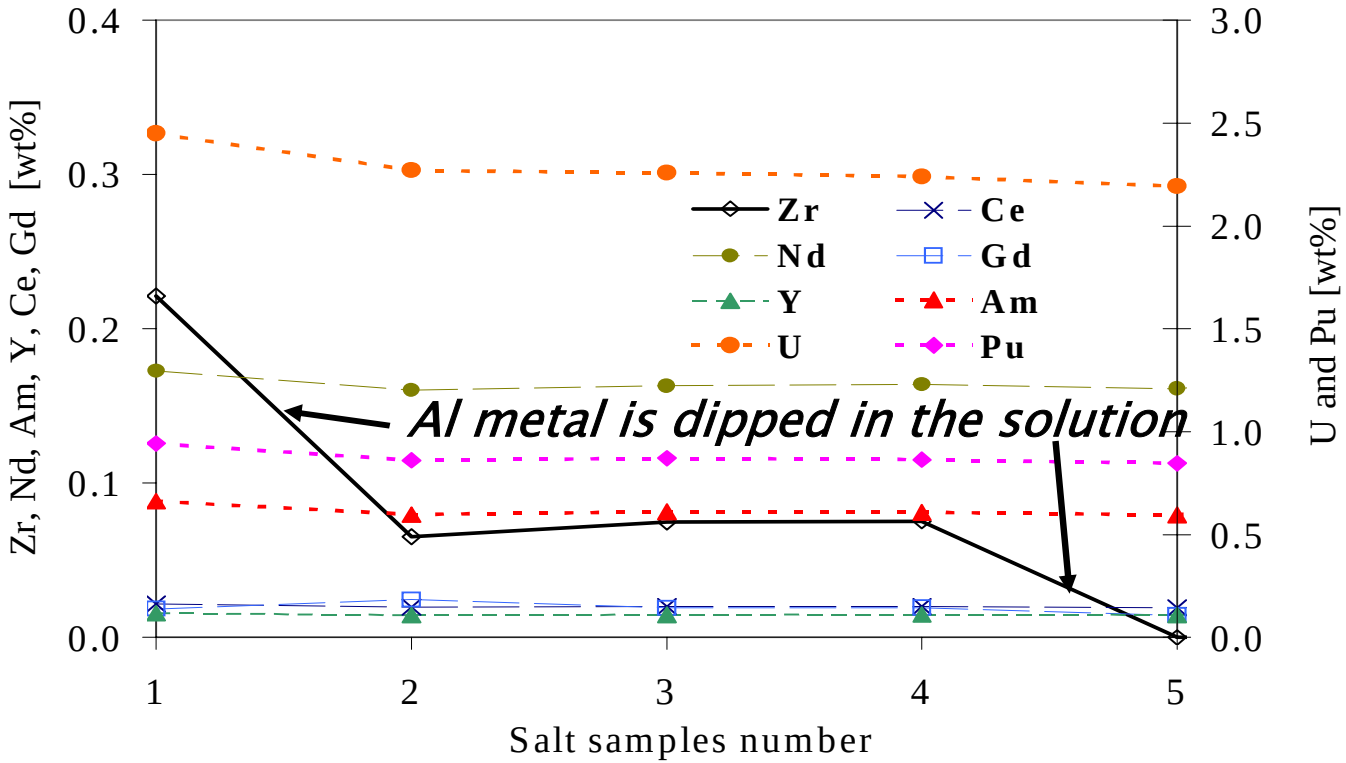
clear reduction peaks of U^{3+} and Pu^{3+} (most concentrated elements in the salt phase)

Small peak is observed for Am,

One global peak is observed for Ln.

Extraction of zirconium by Al

ICP-MS salt analysis



Zr concentration in the salt phase decreases when Al is dipped in the solution. $Zr^{+,\ 2+\ or\ 4+}$ ions are reduced by Al metal according to:

$$Zr^{x+} + Al^{0} \longrightarrow Zr^{0} \text{ or } Zr\text{-}Al_x + Al^{3+}$$

Peaks observed by CV attributed to Zr reduction tend to disappear and a signal for Al^{3+} reduction is observed.

Electrolyses of U,Pu,Zr,Ln,MA alloy: batch experiment involving 25 runs (~30g of fuel)

	Wt % in salt						Composition of the dissolved deposit (mg)			
	Before Run 1	After Run 1	Before Run 11	After Run 11	Before Run 14	After Run 14	Run1	Run 7	Run 11	Run 14
U	2.55	2.14	0.25	0.30	0.20	0.30	936	512	223	176
Pu	0.96	1.58	0.65	0.50	0.32	0.27	94.2	243	203	146
Am	0.09	0.17	0.24	0.23	**0.19**	**0.19**	***4.4***	***13.5***	***9.95***	***8.8***
Zr	-	-	0.056	0.096	0.055	0.075	-	-	-	-
Y	0.016	0.048	0.074	0.075	0.075	0.078	0.039	0.018	0.015	0.008
Ce	0.021	0.047	0.078	0.085	0.089	0.091	0.041	0.026	0.024	0.011
Nd	0.177	0.403	0.59	0.61	0.65	0.65	0.374	0.244	0.183	0.092
Gd	0.025	0.048	0.069	0.073	**1.8***	**1.8***	0.042	0.025	**0.018**	**0.027**
Al	-	-	-	-	-	-	387	301	173	134
				Current density (mA/cm²)			17	9.3	8.2	6.1
				Charge (C)			1386	1193	674	598
				Faradic efficiency (%)			91	70	80	70
				$m_{An}/(m_{An} + m_{Ln})$ (%)			99.95	99.96	99.9	99.9
				m_{Am}/m_{Ln}			8.8	43	**42**	**26**

** added to the melt as $GdCl_3$*

- *Gd has the lowest electrodeposition potential difference compared to Am*
- *at Gd conc. corresponding to ~250 runs (300g of fuel) Am/Ln sepation still efficient*

Actinide separation from U,Pu,Zr,MA,RE fuels

- ✓ Selective grouped separation of actinides (U,Pu,Np,Am and Cm) from realistic fuel.
- ✓ Adherent and compact deposit are obtained on solid Al with a good faradic yield (~ 90%)
- ✓ Separation from Ln: at a cathodic potential Ec > -1. 2V vs. Ag/AgCl 1 wt% < 2% of Ln are in the An deposit
- ✓ separation efficient after 25 electrolyses (> 5g of fuel) of the same salt mixture (more than 6 months of experiments)
- ✓ at Gd (electrodeposition potential close to Am) conc. corresponding to ~250 runs (300g of fuel) Am/Ln separation still efficient

Generation IV overall objectives

- meet clean air objectives and promote long-term availability of the systems and effective fuel utilization
- minimize and manage the nuclear waste produced (co-recycling of **all** actinides) and notably reduce the long term stewardship burden in the future, thereby improving protection for the public health and the environment.
- increase the assurance that systems are a very unattractive and least desirable route for diversion or theft of weapons-usable materials.

Change of philosophy

dirty fuel-clean waste instead of clean fuel-dirty waste

Direct electroreduction of simulated MOX fuels

PYROmetallurgical processing REsearch Programme

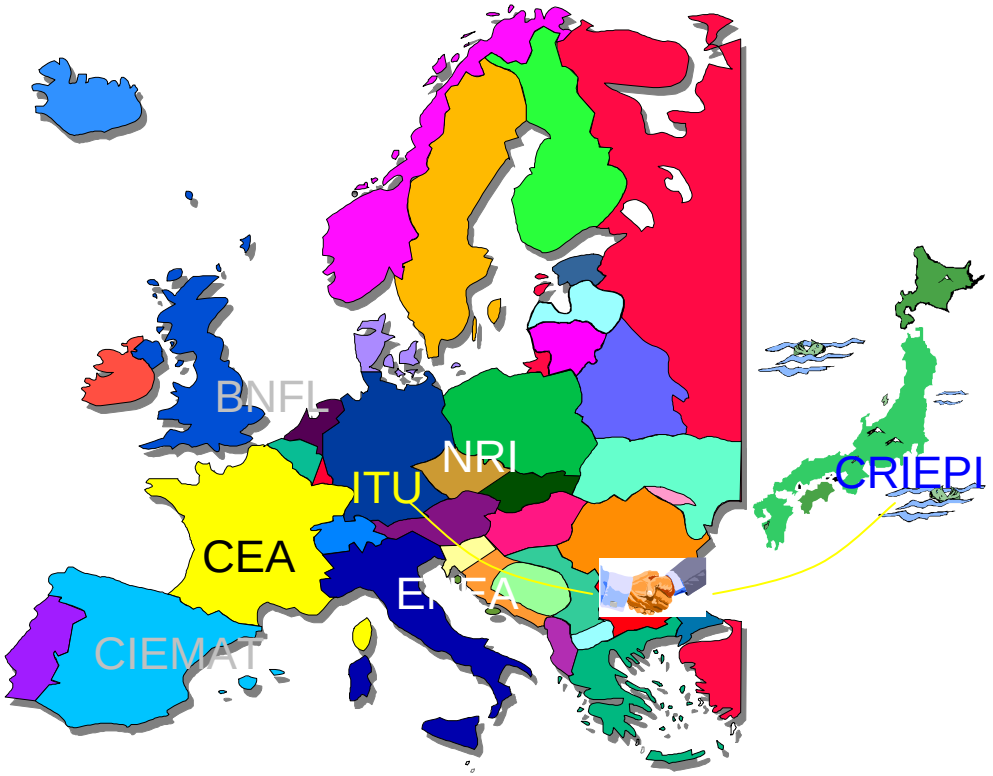
PYROREP

- *major objective*

partitioning of minor actinides (MA) from fuel target or HLW

- *participants*

CEA – Marcoule, F
BNFL – AEA Technology – Harwell, UK
CIEMAT – Madrid, E
NRI – Rez, Cz
ENEA – Casaccia, I
CRIEPI – ITU – Karlsruhe, D



Direct electroreduction of simulated MOX fuels

PYROmetallurgical processing REsearch Programme

PYROREP

- consolidate and revive European expertise in pyroprocessing
- obtain basic data to allow conceptual design of processing processes suitable for
  - fuels
  - targets
  - HLLW calcine
- system and performance assessment
- identify materials usable for industrial implementation
- asses waste and reactive treatment

EU EUROPART Integrated Project

- ✓ *Project full title: EUROpean research program for the PARTitioning of minor actinides from high active wastes issuing the reprocessing of spent nuclear fuels*
- ✓ *hydrometallurgy (5 WP) and pyrometallurgy (4 WP)*
- ✓ *duration 4 years; starting date January 2004*
- ✓ *shared costs*
  - ✓*total eligible 10.3 mio €*
  - ✓*EU contribution 6 mio €*
- ✓ *25 participants including CRIEPI and ITU*
- ✓ *co-ordination CEA*

WP N°	Workpackage title	Person-months
1	Partitioning of An from HAR and HAC from UOX and MOX spent fuels (using polyamides, poly N or S molecules and cosan)	233.1
2	Partitioning of An from HAR and HAC from UOX and MOX spent fuels (using calixarenes, or cosan extractants)	165.2
3	Partitioning of An for advanced dedicated fuel cycles (using polyamides, N-S types of molecules and cosan)	99
4	Partitioning of An for advanced dedicated fuel cycles (using calixarene, cosan and calixarene-cosan molecules)	79.8
5	Methods for co-conversion of separated actinides	25.8
6	Pyro Partitioning of An from UOX and MOX wastes	27.6
7	Study of the chemistry of trans-Cm elements in molten salts and definition of pyro processes for advanced dedicated fuel cycles	56.7
8	Study of the conditioning of the wastes issuing pyro processes	45.1
9	Pyrochemical system studies	18
	Total	750.3

