Fast Reactor Fuel Development in Europe

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Foreword

Extended Fast Reactor fuel development in Europe
Focus on Sodium Fast Reactors
Main contributors: France, United Kingdom, Germany, Belgium, Netherlands, EC
Reactors operated in France, United Kingdom, Germany
Past research exclusively on Pu-bearing fuel with pin geometry
Reference was oxide fuel (MOX) + R & D on nitrides, carbides
Existing data base is huge and will not be reported here

This presentation concentrates on new designs, with minor actinides fuels

Outline

- EUROPEAN framework on MA fuel research
- Fuel and Cycle Options
- Achievements from the past and present
- Looking towards the Future

Fast Reactor Fuel Research in Europe: performed through

EURATOM Indirect Actions DG RTD

GCFR, GOFAST: GFR
EISOFAR, ESFR: SFR
ELSY, LEAD: LFR (reactor design only)
EUROTRANS: transmutation fuels
FAIRFUELS: cross-cutting fuel research
GETMAT: cross-cutting materials research
Carried out by European consortia

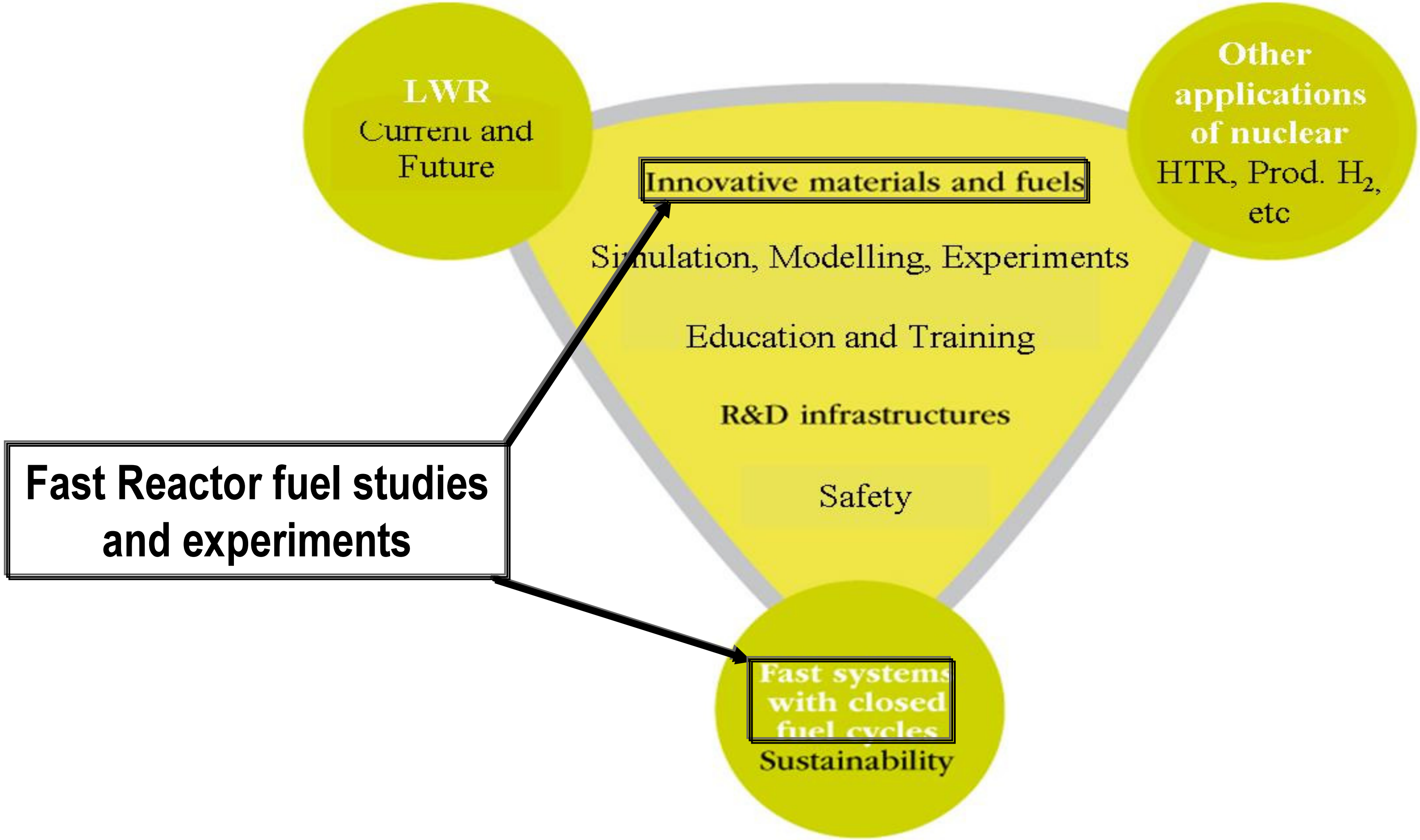
National Organisations

CEA, NRG, PSI, SCK/CEN…

EURATOM Direct Actions DG JRC

Institute for Transuranium Elements (Karlsruhe)
Institute for Energy (Petten)

