EUROPEAN COMMISSION

# EURATOM Fast Neutron Reactor Fuel Cycle Research

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**Joint Research Centre**

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# Outline

1. Fast reactor R&D in Europe
2. Fast reactor fuel cycle R&D: role of EURATOM
3. JRC role in the fuel cycle: solid fuels developments
4. JRC role in the fuel cycle: molten salt fuel properties
5. JRC role in the fuel cycle: advanced fuel reprocessing
6. Conclusion

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# Fast reactor R&D in Europe: The European Sustainable Nuclear Industrial Initiative (ESNII)

1. **Design, construction and operation of a prototype sodium fast reactor (SFR) coupled to the grid**

2. **Design, construction and operation of a demonstrator (not coupled to the grid) of alternative technology, either gas or lead cooled fast reactor (GFR or LFR)**

3. **Supporting infrastructures for prototype and demonstrator**

4. **Cross-cutting R&D programme**
   Basic and applied research to support the activities foreseen in the actions above
   R&D activities: - design and safety,
   - back-end of the cycle,
   - component ageing and lifetime management,
   - materials science and multi-scale modelling of material behaviour (structural materials, fuels, cladding),
   - code development and qualification,
   - severe accident experiments and modelling, etc.

**1– 2 b€ budget (10 years)**

**National programmes**
**EURATOM programme**
**Need for International R&D Cooperation**

# Role of EURATOM in support of R&D

## EURATOM Indirect Actions on Fast Reactors Development

| Project | Period | Total budget M€ | Topics |
|---|---|---|---|
| ESFR | 2009-2012 | 11.5 | SFR design and safety |
| GCFR | 2006-2009 | 3.6 | GFR design and safety |
| ELSY | 2006-2009 | 6.5 | LFR design and safety |
| ACSEPT | 2008-2012 | 23.8 | FR fuel reprocessing |
| GETMAT | 2008-2013 | 14.0 | FR advanced structural materials |
| F-BRIDGE | 2008-2012 | 10.2 | FR innovative fuels research |

**Total of running projects: 70 M€ over 3-4 years (with 50% community funding)**
**New proposals processed on Lead (LEAD) and Gas Fast Reactors (GOFAST)**

# Role of EURATOM in support of R&D

## The JRC: providing robust science for policy makers
## 7 Institutes in 5 Member States

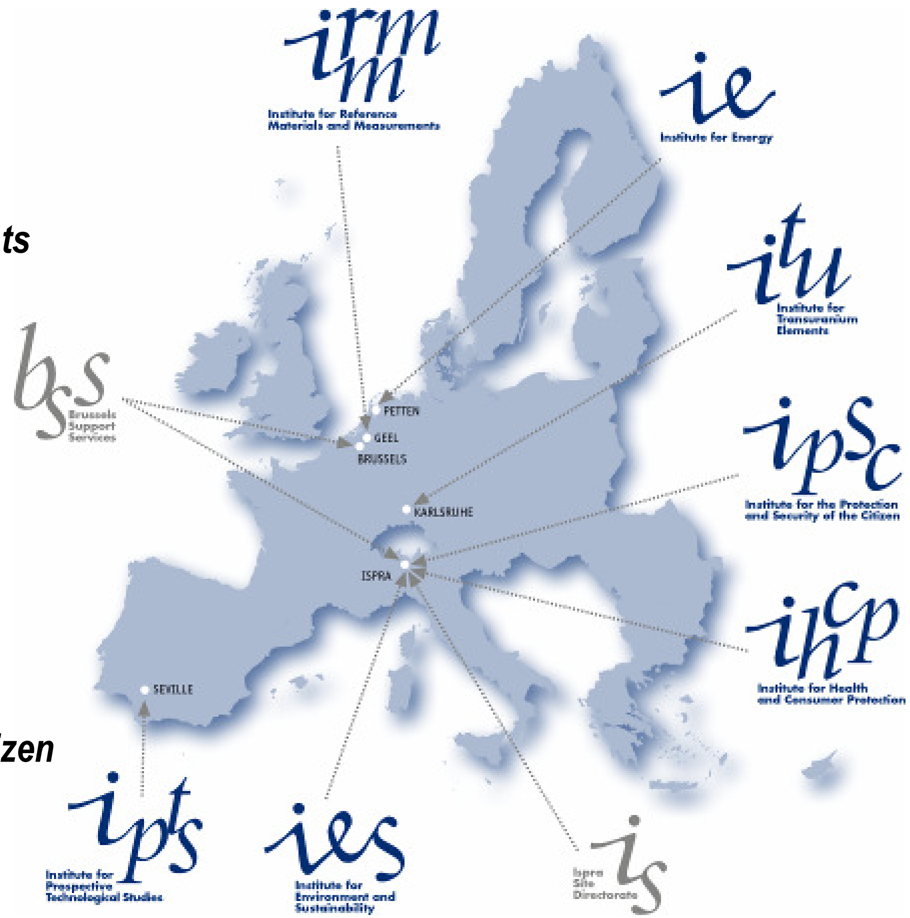
**IE - Petten The Netherlands**
*-Institute for Energy*

**IRMM - Geel Belgium**
*- Institute for Reference Materials and Measurements*

**ITU - Karlsruhe Germany**
*- Institute for Transuranium Elements*

**IPSC - IHCP - IES - Ispra Italy**
*- Institute for Environment and Sustainability*
*- Institute for Health and Consumer Protection*
*- Institute for the Protection and Security of the Citizen*

**IPTS - Seville Spain**
*- Institute for Prospective Technological Studies*

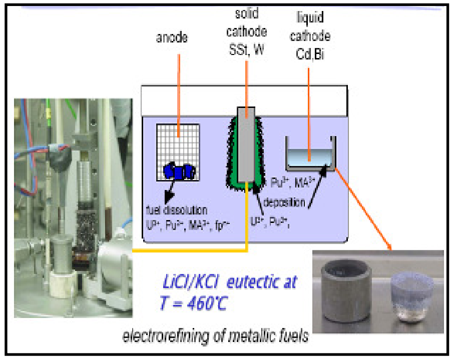


## JRC Contribution to Fast Reactors Development

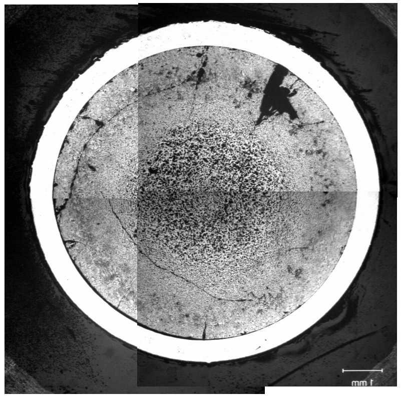
- Involved in research on 4 fast systems (SFR, GFR, LFR, MSFR) with priority to fuel research

- Particular fuel research topics are:
  - Fuel fabrication
  - Physical and chemical properties
  - Irradiation experiments and PIE
  - Advanced fuel reprocessing experiments

- Most experiments are performed within European projects or international collaborations




Reprocessing: Aqueous & Pyro



Carbide Pu fuel irradiated in Phenix FR

# Advanced fast Reactor Fuels: challenges

- FR fuel composition (typical): 25% Pu, 3% MA in the homogeneous recycling mode; >20% MA in the heterogeneous mode

- Reference in Europe: MOX
  - Advantages: experience, stability, fabrication, reprocessing…
  - Drawback: thermal properties (low conductibility)