METAPHIX irradiation experiment
Irradiation of U,Pu,Zr,Ln,MA alloys

CENTRALE PHENIX
CEA-EDF

3 capsules;

3 different compositions

under irradiation since November 2003 in the PHENIX reactor in Marcoule

1. 90 PEPD 1.7 % burn-up
   unloaded: 8. August 2004
   transport to ITU 25. September 2006
   NDE performed
2. 3 cycles of 120 PEPD 7 % burn-up
   unloaded: 20. July 2006
3. 5 cycles of 120 PEPD 11 % burn-up
   to be unloaded beg. 2009

work initiated by CRIEPI, Japan; now trilateral project CRIEPI, CEA, ITU

CRIEPI Central Research Institute of Electric Power Industry

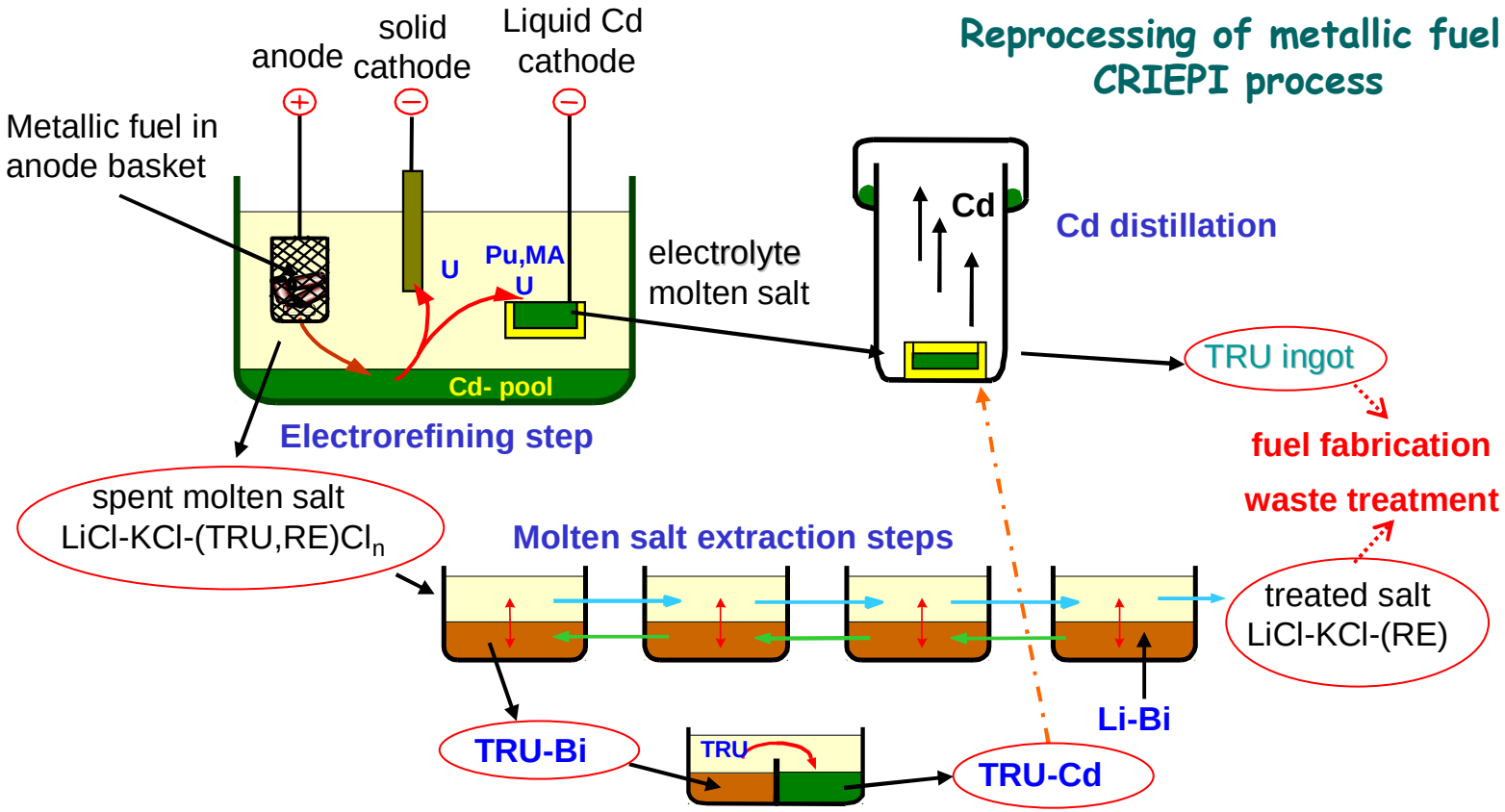
Pyrometallurgical Processes
CRIEPI-ITU collaboration

Objectives

- Reprocessing of the metallic fuels U, Pu, Zr with up to 5% An's and Ln's
  - un-irradiated material from the fuel production
  - irradiated METAPHIX target fuels after irradiation in PHENIX reactor
- Study processes on calcined and chlorinated HLW from PUREX type waste
  - Electrorefing
  - Molten salt liquid metal extraction
- Study of direct electroreduction processes for the head-end conversion of oxides to metal

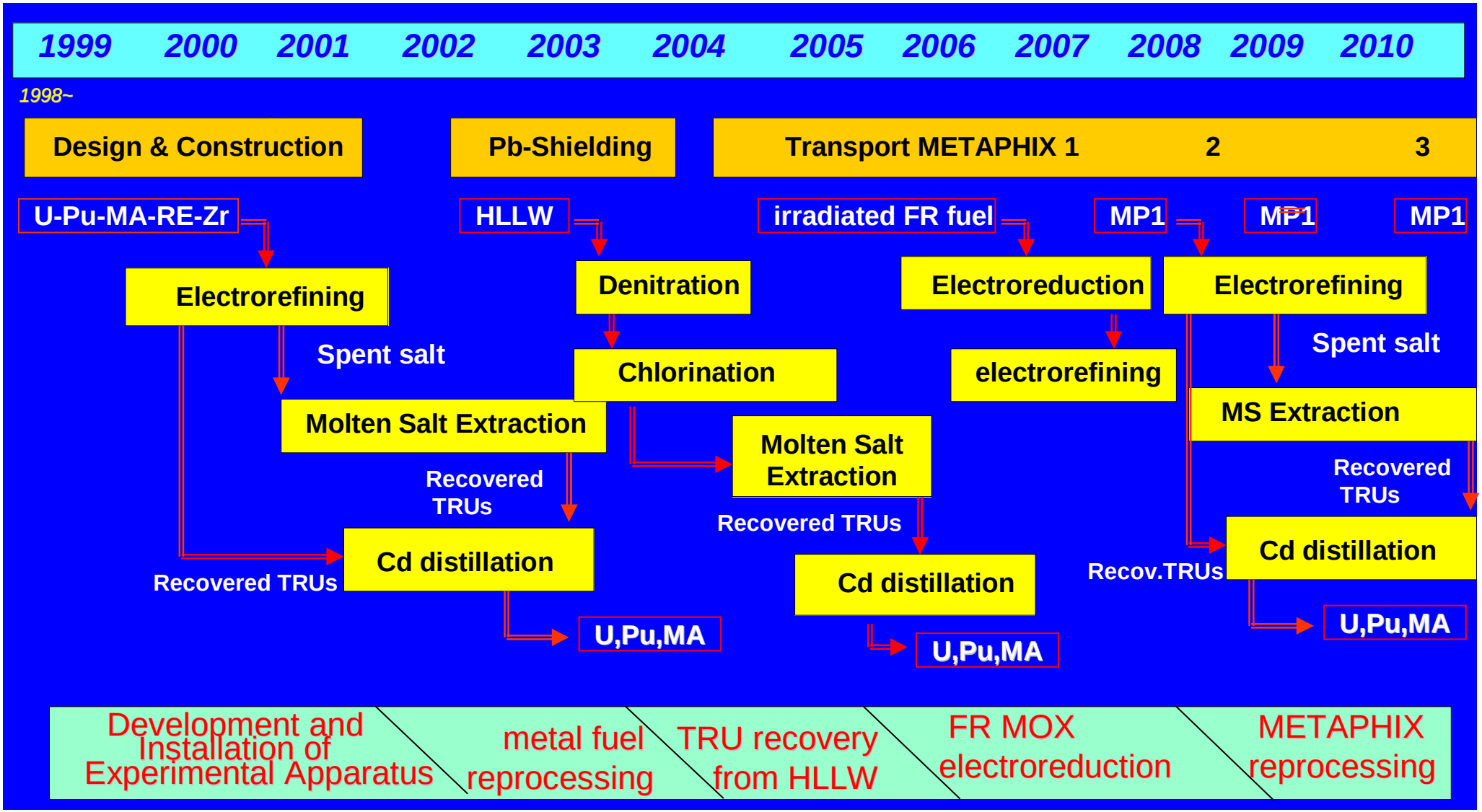
⇒ Main Tasks

- Installation of GBs and hot cell for experiments
- Setting-up of necessary equipment
- Colds test using U, Pu and fresh metallic fuels
- Hot tests using fresh and irradiated fuels (METAPHIX) & HLW
- Optimisation of the process