Sustainable Nuclear Energy Technology Platform SNETP



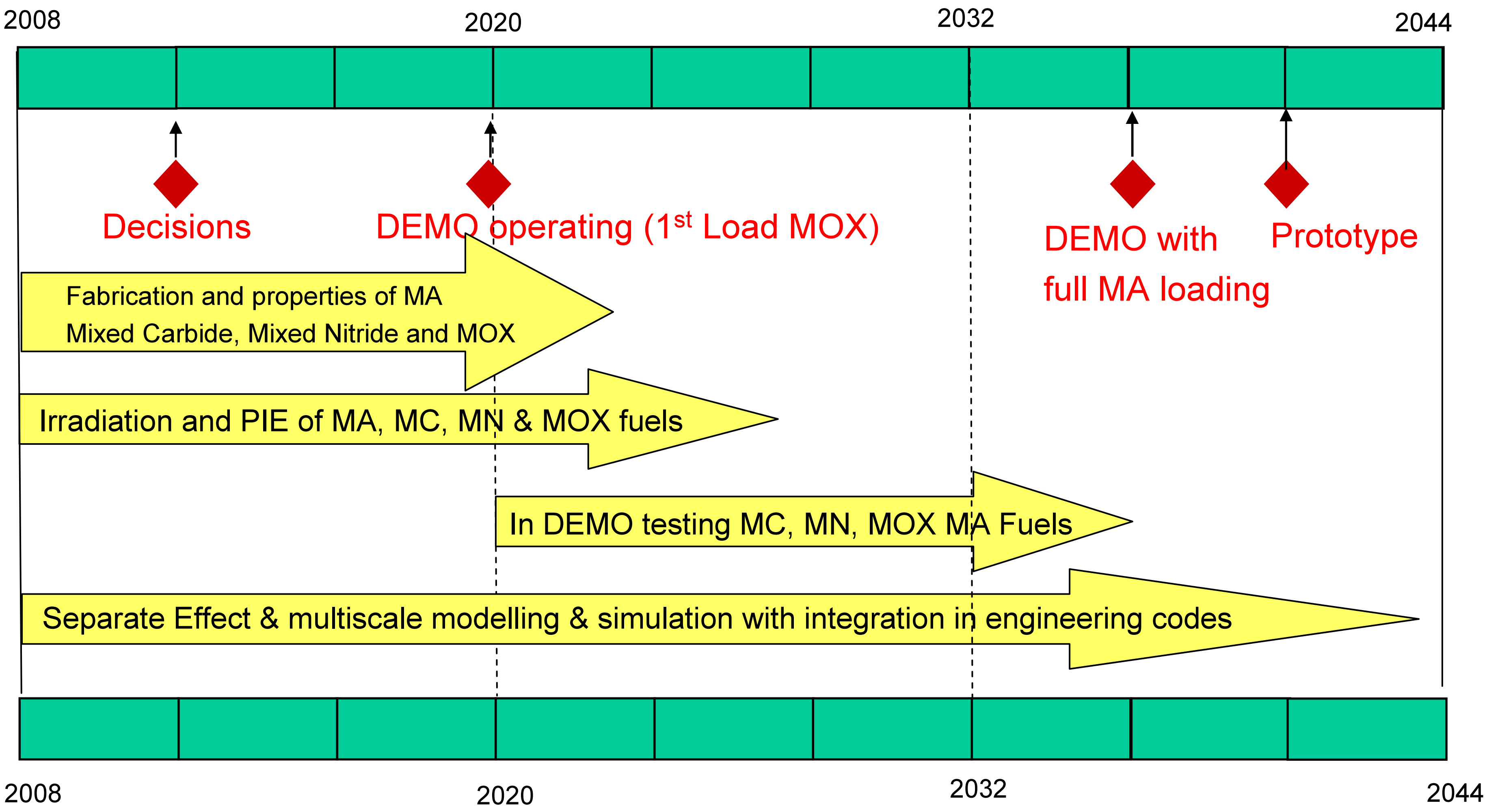
SNETP Strategic Research Agenda SRA

- Fuel for fast reactors have many commonalities

- The SRA has defined 3 pillars for cross cutting fuel R&D:

  - Properties of Minor Actinide fuels
  - Multi-purpose irradiation experiments
  - Separate effects and modelling

Strategic Research Agenda : time frame for fast reactor fuel development



Fuel and Cycle Options

Fuel requirements are based on:

- **Neutronics and core physics**
  - Safe operation, breeding ratio
- **Material properties**
  - Fabrication feasibility
  - Margin to melt (T_f, λ, C_p)
  - Mechanical and chemical properties
  - Interaction with coolant
  - Interaction with cladding (chemical and mechanical)
- **Irradiation Performance**
  - High burnup
  - Swelling behaviour
  - Relocation/vaporisation behaviour
  - Fission Products
  - Reprocessability