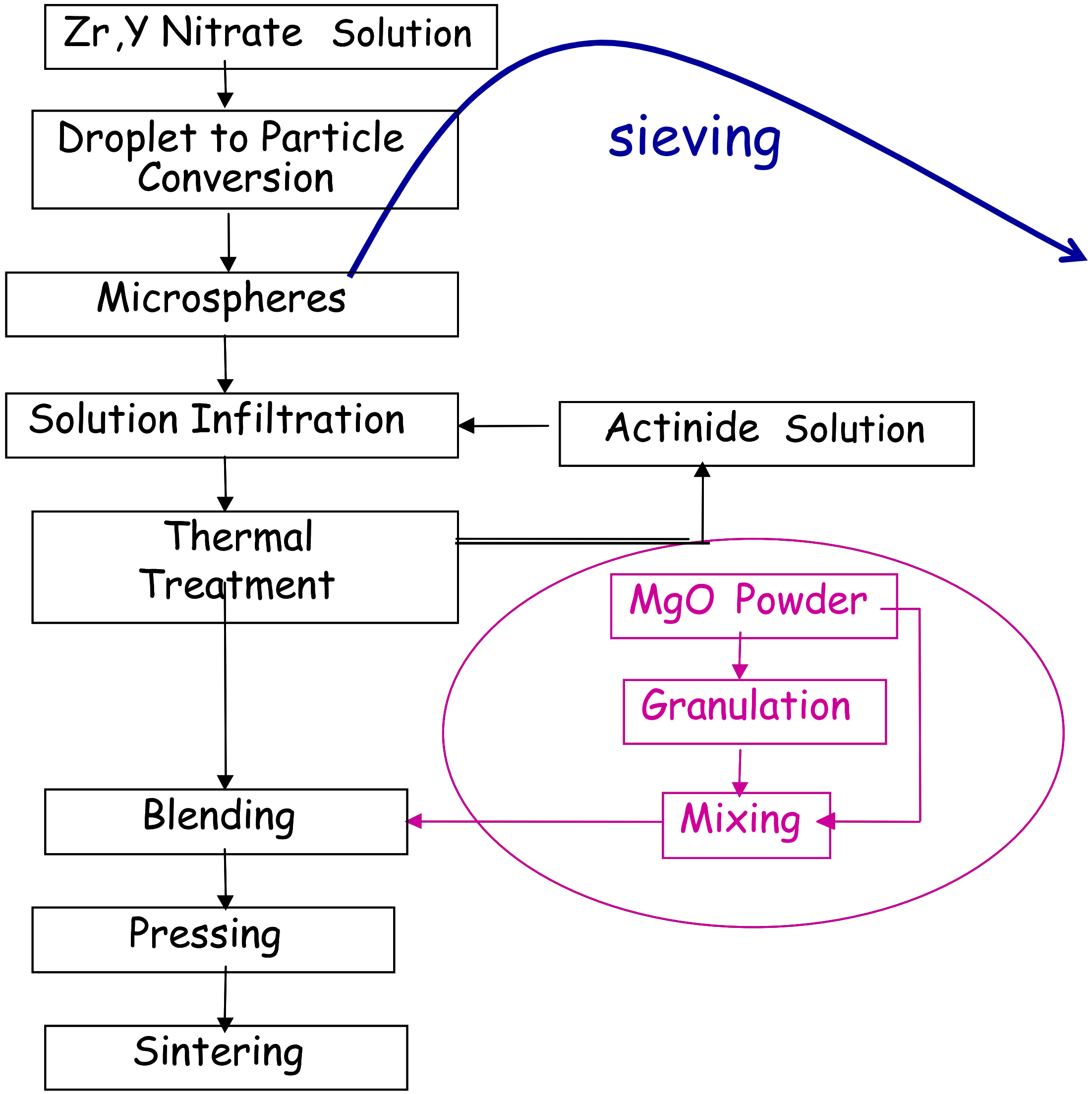
- Other fuels: metals, carbides, nitrides

- Challenge: licensing of MA- bearing fuels (chemical stability, He production…)

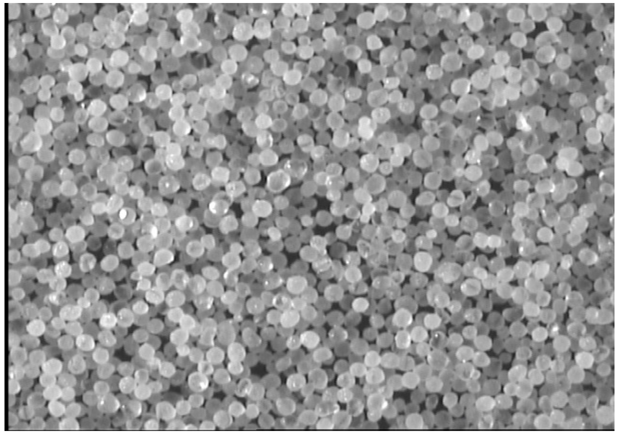
- High burnup: advanced cladding materials (e.g. Ferritic: high Cr- low C steels)

- Advanced reprocessing and minor actinides separation

# JRC role in the fuel cycle: solid fuels developments

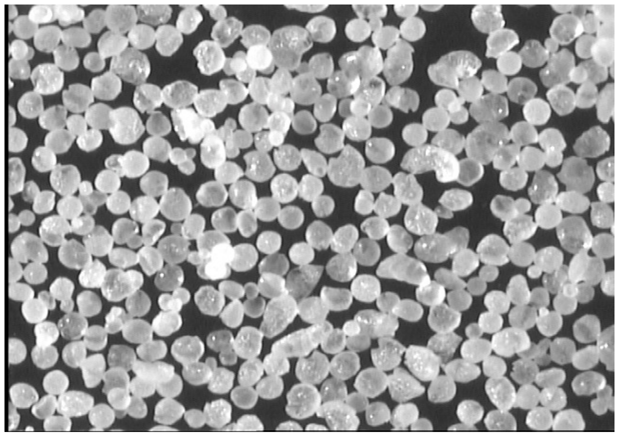



microdispersion



40-60µm

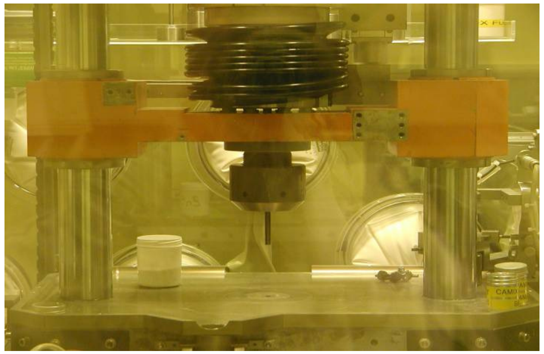
macrodispersion



80-100µm

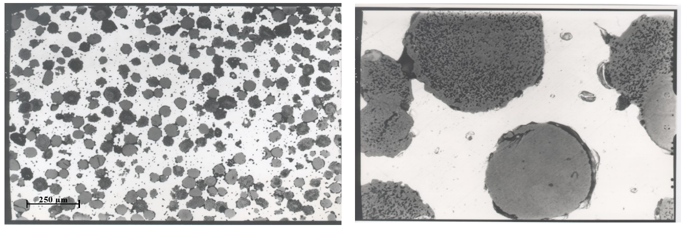
# JRC role in the fuel cycle: solid fuels developments