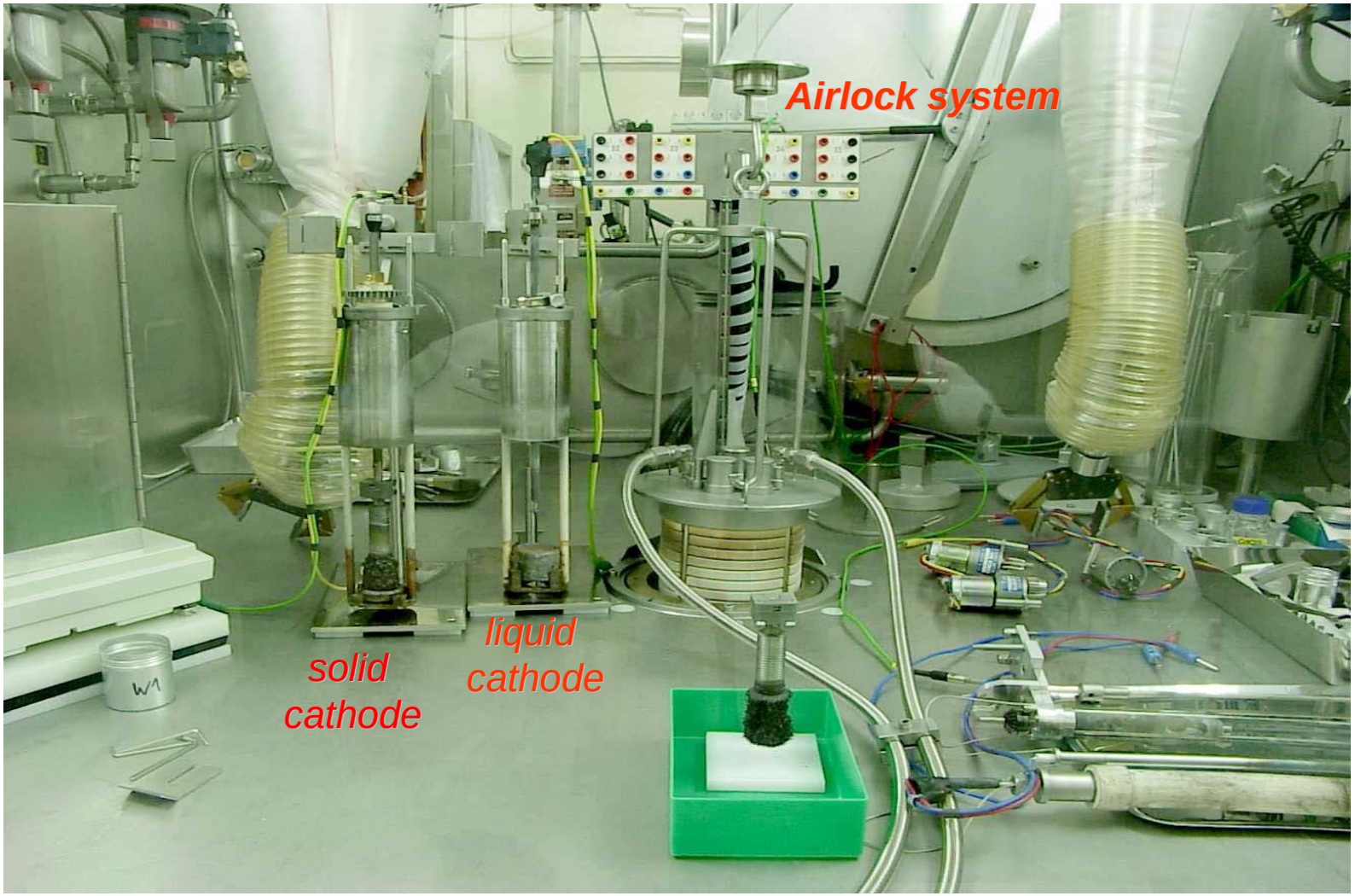


Alternative Fuel Cycles

Pyroprocessing: Tentative Test Plan



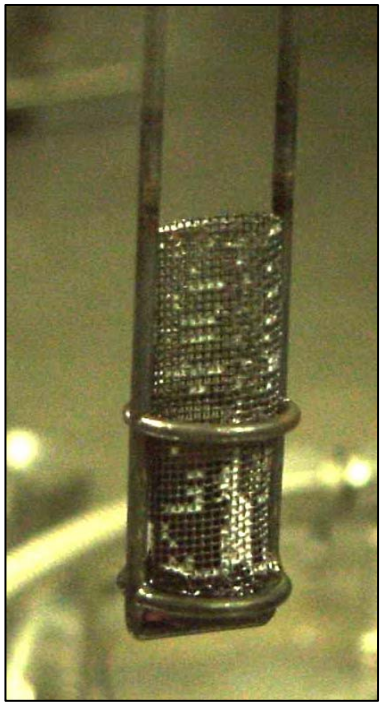
Pyrometallurgical Processes
CRIEPI-ITU collaboration



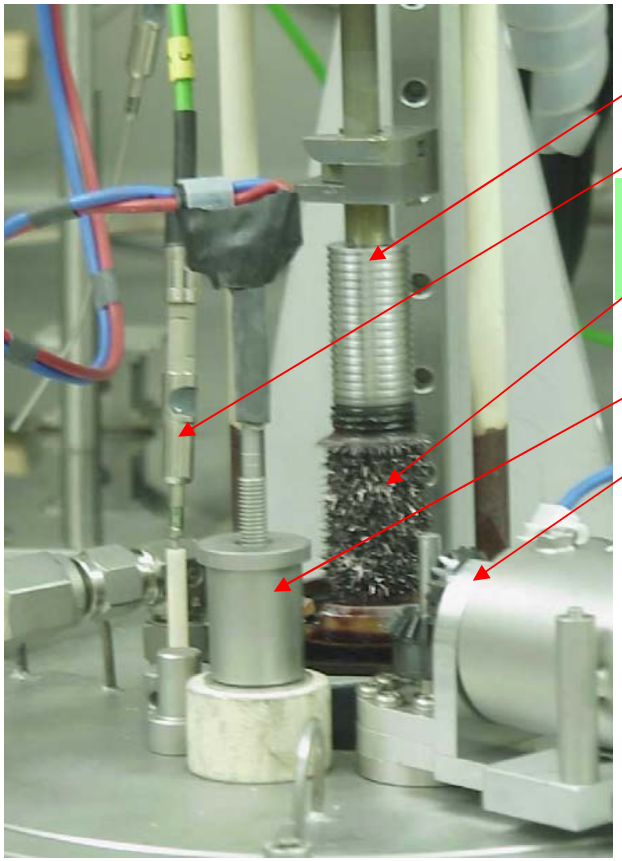
inside view of the electrorefining caisson

Pyrometallurgical Processes

CRIEPI-ITU collaboration



anode basket loaded with U metal (60g)



solid cathode with U dentrite deposit

salt sample

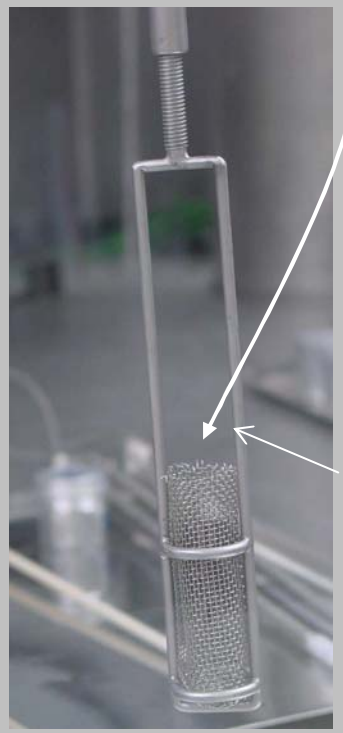
electrodeposition parameters:
. constant current: 500 mA
. time: 4 hours
. temperature: 773K

U-Salt sample

U electrodeposition

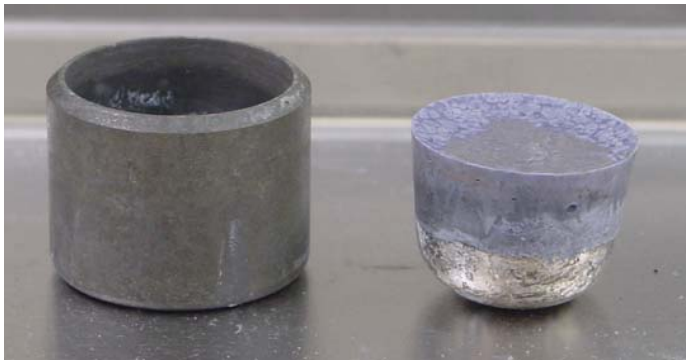
Pyrometallurgical Processes

CRIEPI-ITU collaboration



anode basket loaded with Pu/Am metal (45g)

Cd liquid cathode (85g) after electrodeposition of Pu/Am (~5g)



Recovered Cd-Pu/Am ingot and AlN crucible

electrodeposition parameters:
. constant current: 500 mA
. time: 4 hours
. temperature: 653K

Pu electrodeposition

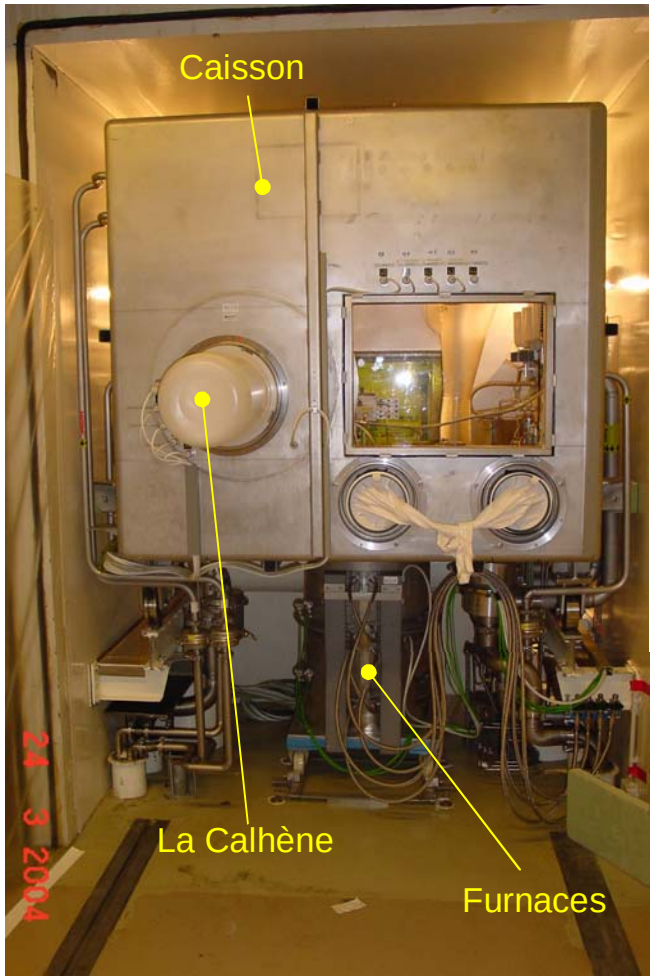
Pyrometallurgical Processes

CRIEPI-ITU collaboration

⇒**Phase 1:** Installation of the equipment in an alpha laboratory

- Adaptation & testing of equipment
- U & Pu runs
- UPuZrMA runs
- Reductive extraction

Atmosphere in caisson: Ar with O_2 and H_2O concentrations < 10ppm respectively

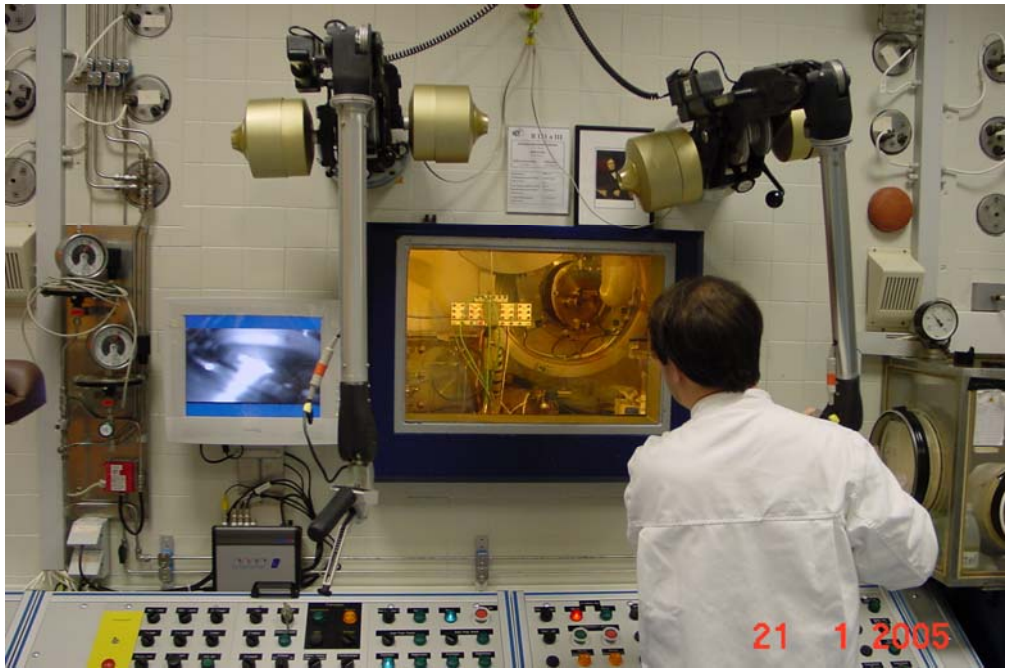


⇒ **Phase 2:** Installation of the equipment in a beta-gamma laboratory (15cm lead shielding