Candidate fuels for Fast Reactors

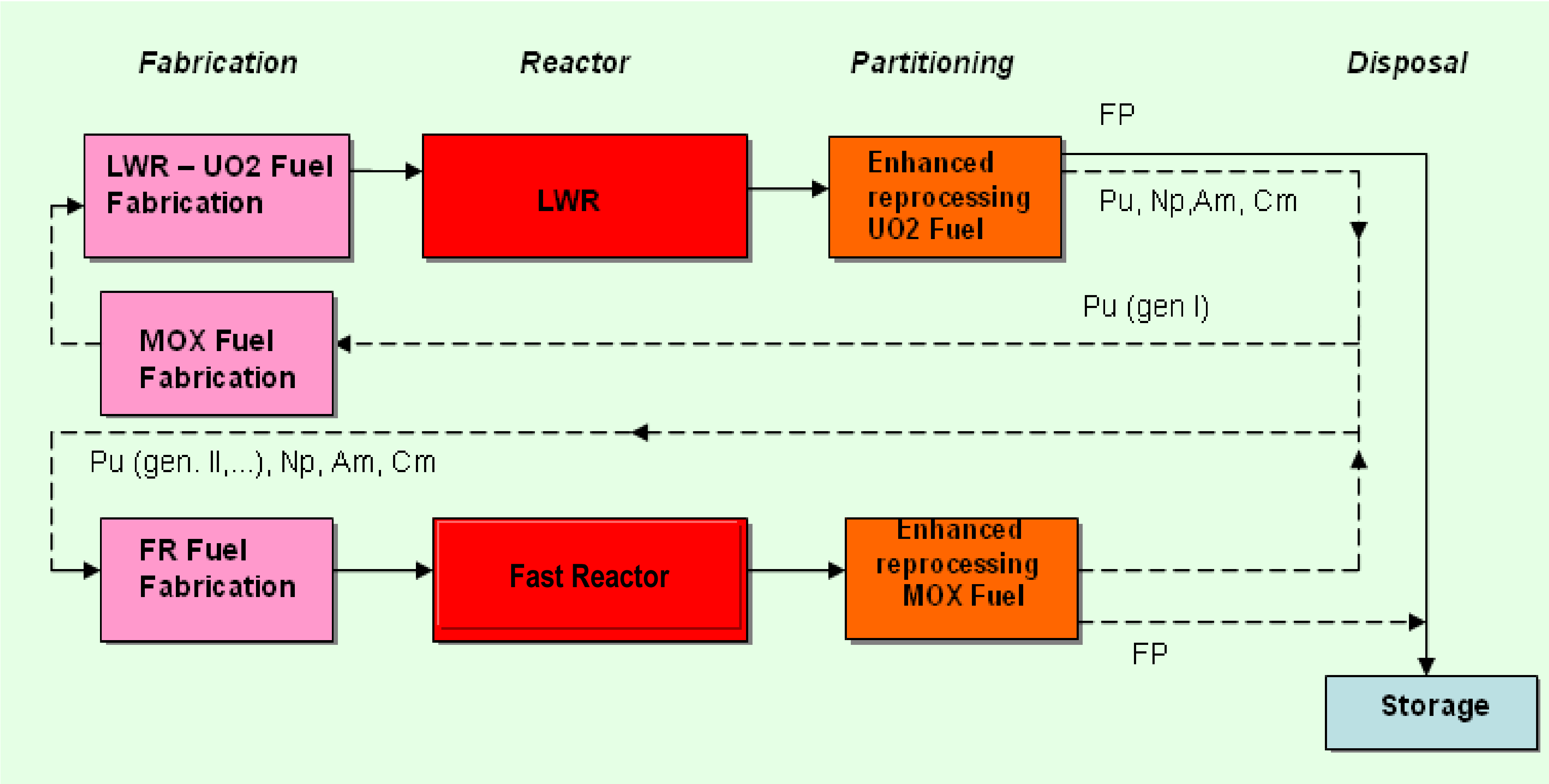
Fuel properties (U,Pu)

	Metal	Oxide	Nitride	Carbide
Heavy metal density ($g.cm^{-3}$)	14.1	9.3	13.1	12.4
Melting point (K)	1350	3000	3035	2575
λ ($W.m^{-1}K^{-1}$)	16	2.3	26	20
T centreline (K)	1050	2350	1000	1000

Note: metal fuels with minor actinides are also considered, within international collaboration (FUTURIX, METAPHIX irradiations)