## Minor Actinide Fuel Fabrication Laboratory

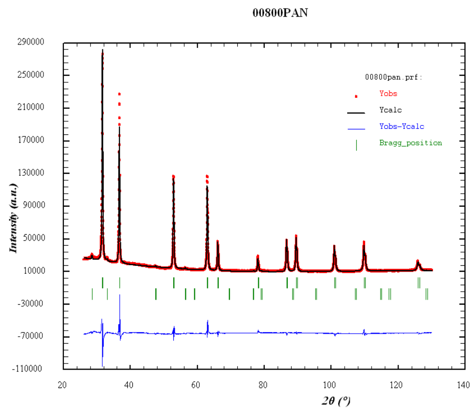


MA Lab press

## Advanced fuel fabrications (ITU)



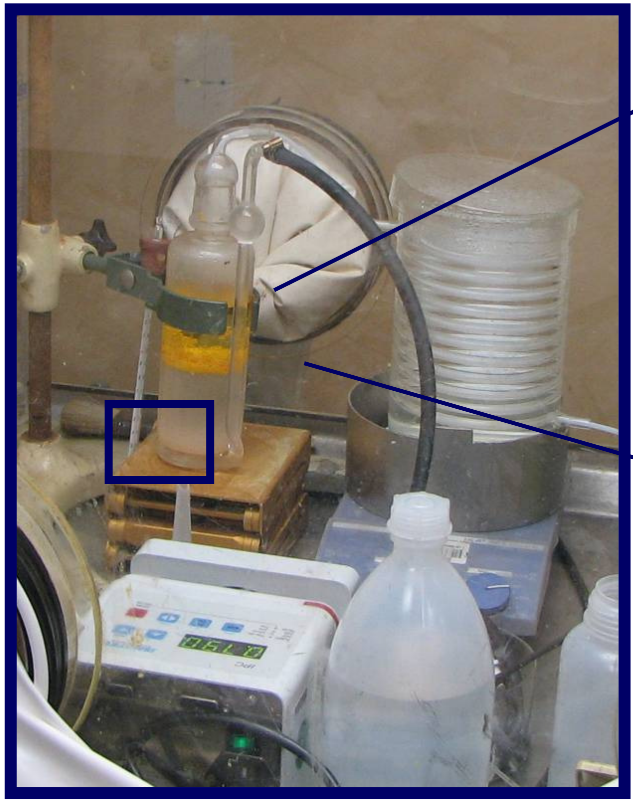

CERMET Am, Pu oxide in Mo matrix

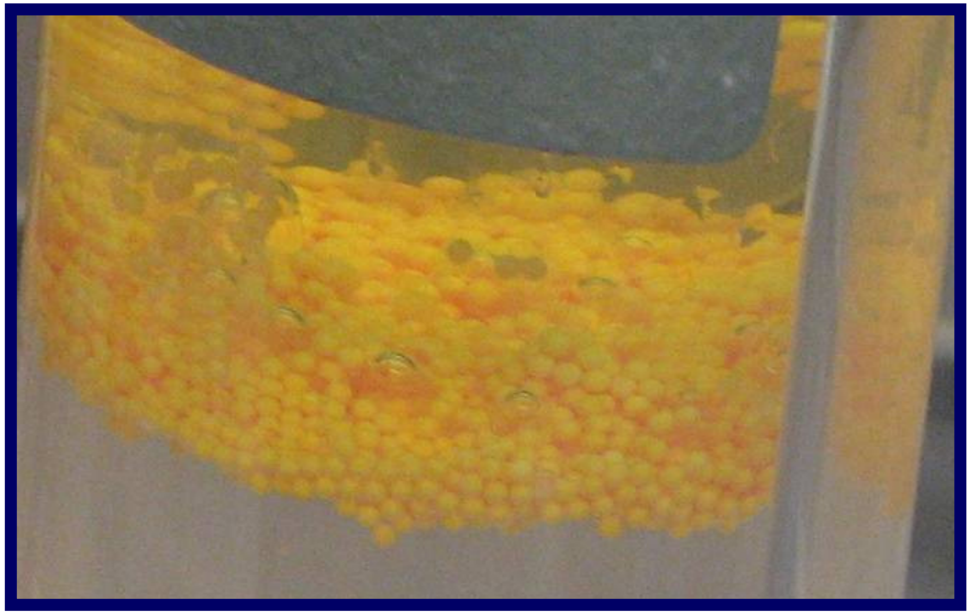



$U_{0.805}Pu_{0.175}Am_{0.02}N$ nitride fuel pellets

# JRC role in the fuel cycle: solid fuels developments

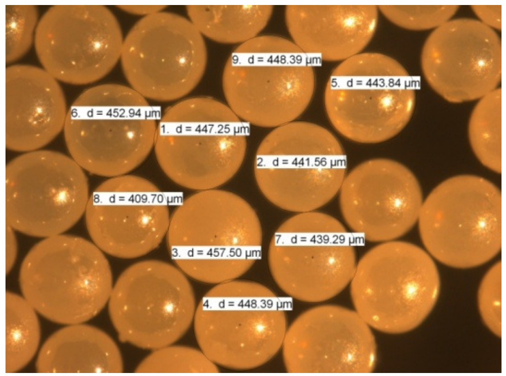
## UO$_2$ microspheres: First tests before infiltration





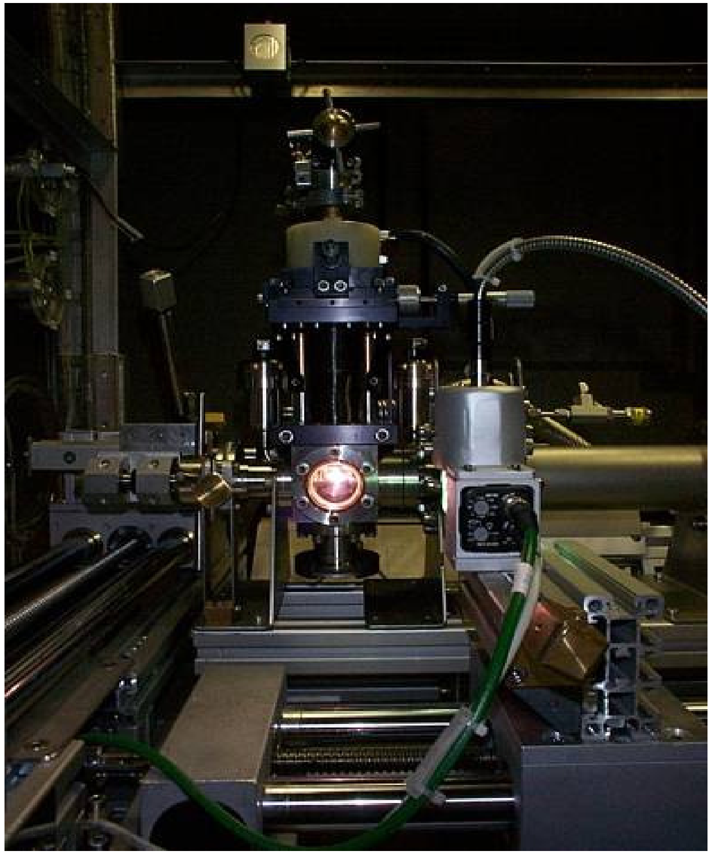
**FP7 SPHERE Irradiation programme in HFR: (U,Pu)O$_2$ Pellets vs Spherepac**