- Hot tests with HLW & irradiated METAPHIX metallic fuel

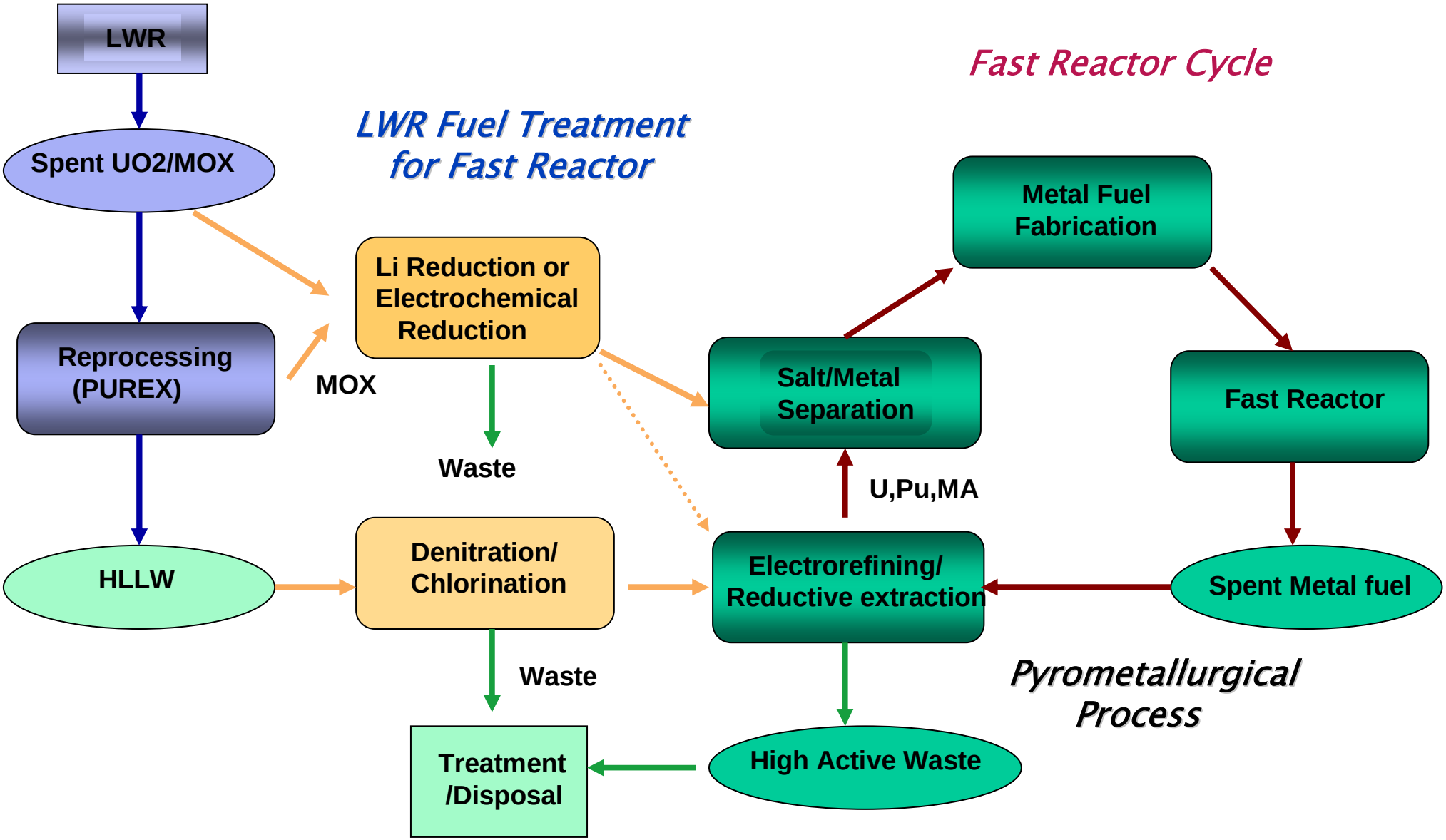
Pyro-reprocessing cell

Installation of Caisson (2003)



Introduction of material through an Ar flushed LaCalhène door (2005)

Combined Oxide-Metal FR Fuel cycle
Actinide Recycling



Chlorination of HLLW

Raffinate from Purex reprocessing of commercial MOX.

- *Pu/(U+Pu)=4.9% before irradiation*
- *Burn up: ~ 30GWd/t*

To better observe the behavior of Np and Pu, HLW from reprocessing of LWR UO_2 fuel and FR MOX fuel were mixed to form the raffinate.

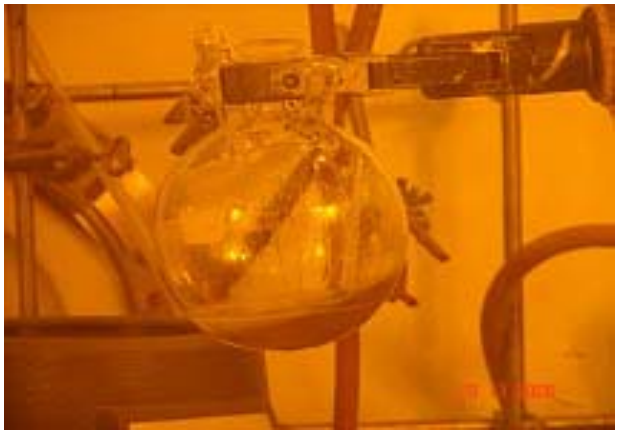
Final composition

- *U: 8400 μg/g*
- *TRU: 600 μg/g*
- *Fission products: 2000 μg/g, including 900 μg/g of rare-earth elements*

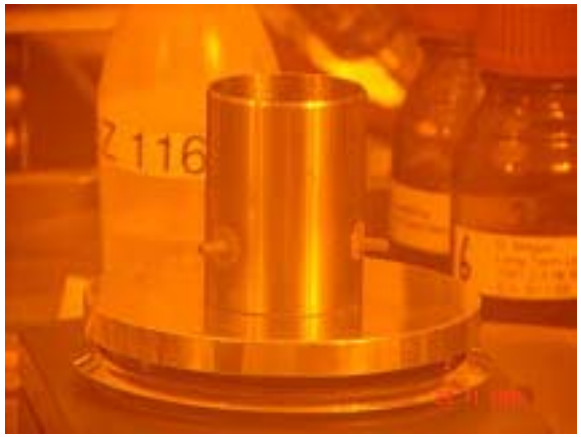
Chlorination of HLLW

The mixed HLLW was concentrated in a glass flask in an air atmosphere hot cell.
Then, the concentrated solution was poured into a stainless steel crucible and heated on a hot plate to remove most of the water.

Concentration of HLLW



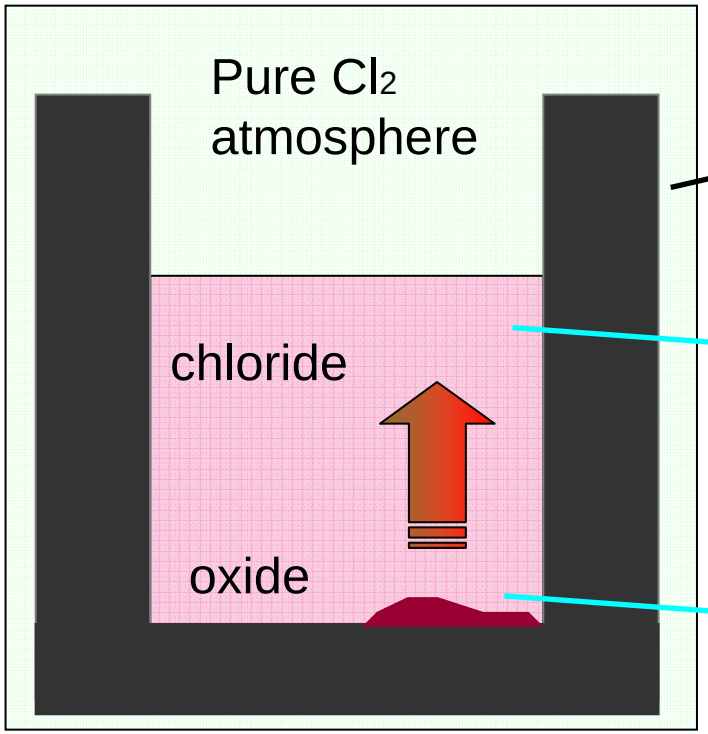
HLLW after concentration



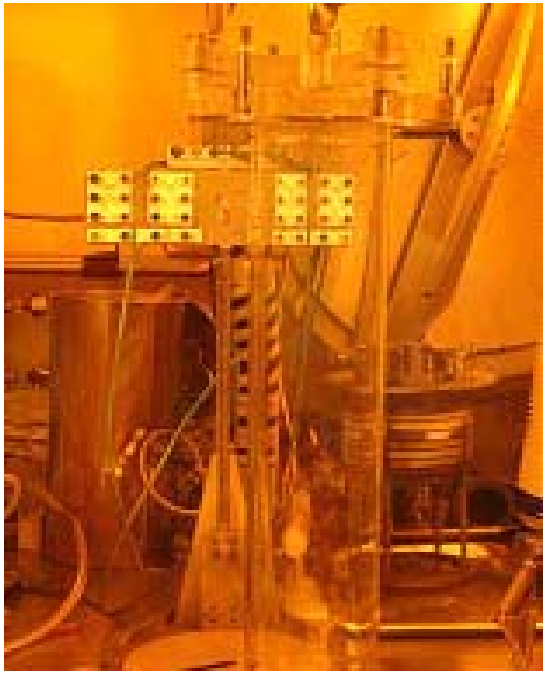
Heating on a hot plate

Chlorination of HLLW

The calcinated material is converted to chloride under pure chlorine gas atmosphere at 650°C .
The chlorination is performed in the argon atmosphere hot cell.