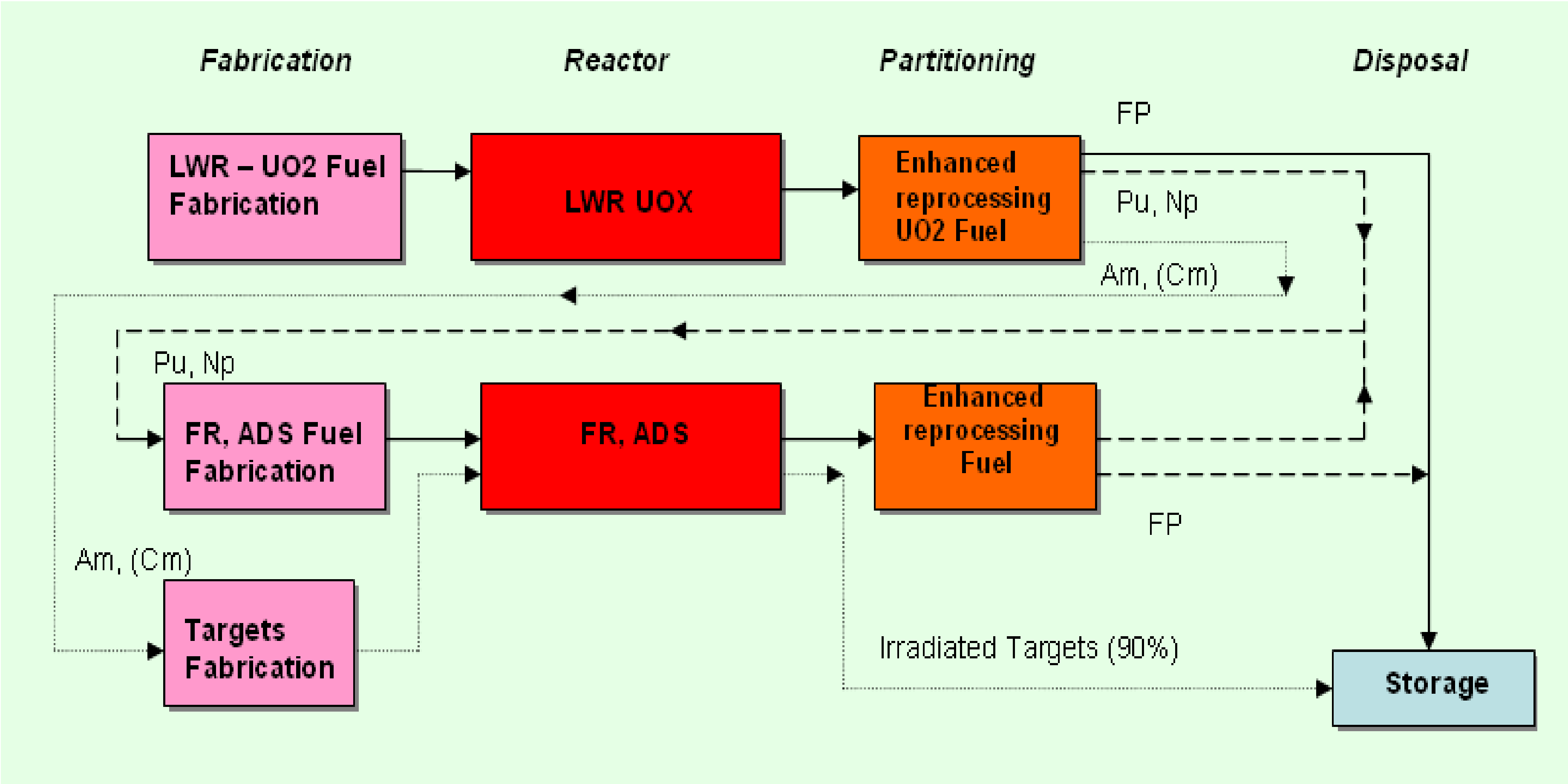
Fuel and Cycle Options

Homogeneous recycling with MA content < 3% in MOX (or MC, MN)

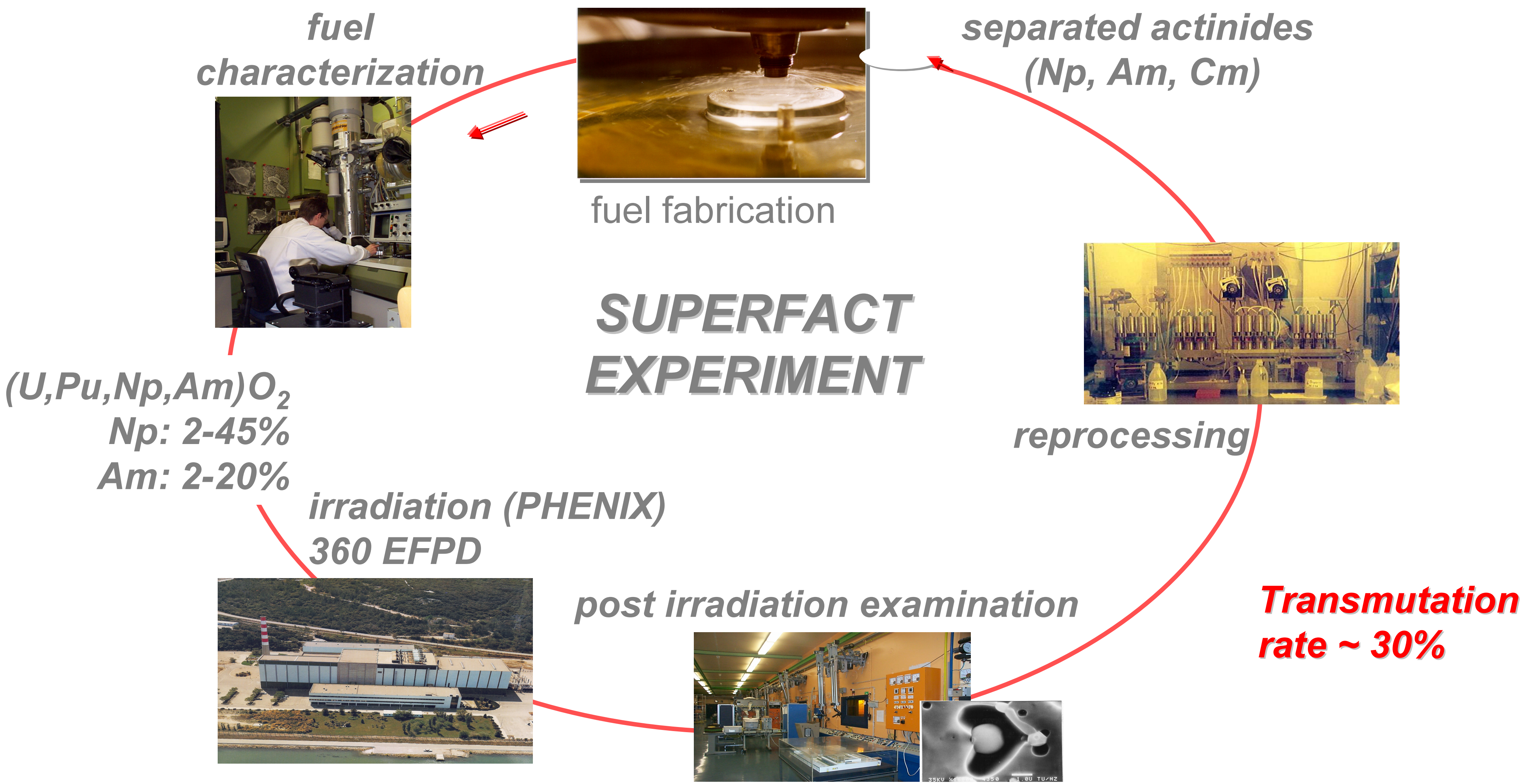


Fuel and Cycle Options

Heterogeneous recycling (MA loaded in „targets“ ,the matrix being UO2 or U-free oxide, or metal)