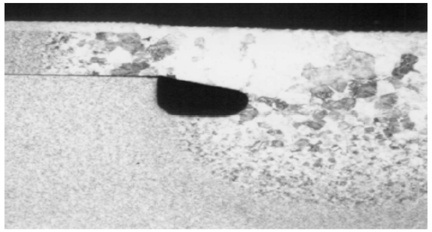
ZrYCe)O2-x
30% Ce Infiltration

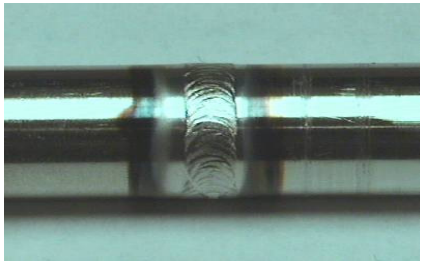


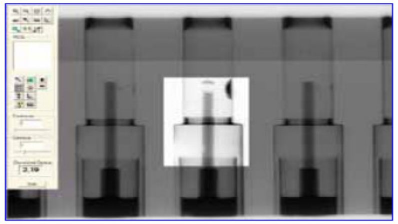
# JRC role in the fuel cycle: solid fuels developments

## Minor Actinide Laboratory: fuel pin fabrication facility

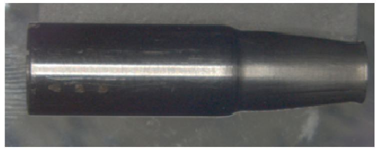








TIG: Tungsten Inert Gas



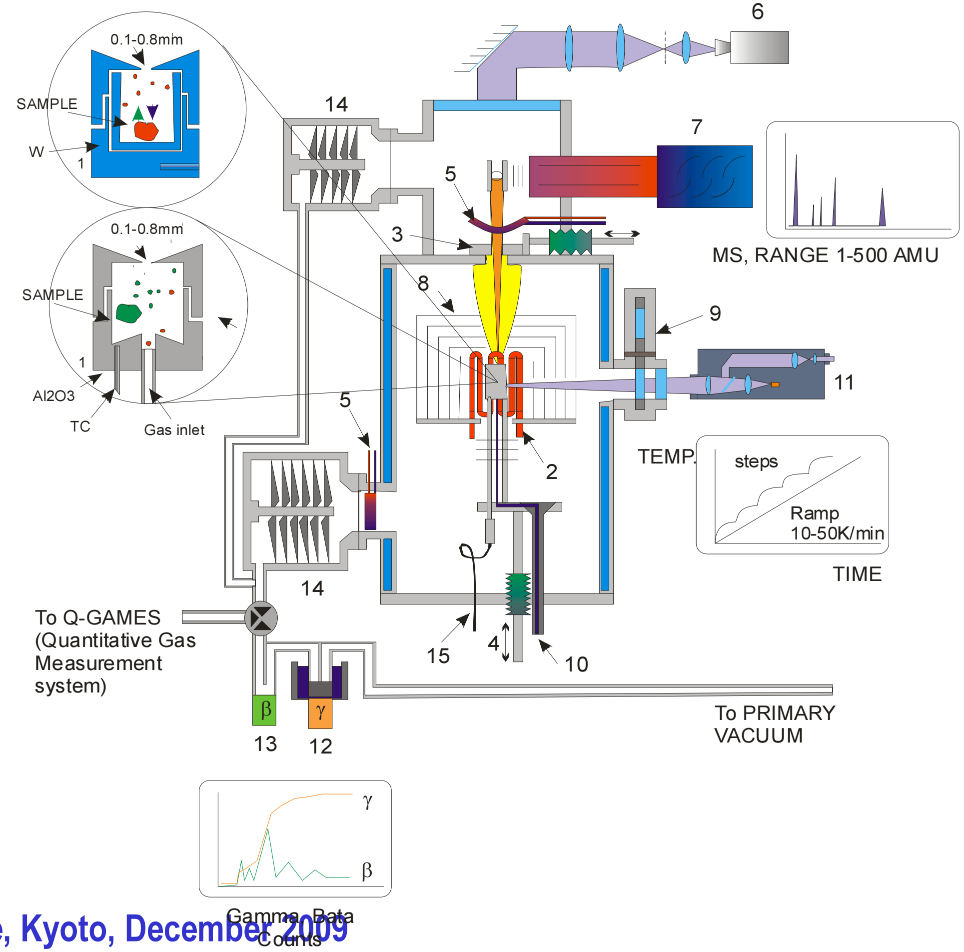
T91 plug-clad joining

R & D on Electromagnetic Pulse Technology

# Knudsen-cell effusion set-up with mass spectrometer

***Various types of cells are used***
***in high vacuum or under controlled, chemically reacting atmosphere up to 3100 K.***

Measurement of **effusion and release** from **irradiated fuel** with temperature programs up to complete vaporization of the sample




*Type of measurements:*

- Equilibrium vapour pressure over the fuel
- Release behaviour and analysis of He, *fg*.

# Effusion behaviour of (Zr, Pu)N

## Knudsen cell

Nitrogen release starts at 1500 K.
Pu release complete above ~2350 K.
Zr vaporizes at the highest temperatures.