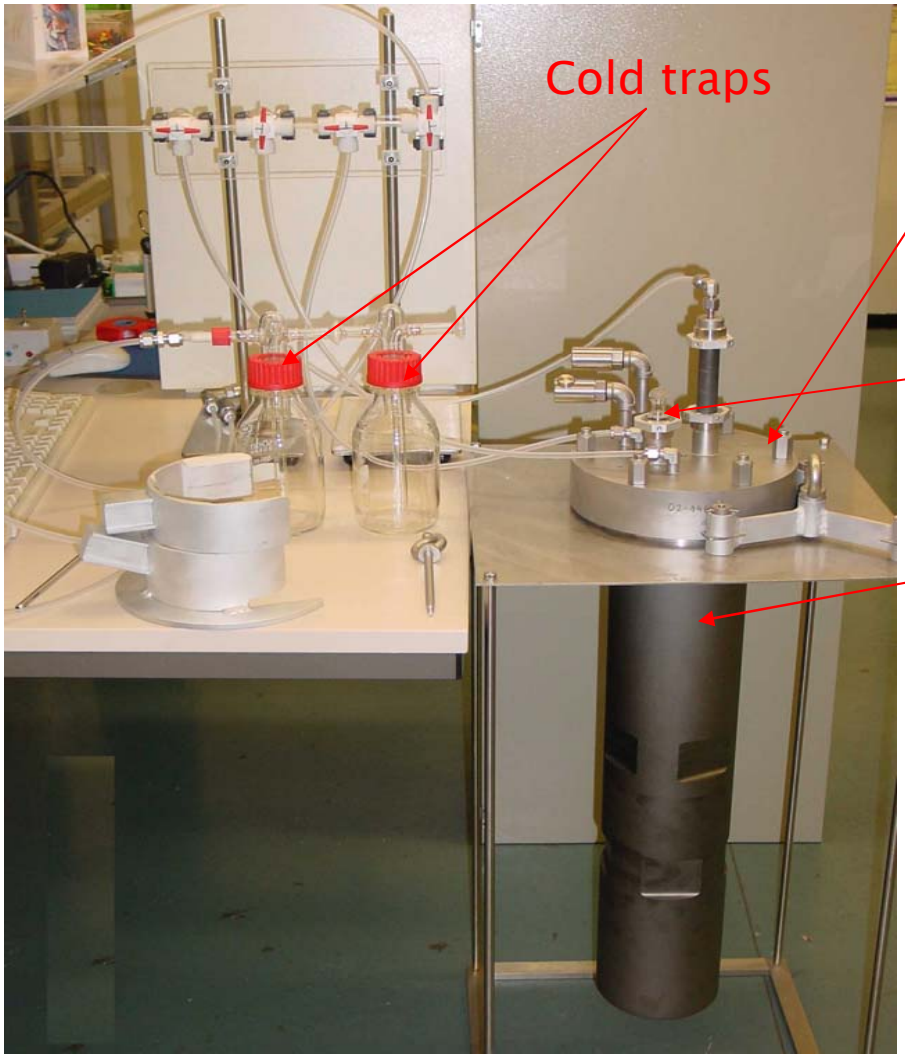


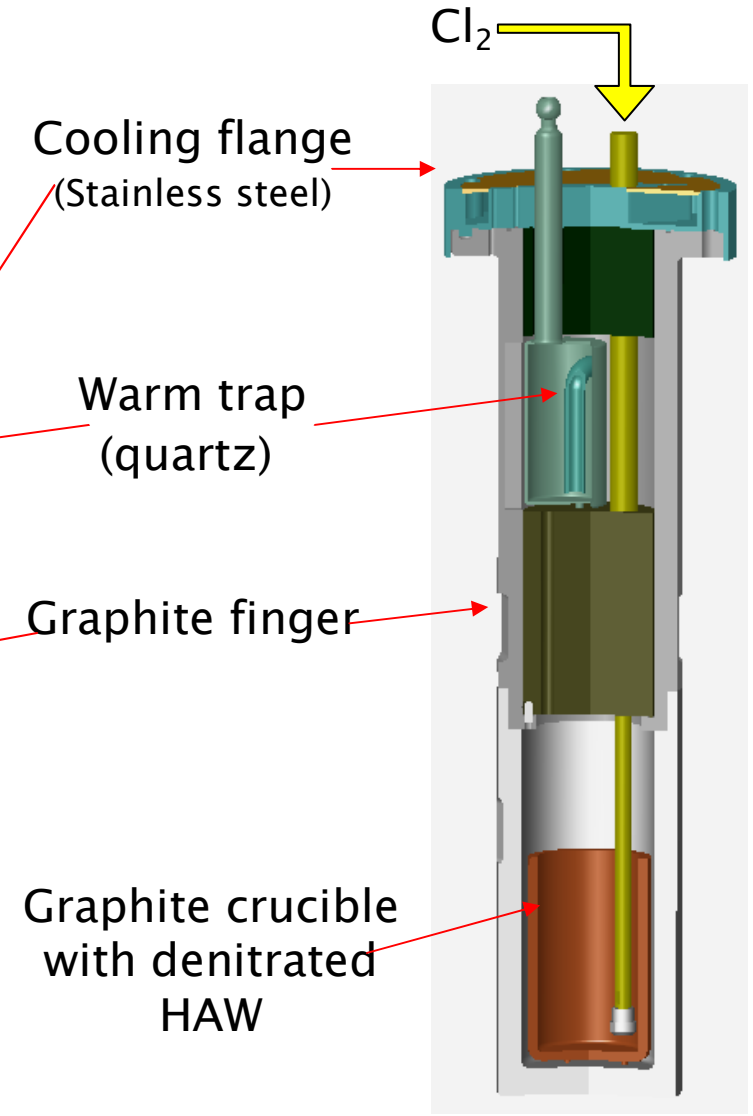
Schematics of chlorination



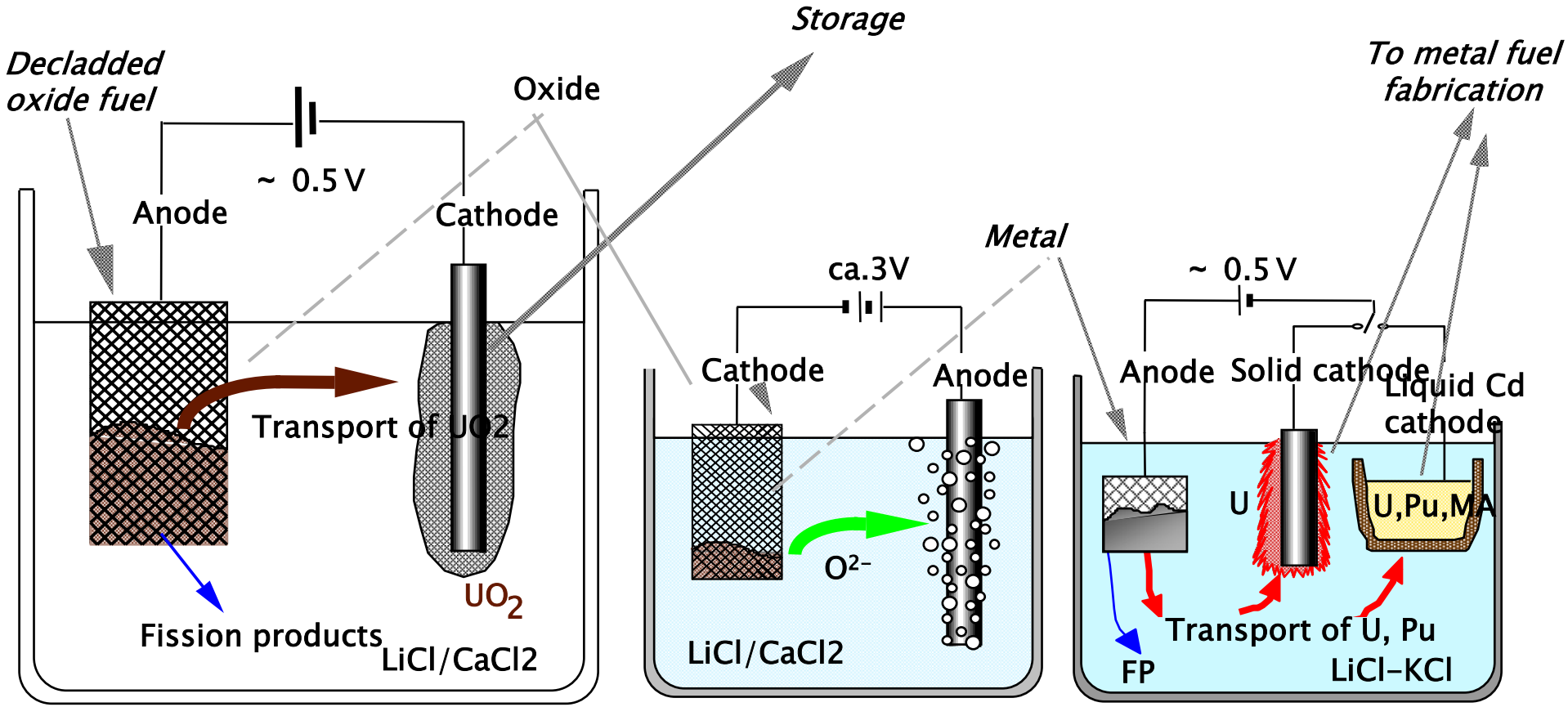
Quartz reactor for chlorination

Chlorination device





electrochemical reduction and electrorefining



Selective collection of UO2 (large part of UO2 is collected)

Oxide to metal conversion

U,PU,MA refining (FP removal)

Spent oxide treatment by pyro-porcess with UO_2 separation

Lithium Reduction Process

reduction using lithium metal in a molten LiCl salt at 650 ºC; major concern in this process is the carryover of unreduced rare-earth oxides into the electrorefiner.

Calcium Direct Oxide Reduction Process (DOR)

used for many years in production of plutonium metal from oxide using calcium metal in molten $CaCl_2$ or $CaCl_2$-CaF_2 at 850°C; the drawback is the high temperature

Direct electroreduction

new process with a lack of fundamental data for actinide oxides; efficiency for the reduction of unirradiated oxide fuels to be tested followed by the reduction of irradiated oxide fuels. Important parameters to investigate are the influence of temperature, salt bath composition, potentials.

Direct electroreduction of oxide fuels

apparatus

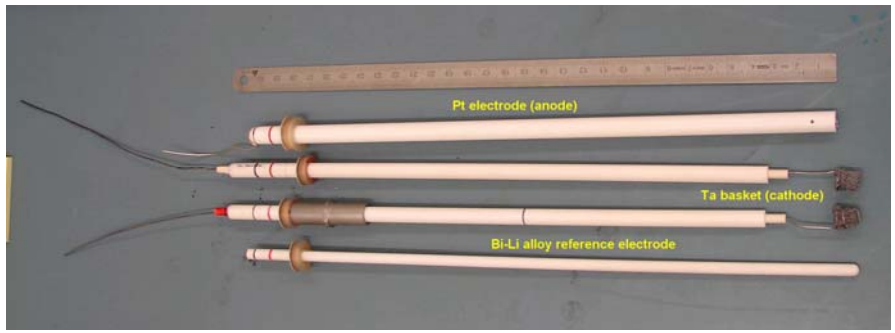
Experiments ongoing using SUPERFACT irradiated fuel, fabricated by ITU:

2 pieces of $(U_{0.74}Pu_{0.24}Am_{0.02})O_2$ *and*

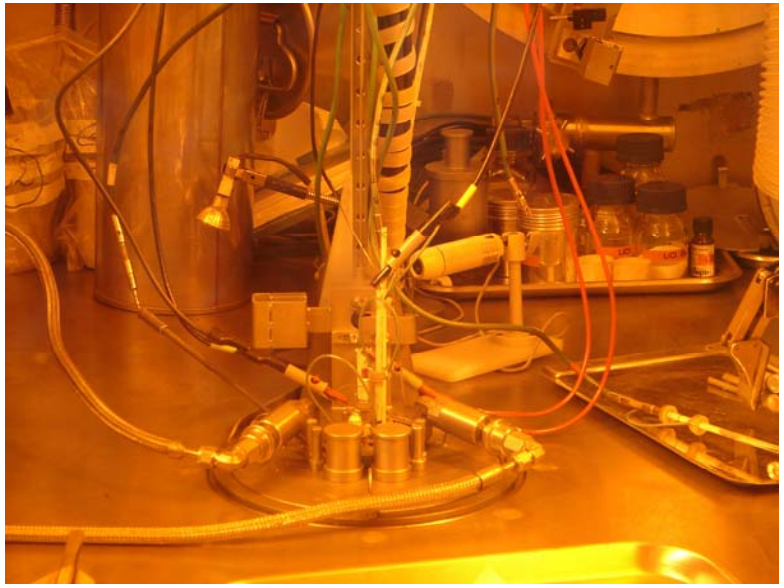
2 pieces of $(U_{0.74}Pu_{0.24}Np_{0.02})O_2$