SUPERFACT: FUEL CYCLE CLOSURE DEMONSTRATION CEA-JRC

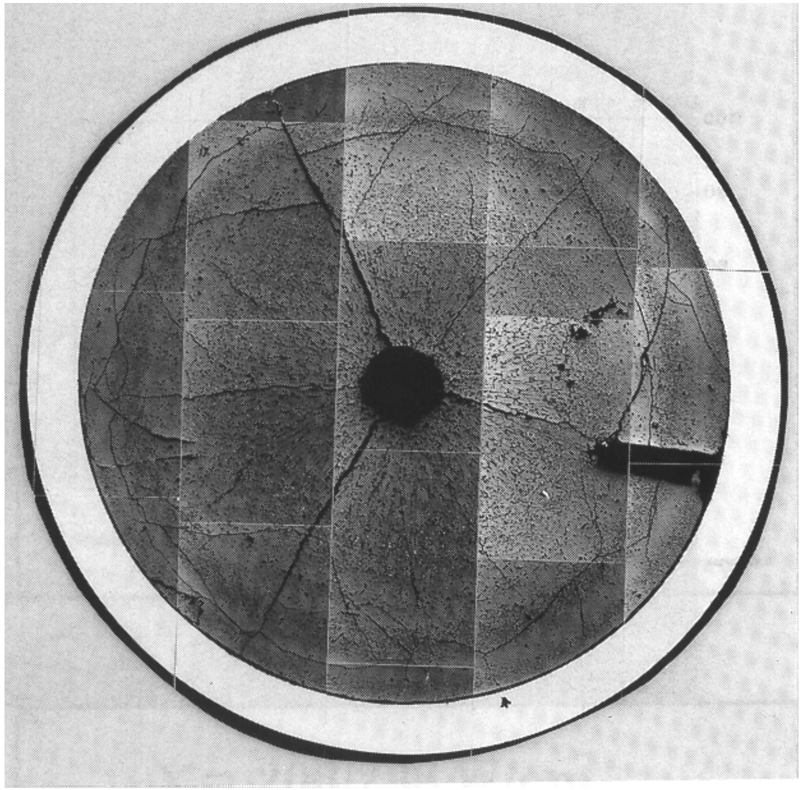


SUPERFACT

Fuel -Materials	$(U_{0.74}Pu_{0.24}Np_{0.02})O_2$
	$(U_{0.74}Pu_{0.24}Am_{0.02})O_2$
	$(U_{0.55}Np_{0.45})O_2$
	$(U_{0.6}Am_{0.2}Np_{0.2})O_2$

- Produced by Sol-Gel Process
- Irradiated in Phenix (4 Cycles)
- Linear power: 174/273 Wcm^{-1}
- Burn up: 4.5 at%

SUPERFACT – A milestone (yet unequalled) irradiation test (CEA/ITU)

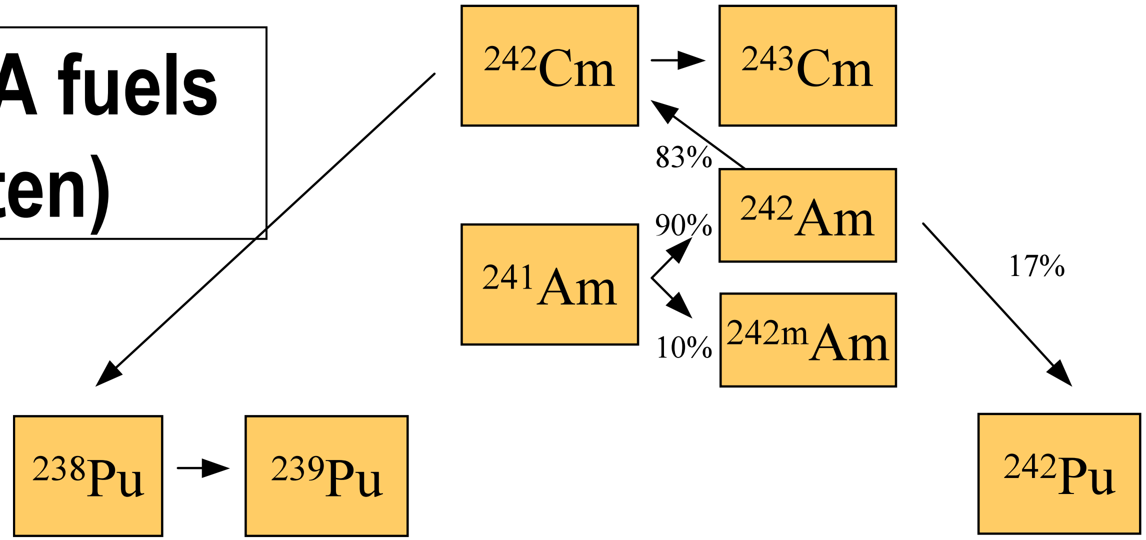


Typical observations for $(U_{0.74}Pu_{0.24}Am_{00.2})O_2$ fuel:

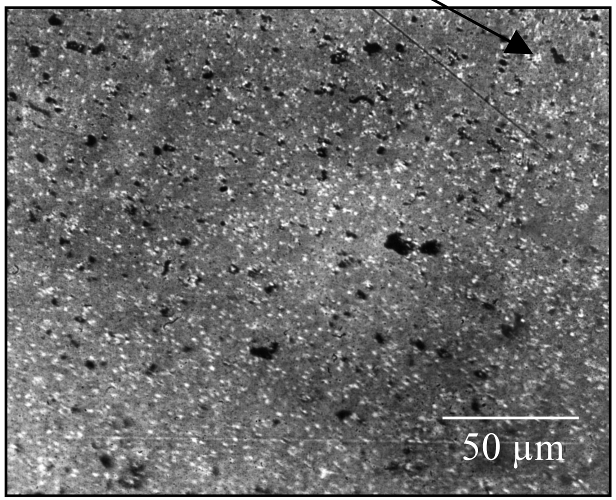
- **Restructuring very similar to that of standard MOX fuel**
- **Pore migration results in central hole formation**
- **U and Pu showed little radial distribution change**
- **He production increased**

HELIUM is an issue in MA fuels EFTTRA T4 (HFR Petten)

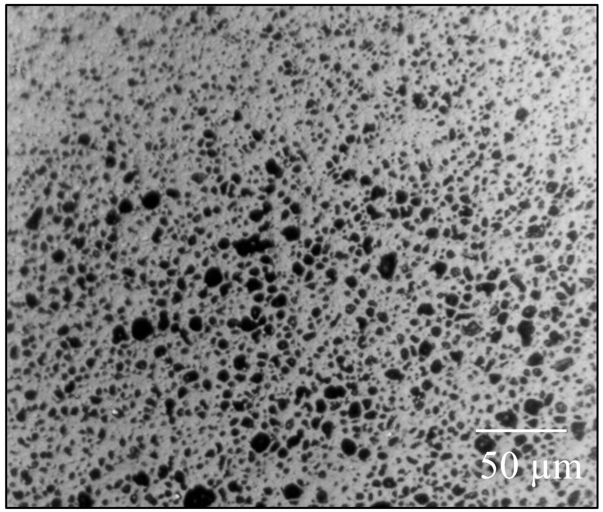
10 w/o Am in Spinel



$AmAlO_3$

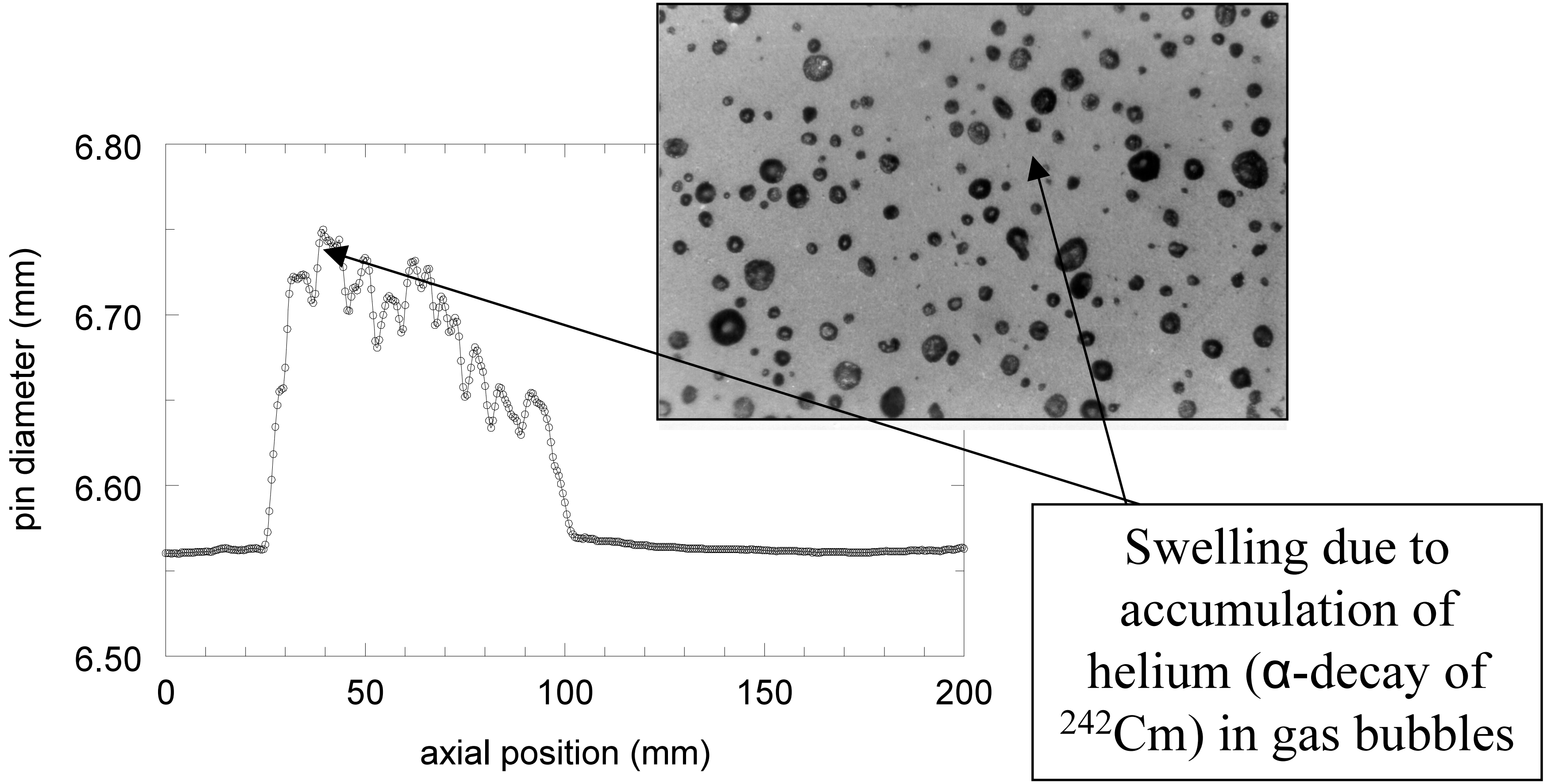


Before irradiation



After irradiation

EFTTRA T4: 10 w/o Am in spinel: effect of He accumulation in the pellets



Konings et al. (2000), J. Nucl. Mat. 282:159

Achievements from the past and present

EFTTRA collaboration CEA-JRC-NRG:
past and current irradiation programmes (Inert Matrix Fuels)