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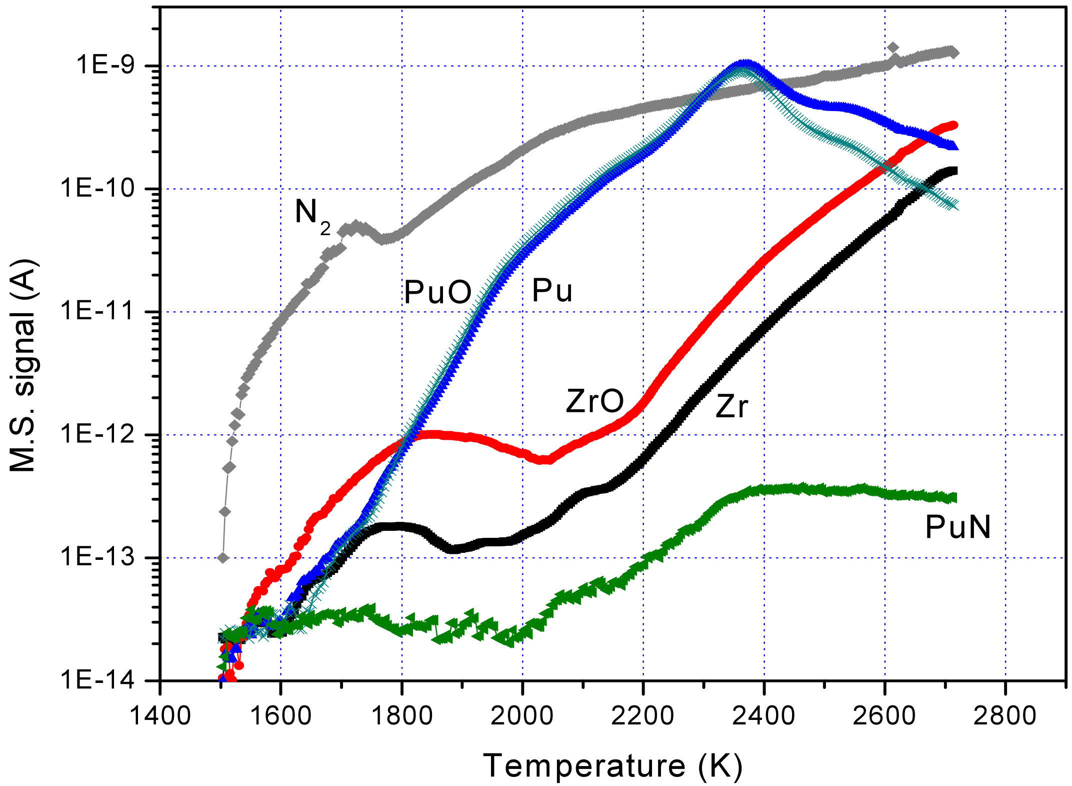
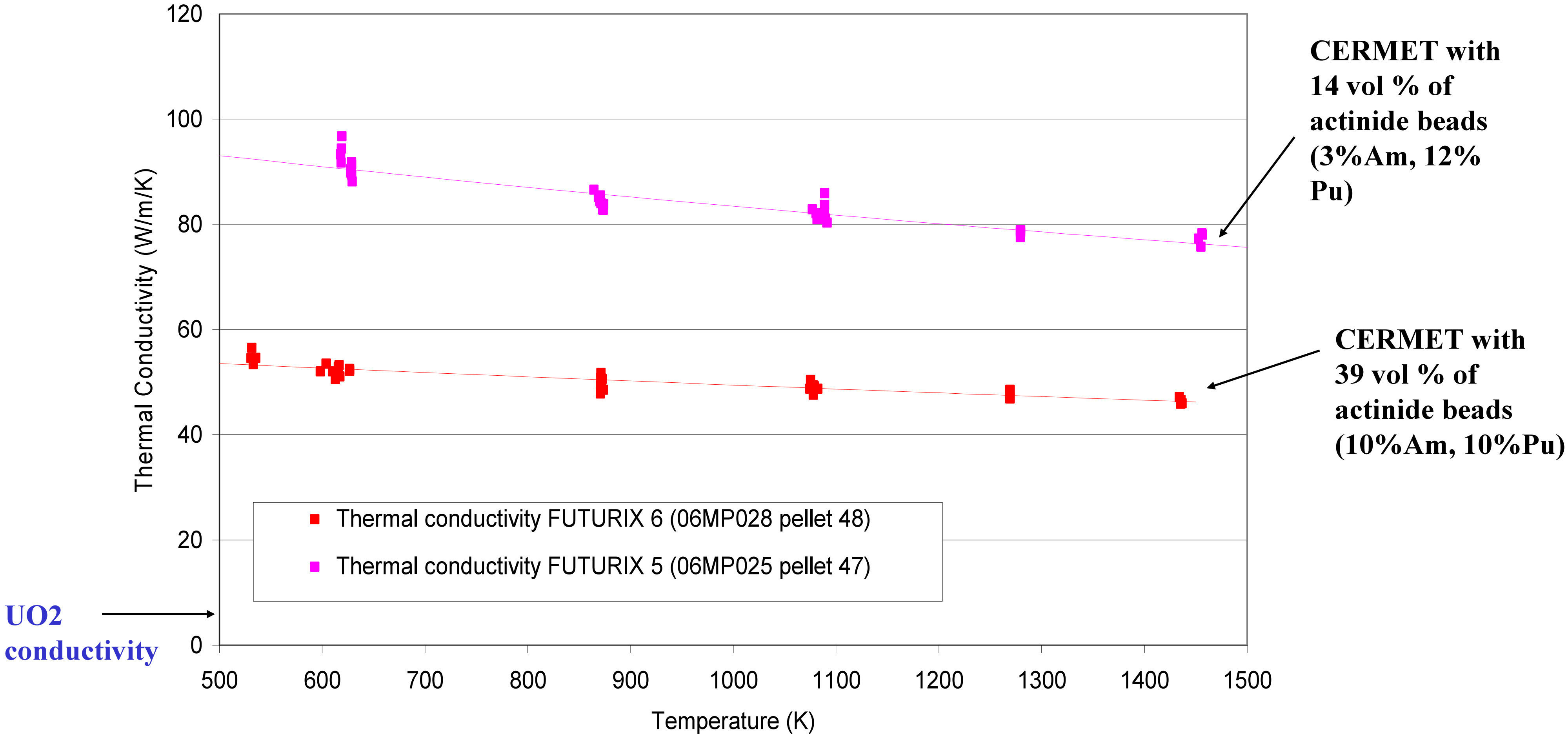