Crucible material: MgO

Electrolyte: $LiCl + Li_2O$ *(T=650°C)*



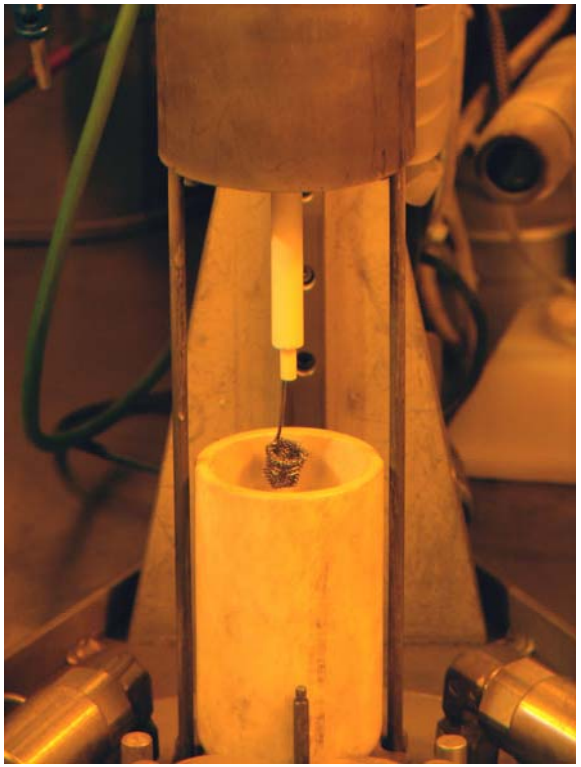
Set of electrodes



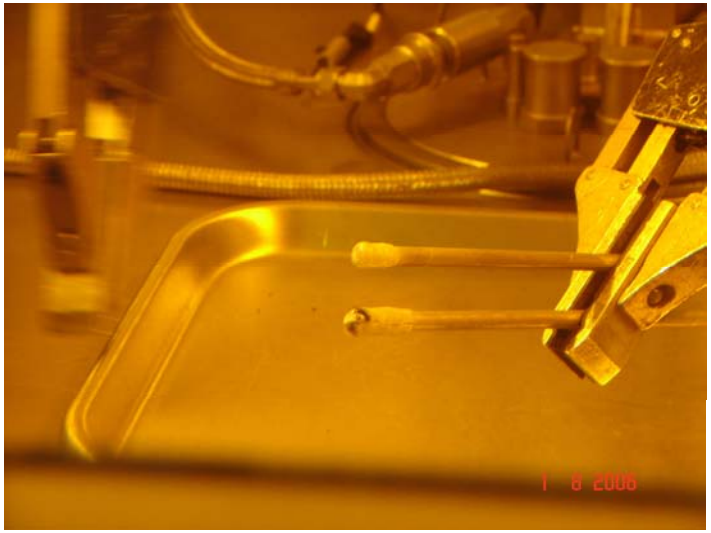
Setup inside the pyro caisson

Direct electroreduction of irradiated oxide fuels

Direct electroreduction of oxide fuels

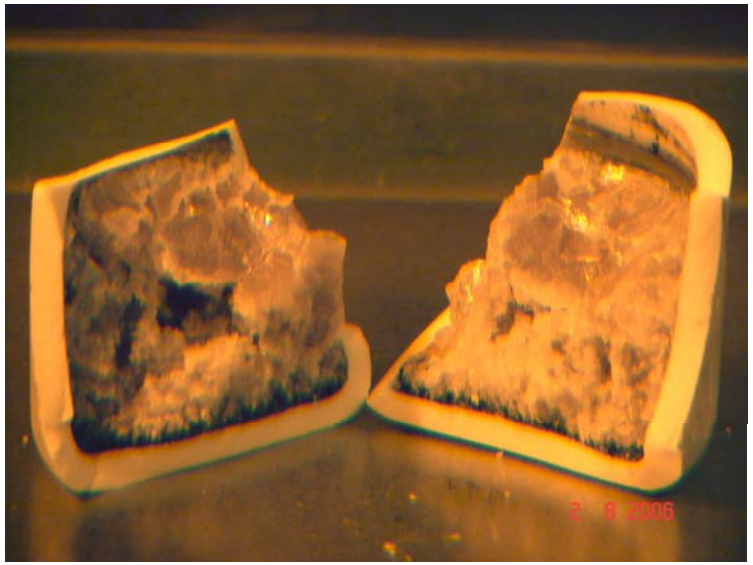


fuel loading



Salt samples taken from the top and bottom (incl. black fuel deposit) of the crucible

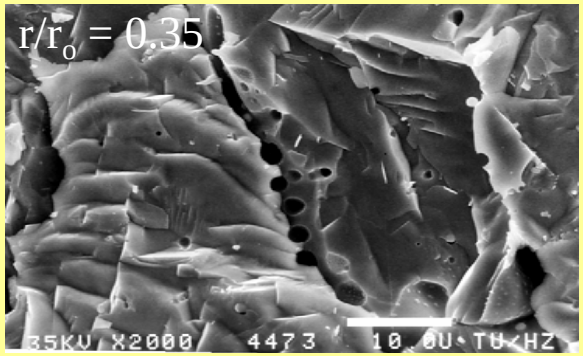
Crucible showing a black reduced fuel deposit on the bottom

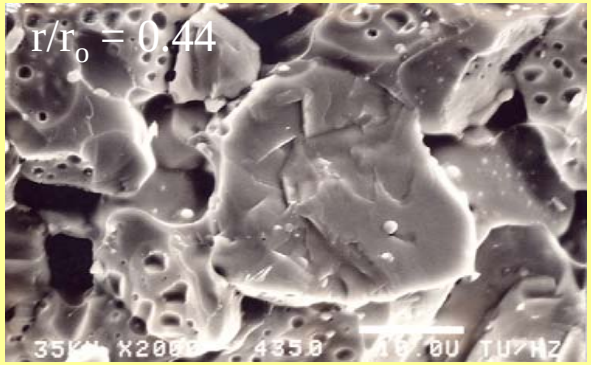


Direct electroreduction of irradiated MOX

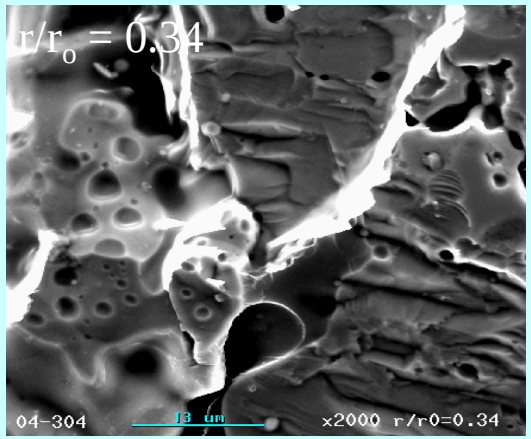
Direct electroreduction of oxide fuels

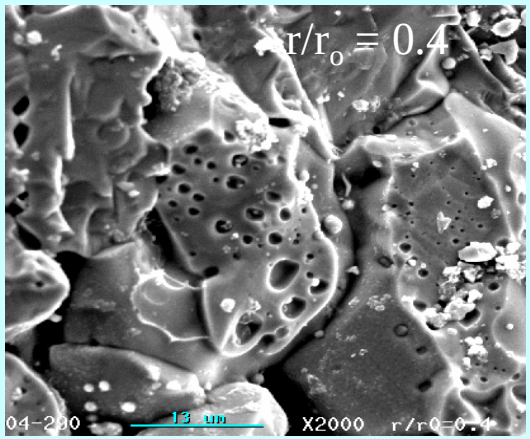
After irradiation 1991





After storage 2003





SEM examination of SUPERFACT fuel showing a strong intergranular porosity due to fission gas release

safeguards/non proliferation

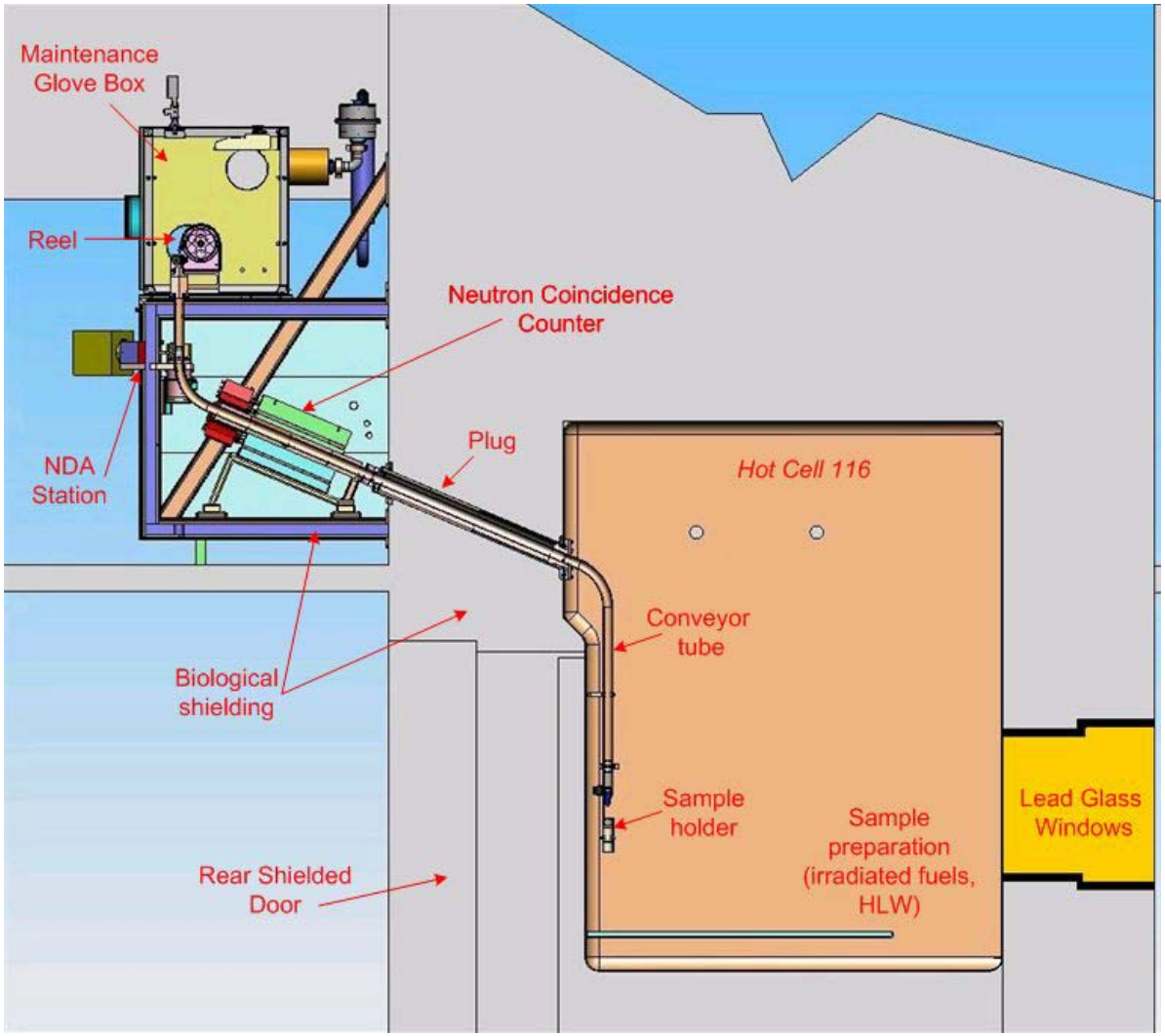
- *mature for PUREX to be extended to advanced aqueous*
- *development of destructive and non-destructive assay techniques for inventory and flow verification purposes, including new type of fuels containing minor actinides, Np-237, Am-241, Am-242*

  IAEA and EURATOM: effective flow sheet verification (FSV) at ITU to update the existing design information as provided for safeguarding U and Pu, and to provide additional information relevant to Np

- *proliferation and safeguards issues are far less defined and investigated for pyroprocessing; new schemes, approaches and analytical techniques have to be developed*
  - K- X ray Fluorescence (K-XRF)
  - Neutron Coincidence Counting (NCC)
  - High Resolution Gamma Spectrometry (HRGS)
  - Calorimetry