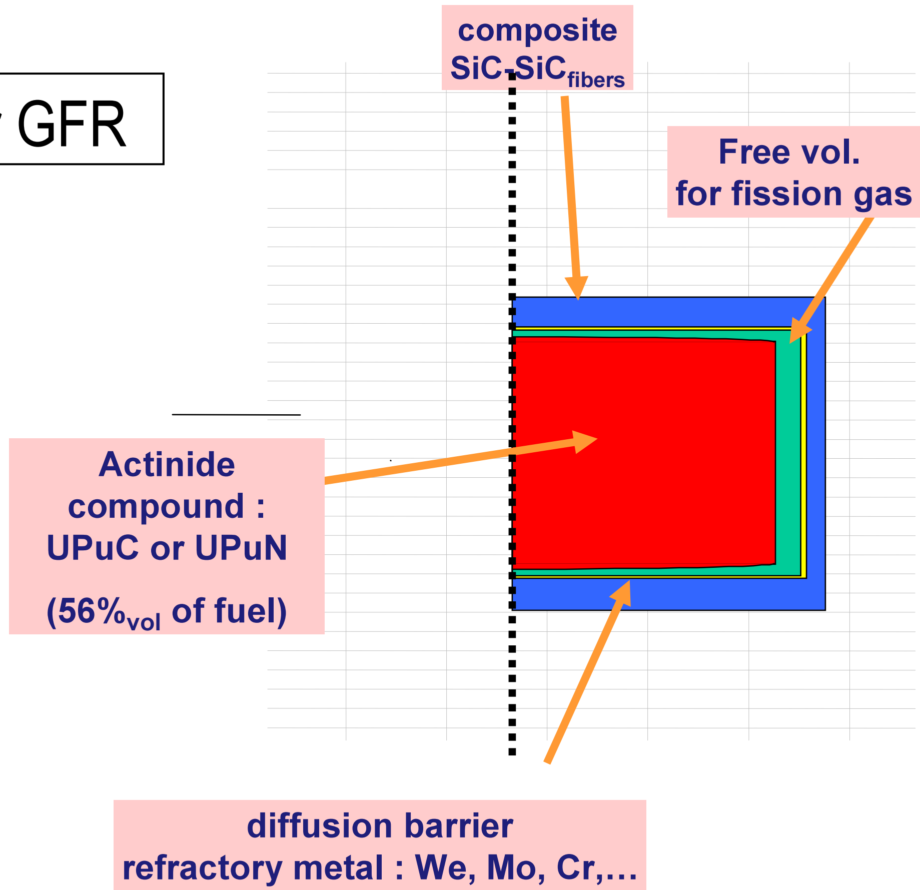
CER	$(Zr,Y,Am)O_2$	Phenix	CAMIX	Irradiated
	$(Zr,Y,Am)O_2$	HFR Petten	HELIOS 2	In pile
	$(Zr,Y,Pu,Am)O_2$	HFR Petten	HELIOS 3	In pile
CERCER	$MgAl_2O_4$ – $AmAlO_3$	HFR Petten	EFTTRA T4	PIE complete
	MgO –AmO_2	Phenix	ECRIX- E	PIE ongoing
	MgO –AmO_2	Phenix	ECRIX- H	Irradiated
	MgO - $(Zr,Y,Am)O_2$	Phenix	COCHIX	Irradiated
	MgO – $(Pu,Am)O_2$	Phenix	FUTURIX 7	Irradiated
	MgO – $(Pu,Am)O_2$	Phenix	FUTURIX 8	Irradiated
	MgO – $Zr_2Am_2O_7$	HFR Petten	HELIOS 1	In pile
CERMET	Mo – $(Pu,Am)O_2$	Phenix	FUTURIX 5	Irradiated
	Mo – (Zr,Y,Pu,Am)O2	Phenix	FUTURIX 6	Irradiated
	Mo – $(Pu,Am)O_2$	HFR Petten	HELIOS	In pile
	Mo – (Zr,Y,Pu,Am)O2	HFR Petten	HELIOS	In pile