-10 K/min
- vacuum condition

# JRC role in the fuel cycle: solid fuels developments

## Mo-CERMET pellets: Thermal Conductivity (Laser Flash method)

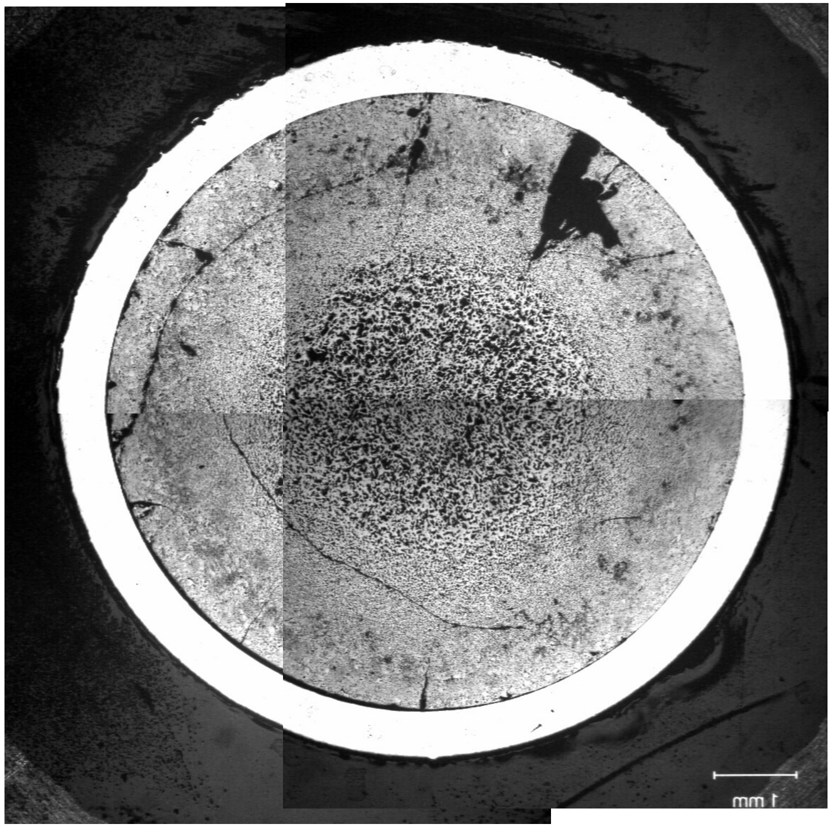



From: Konings & al ICENES 2007

# JRC role in the fuel cycle: solid fuels developments

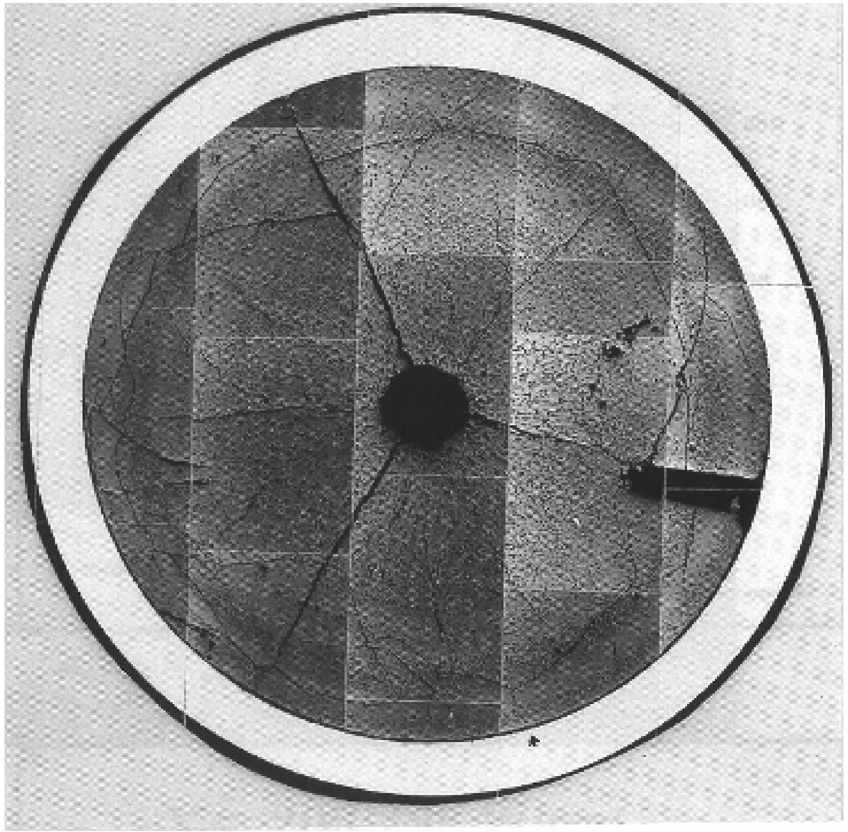
## Nimphe 2 and Superfact experiment in Phenix examined at JRC/ITU

UPuC fuel pin




Low fission gas release, grain size increase
High porosity in the central zone

$(U0.74Pu0.24Am00.2)O_2$ fuel



Excellent fuel behaviour, similar to MOX fuel.

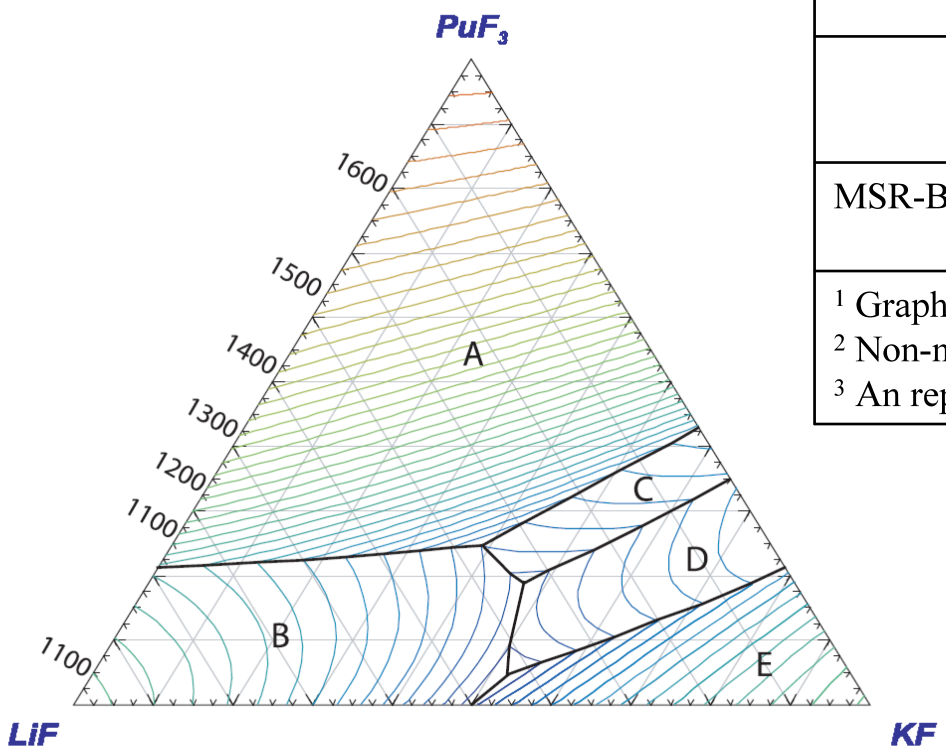
In collaboration with CEA

# JRC role in the fuel cycle: molten salt fuel properties

| Reactor type | Neutron spectrum | Reference fuel | Alternatives |
|---|---|---|---|
| MSR-Breeder | Thermal[1] | $^7LiF$-$BeF_2$-U,$ThF_4$ | |
| | Fast[2] | LiF-U,$ThF_4$ | LiF-$CaF_2$-U,$ThF_4$ |
| MSR-Burner | Fast | NaF-LiF-$BeF_2$-$AnF_3$ [1] | NaF-LiF-KF-$AnF_3$ [3], NaF-LiF-RbF-$AnF_3$ [3] |

[1] Graphite moderated
[2] Non-moderated
[3] An represents the actinides Pu, Am and Cm

**Fuel salt composition for various MSR concepts**




**Calculated liquid surface of the system $PuF_3$-LiF-KF**

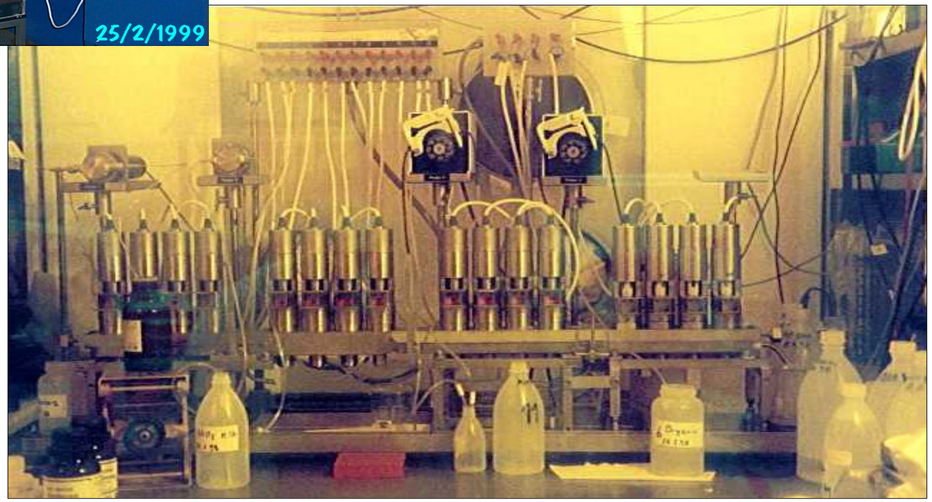
# JRC role in the fuel cycle: advanced fuel reprocessing

spent fuel
↓
dissolved fuel
↓
PUREX → *U / Pu (Np)*
↓ *HLLW*
Ln/MA separation → *FP*
↓ *Ln / MA*
MA separation from Ln → *Ln*
↓ *MA*
transmutation


Hot Cell Laboratory for the characterisation of spent nuclear fuel by aqueous method

| | |
|---|---|
| CMPO | USA |
| DIDPA | Japan |
| TRPO | China |
| DIAMEX | France |
| TODGA | Japan |

| | |
|---|---|
| DTPA | China |
| TPTZ | France |
| ClΦ DTPA | FZJ |
| BTP | FZK |
| BTBP | UK |