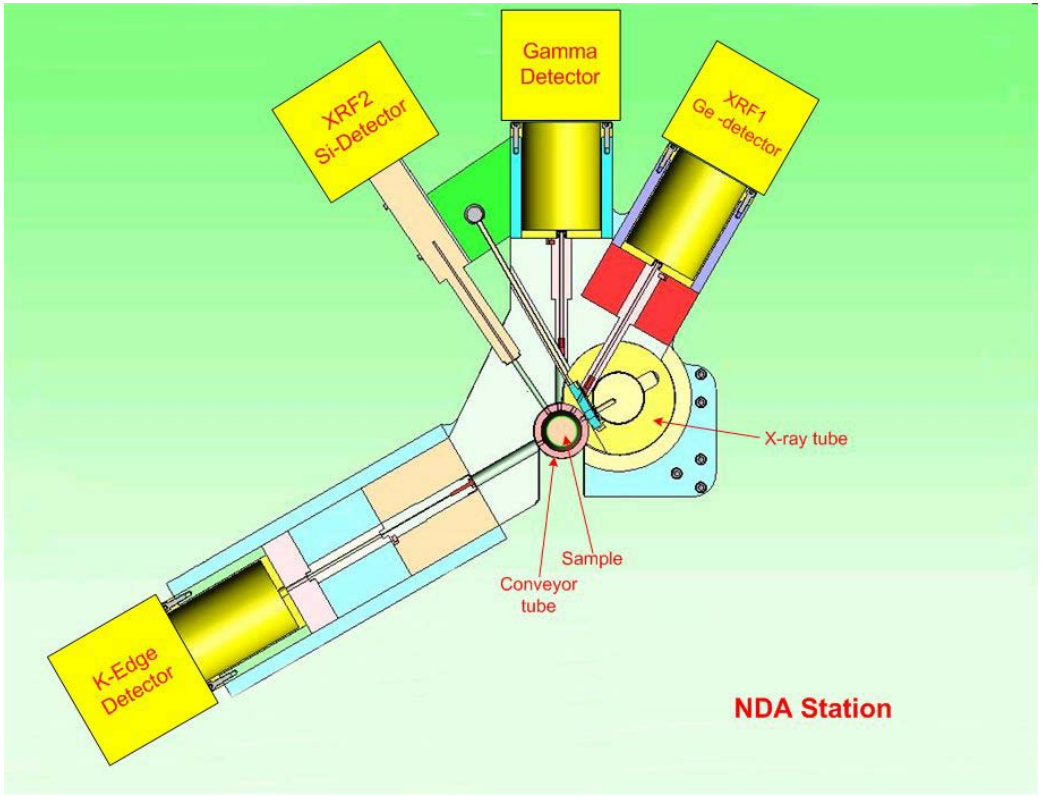
Pyrometallurgical Processes

new analytical equipment

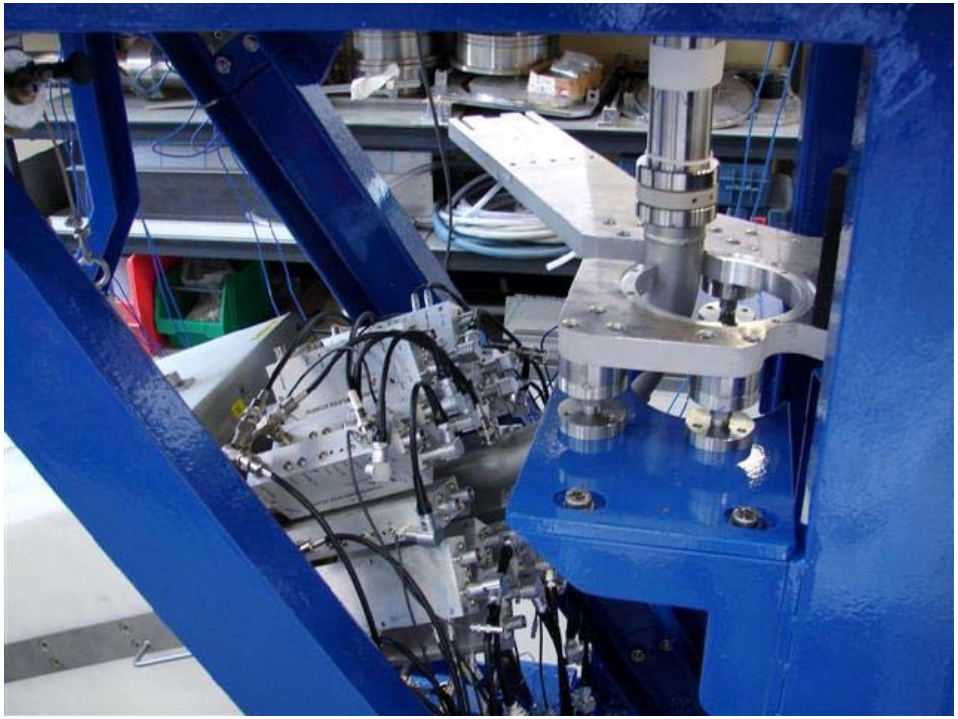


Objective: to install NDA assay system for a direct non-destructive assay on high active samples

Advanced NDA assay system connected to a hot cell



Advanced NDA assay system detector arrangement



Testing of equipment

Status of the project

- *installation for testing in A117*
- *x-ray and detectors to be installed and tested*

Head- and Back-end

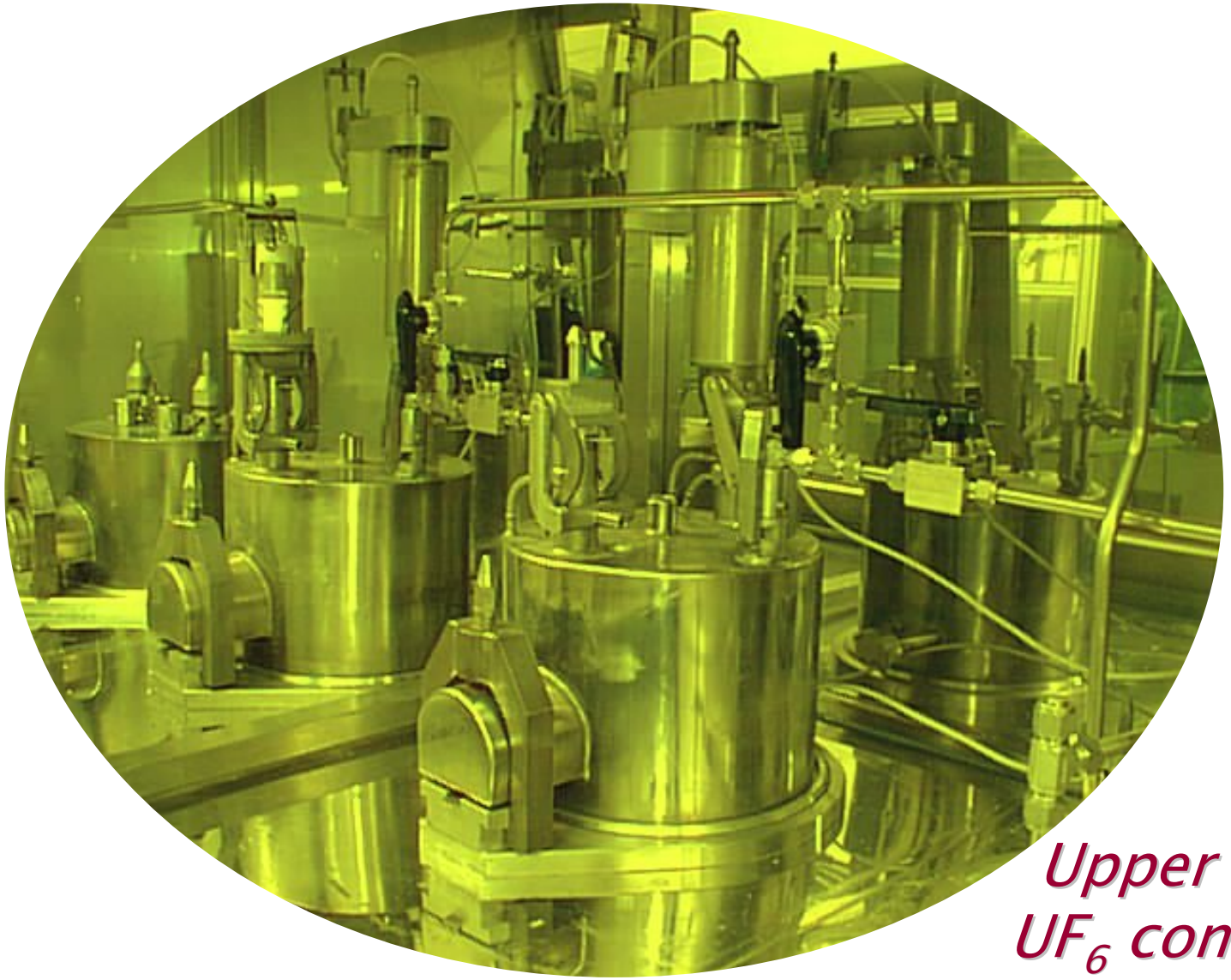
Operations at the front end or the tail end of the main process, where research and development are also mandatory:

- *preparation of the feed stream to ensure compatibility with the core process (e.g., de-cladding of solid fuel, halogenation of oxide fuel, and dissolution in molten salts)*
- *Purification of the output stream with recycling of contaminants back into the core process and treatment of the process and conditioning of waste materials in accordance with their chemical and radiological properties (e.g., vitrification)*
- *Decontamination of technological waste (e.g., crucibles) with recycling back into the core process and conditioning of the actual waste materials (e.g., melting of scrap metal)*
- *Decontamination of all process off-gases with recycling of contaminants back into the core process.*

Future pyro-partitioning studies

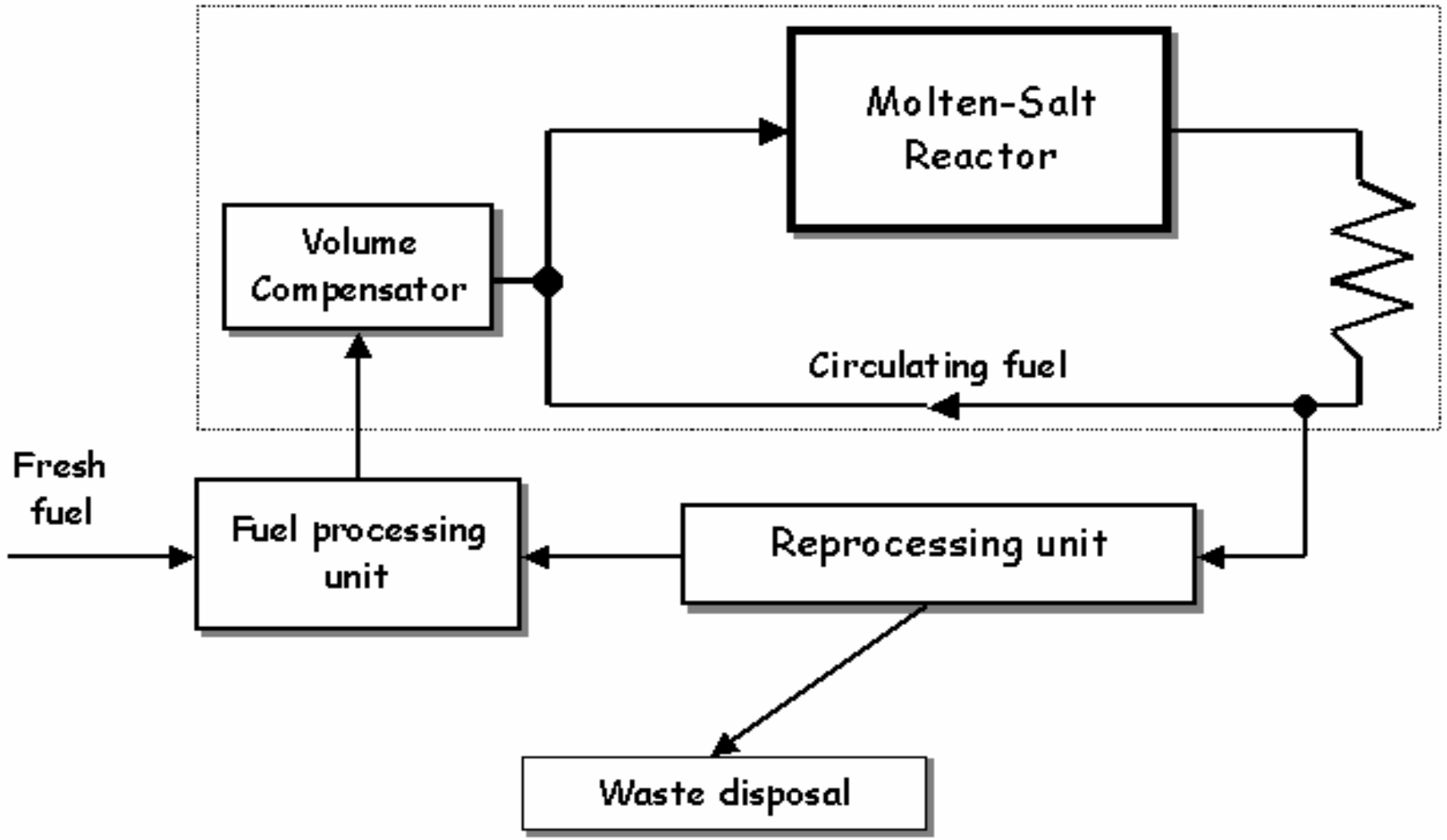
- complete the basic thermodynamic and electrochemical data especially Cm (collaboration with RIAR Dimitrovgrad in an ISTC project)
- further develop head-end and back-end treatment in view of large scale process development
  - techniques for cathode reprocessing
  - direct electroreduction
  - waste treatment
- electrorefining in molten fluoride systemes (expertise Rez)
- ACSEPT project in the European 7th FP
- develop a safeguarding technology for a pyrometellurgical process

Czech molten fluoride reprocessing



Upper part of UF_6 condensers

Czech molten fluoride reprocessing



Czech molten fluoride reprocessing

Main groups of elements, which have to be extracted from the fuel (primary) circuit of the MSTR

- *Noble gases (Xe, Kr)*
- *Noble metals (Nb, Mo, Ru, Sb, Te), which tend to leave carrier molten salt*
- *Lanthanides (rare-earths) forming stable fluorides in molten salt medium*
- *Actinides forming stabile fluorides in molten salt medium. (However TRU elements have to be returned back into the fuel circuit)*

R&D requirements for a MSR fuel cycle

Research defined in the frame of the European MOST project

- ✓ Molten salt fuel processing (liquid–liquid extraction, fluorination, ...)
- ✓ Most of the data are not measured (only calculated) : need of measurement of the static and kinetic parameters (Decontamination factors, Gibbs energy, ...)
- ✓ Reprocessing will be done by small batch during MSR operation
- ✓ One reprocessing unit for one site (3 or 4 MSR) having a capability of 1 to 3 m^3 of fuel salt per day.
- ✓ Reprocessing part of MSR has a strong impact on economy of the system

- New European Research Area concept
  - P&T integrated projects EUROPART and EUROTRANS
  - ACTINET network
    - Increase training, education, exchange of scientific staff
    - Pooling of facilities
- EURATOM participation in GIF (charter signed on 30.6.2003)
  - VHTR; GFR, SCWR, SFR, MSR
  - develop fuel cycles including safeguards
    - simplified PUREX + advanced aqueous
    - dry reprocessing techniques
    - development of advanced fuels including inert matrix fuels and targets

Advanced Nuclear Fuel Cycle at ITU

- ✓ Contract with CRIEPI in support to the start-up of the reprocessing in Rokasho:
  - ✓ successful cold tests on sludge formation upon fuel dissolution,
  - ✓ possible follow-up projects until 2012
- ✓ demonstration of the TODGA MA extraction process
  - ✓ collaboration with FZ Jülich
- ✓ implementation of HFM extraction equipment
- ✓ successful MA separation from chlorinated PUREX raffinate
  - ✓ extraction by liquid Bi from molten salt
- ✓ new partitioning project ACSEPT 2008-2012
  - ✓ ITU contributions on hydro- and pyro-reprocessing (~750 k€)
- ✓ participation in the PATEROS project to prepare the SNETP platform

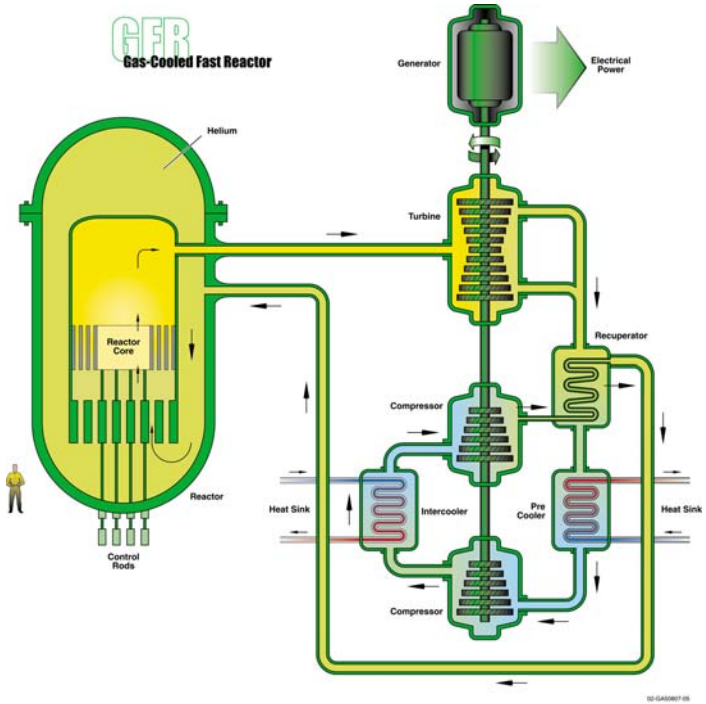
Hydro-pyro

- ✓ No competition but complementarity between aqueous and pyrochemical techniques

  - ✓ Advanced and extended PUREX in the LWR cycle for separation of all actinides
    - ✓ Industrial implementation in progress
  - ✓ Pyroreprocessing in the advanced FR cycle for grouped actinide recycling
    - ✓ Demonstrated on laboratory scale

CEA R&D on GFR fuel reprocessing

- Fuel dissolution
  - First tests to dissolve selected materials in aqueous media and molten salts
  - Evaluation of mechanical pre-treatment (burn & crush, sonic waves, …)

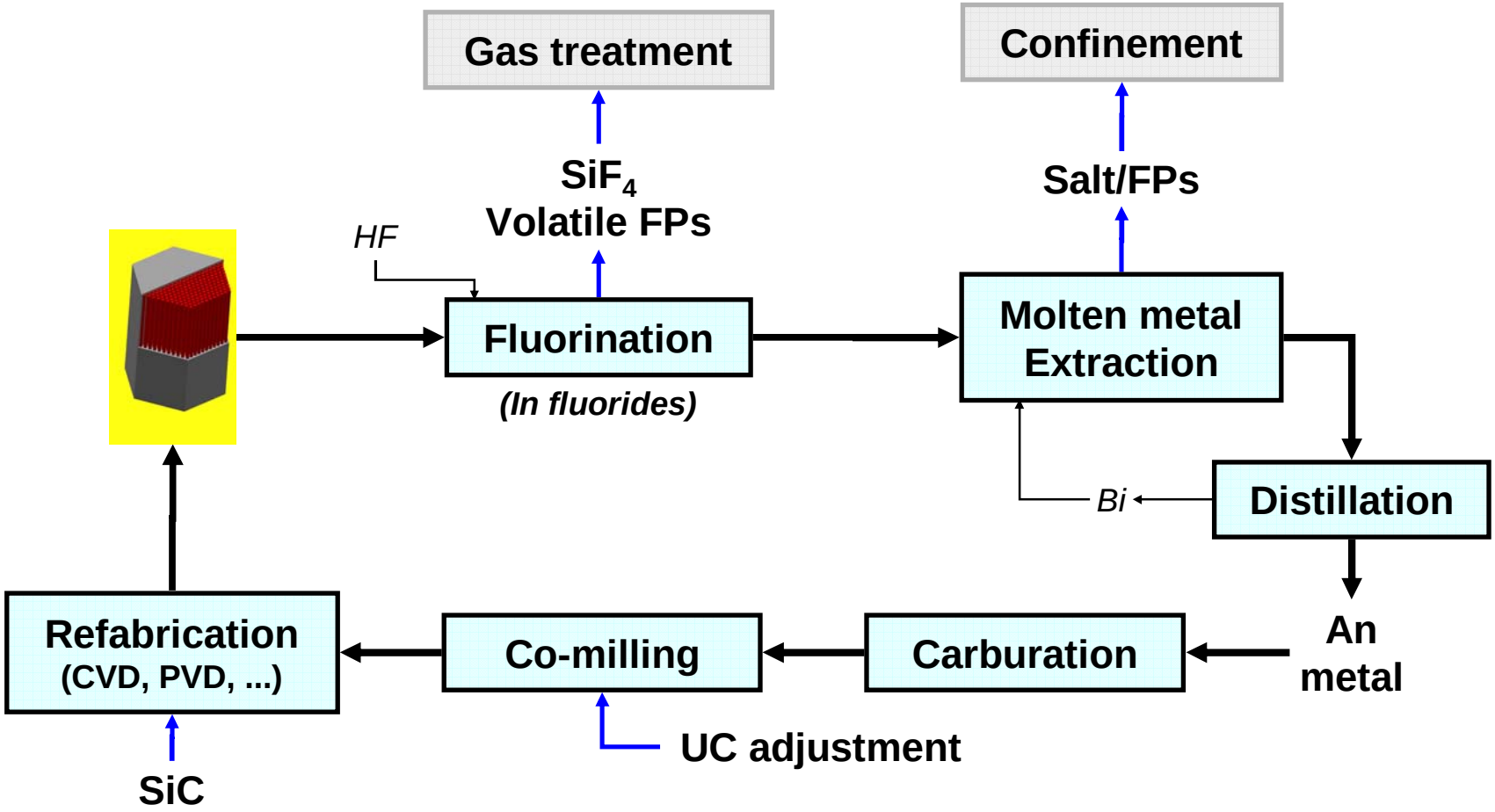


- Grouped Actinides recycling
  - Hydro
    - Calculation of a separationscheme to meet required extraction performances
    - R&D on specific extractant for the actinides family
  - Pyro :
    - Hot cell tests of actinides electrochemical recovery in molten chlorides
    - R&D on the liquid-liquid extraction with a metal

Th fuel Reprocessing: Dry Route

- Head-end process and fuel dissolution in molten salt difficult, especially in the case of coated particles
- Conversion processes (of e.g. ThO_2 or ThC) if metallic concepts have to be applied
- ^{231}Pa problem; can possibly be transferred to the waste treatment part of the process
- difficult fuel fabrication also due to ^{232}U

Example of advanced fuel cycle



AnC/SiC macrodispersed concept
Pyrochemical treatment

Major future research topics

Performed in close international collaborations, the research work should focus on the following major topics:

- *completion of thermodynamic database on actinide containing fuels for molten salt systems*
- *Testing and evaluating advanced dry reprocessing techniques including scale-up*
- *Installing new large scale facilities for pyrochemical reprocessing*
- *Developing supporting analytical techniques in combination with a safeguarding process*