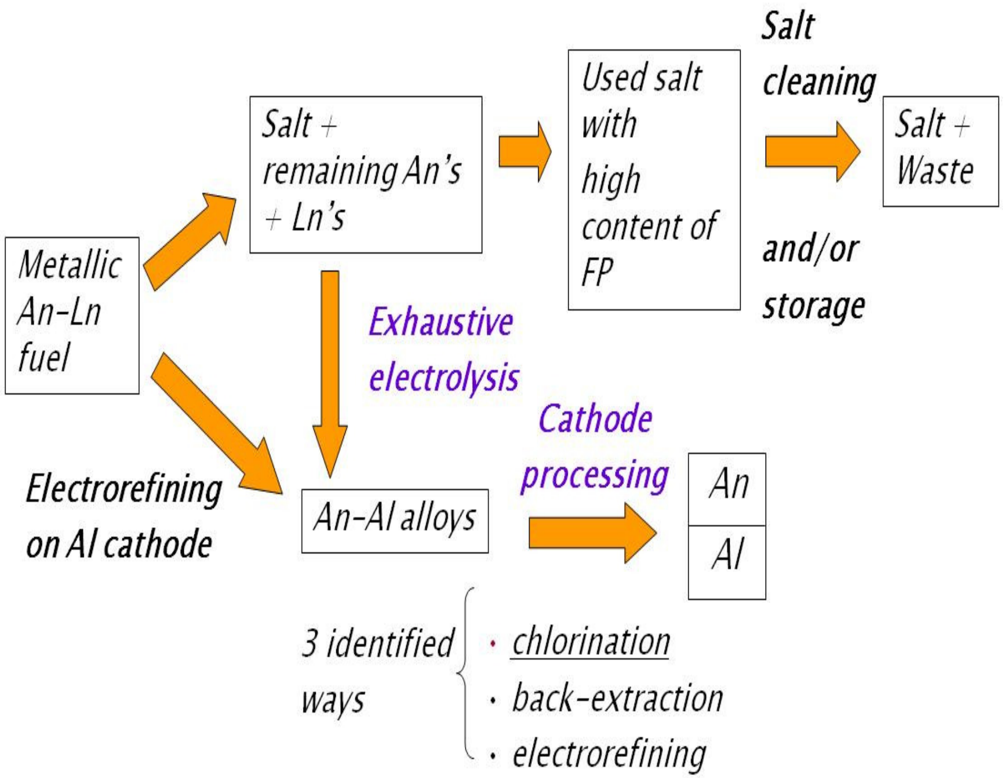


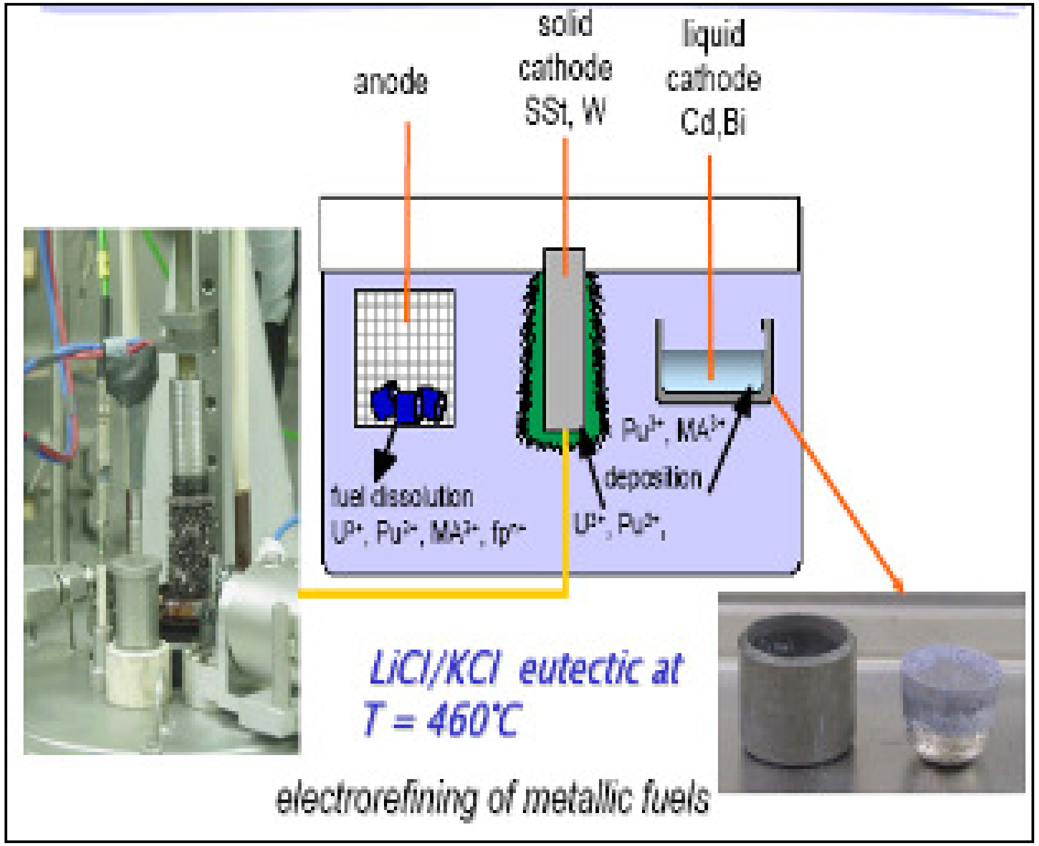
centrifugal extractor battery for continuous counter-current extraction

*Cm and Am recoveries ~ 99.9 %*

# JRC role in the fuel cycle: advanced fuel reprocessing

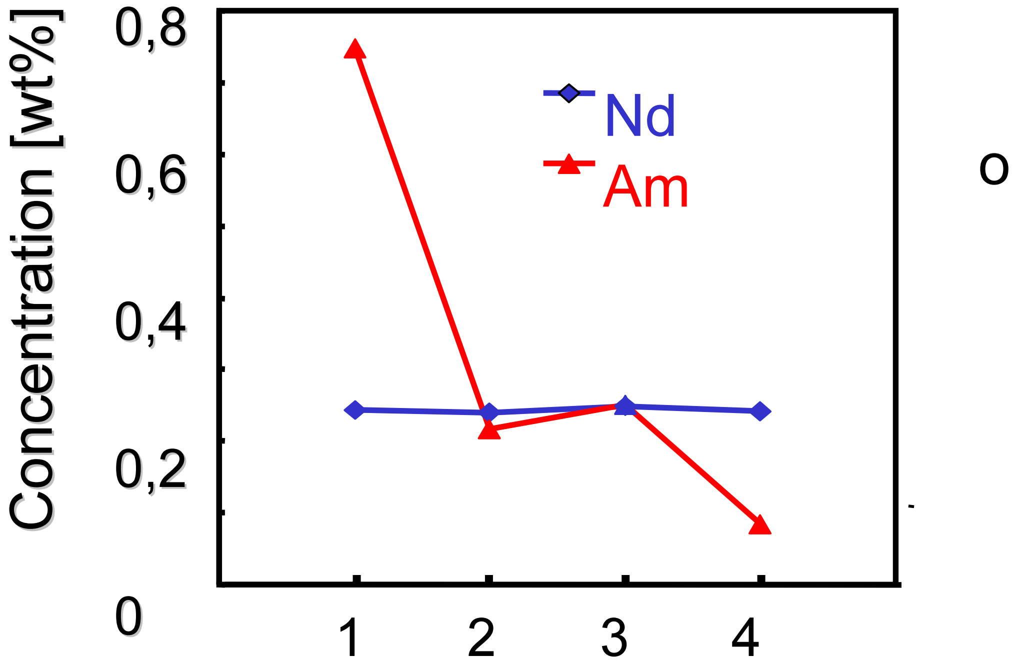
## Process scheme for electro-refining of metallic fuel



# JRC role in the fuel cycle: advanced fuel reprocessing

## Am/Nd separation by electrodeposition on Al cathode

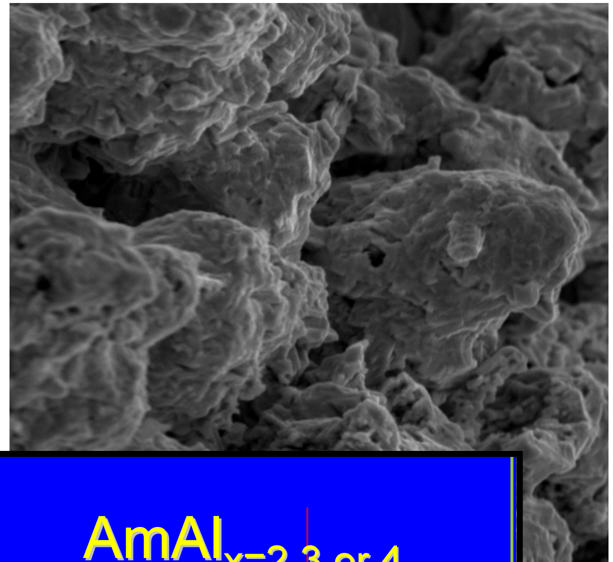


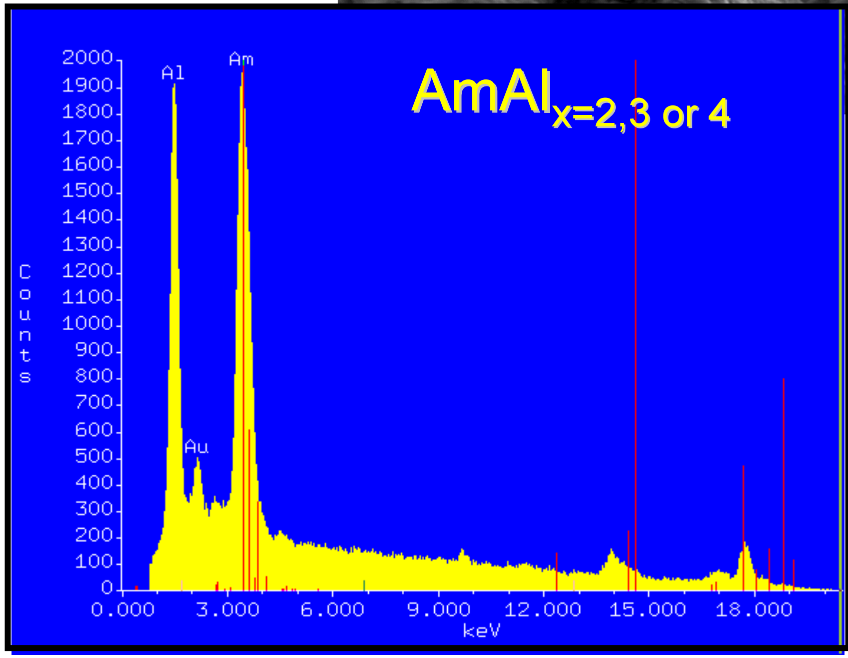

Am and Nd concentration in LiCl/KCl

1: before 1st electrolysis
2: after 1st electrolysis
3: before 2nd electrolysis
4: after 2nd electrolysis

**Efficient separation of MA from Ln by electrolysis !!!**

Am deposit on Al cathode



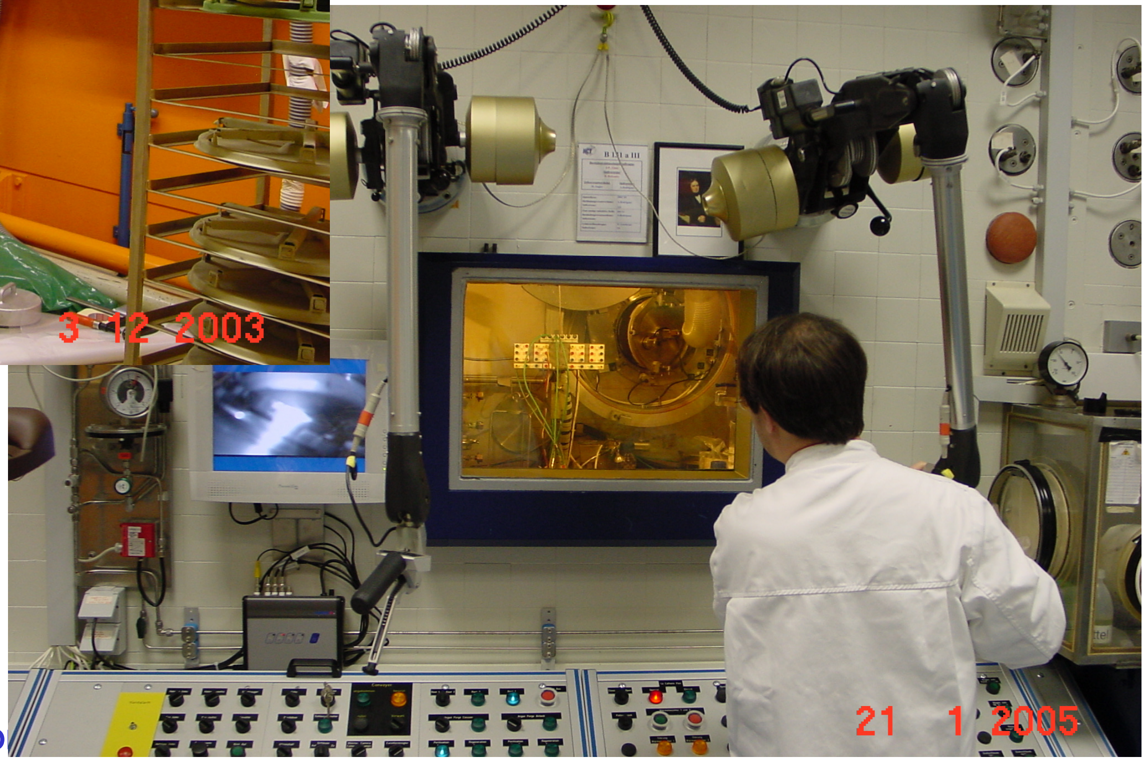



SEM / EDX measurement of solid Al cathode

# JRC role in the fuel cycle: advanced fuel reprocessing

## Pyro-reprocessing cell


Installation of Caisson (2003)




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

# Conclusion

- Long-term resources availability and reduction of waste hazards favour the development of fast reactors

- The European Sustainable Nuclear Industrial Initiative aiming at the developement of the fast neutron reactors has been launched within the Strategic Energy Technology Plan

- Fast reactor systems considered: sodium, helium, lead or molten salt

- The R&D is being pursued in agreement with the GIF targets, through indirect actions partly financed by EURATOM/RTD and direct actions of the JRC

- JRC (ITU-Karlsruhe) is mainly involved in fuel cycle studies (fuel fabrication and properties, partitioning)

- Other JRC activities are related to design and safety, structural materials, PRPP, basic science

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# Conclusions

- Overall efforts for the successfull development of new fast reactor fuels will remain enormous

- The main financial contribution comes from the national organisations. EURATOM funding represents about 20%

- JRC contributes through its large experience and high quality equipment in specific fields

- Any future development will require international collaborations. EURATOM has put in place the possible framework for it, both at an European level (SNETP and joint projects), and internationally (JRC is the implementing agent for the EURATOM participation in GIF)