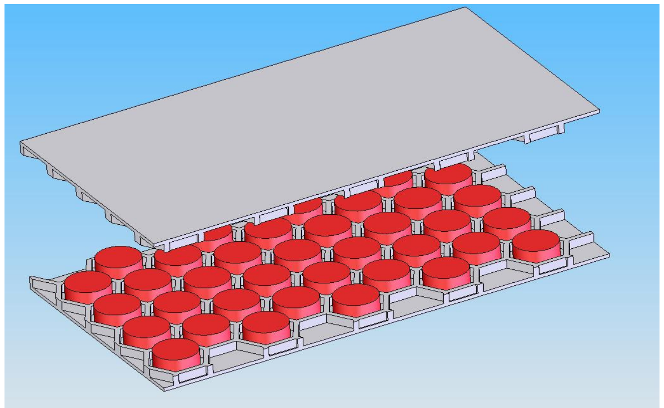
HELIOS 01

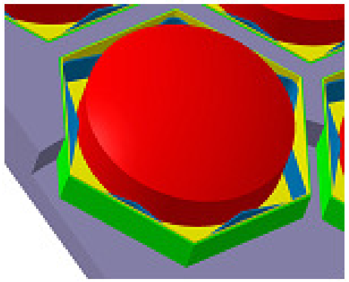
Achievements from the past and present

Non Standard Geometries: Plate fuel for GFR

<u>Axial gap</u> closed at BOL for good heat transfer
<u>Radial gap</u> closed at EOL







CEA Patent

Plate fuel Behaviour

Plate : thermal behaviour at BOL (hottest cell)

Large ΔT in the clad

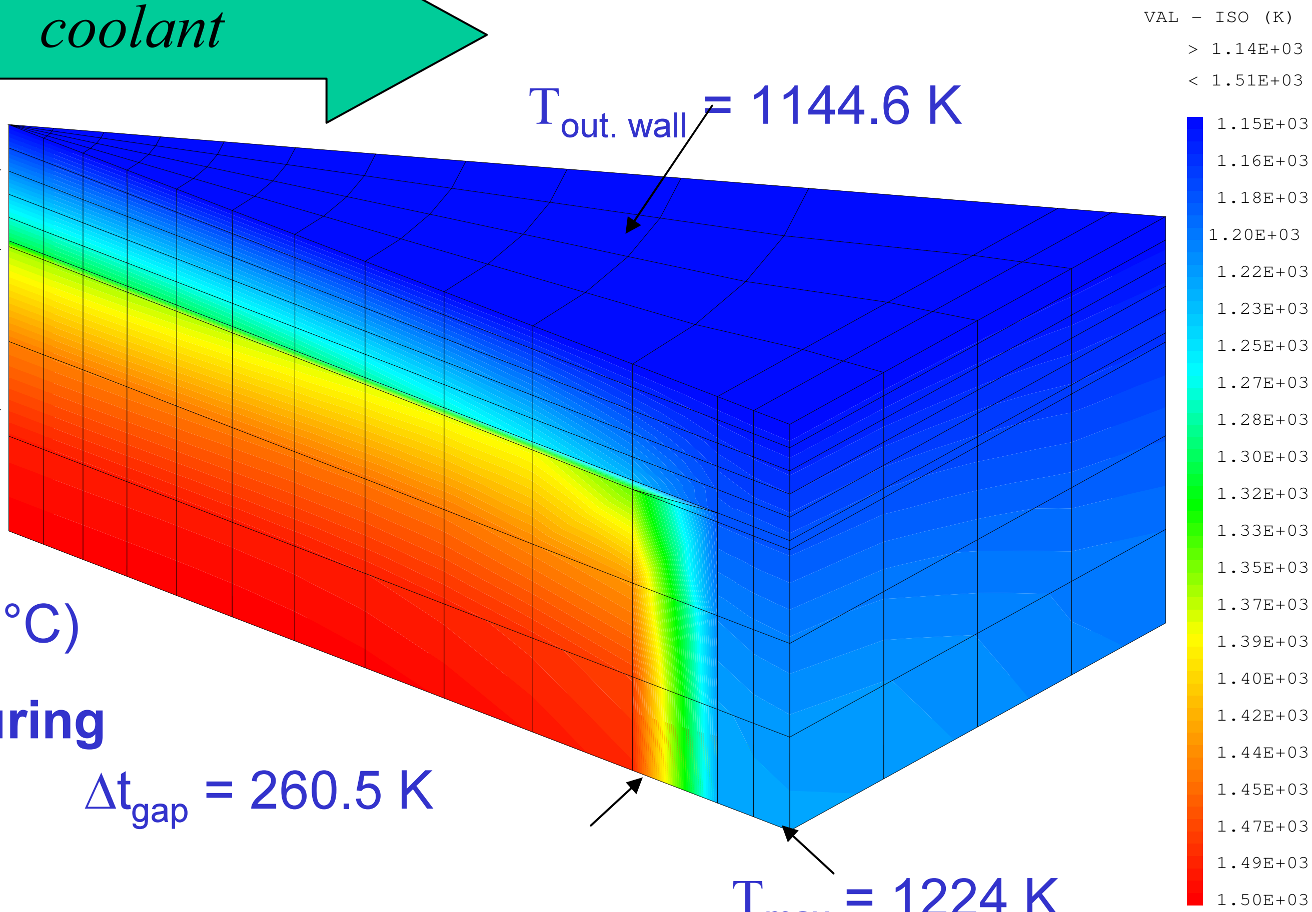
coolant

$T_{out.\ wall}$ = 1144.6 K

Δt_{clad} = 158 K

Δt_{gap} = 58 K

Δt_{fuel} = 146 K



T^{max}_{fuel} = 1507 K (1234°C)

Remains constant during irradiation

Δt_{gap} = 260.5 K

T_{max} = 1224 K

Looking towards the Future

SNETP - Strategic Research Agenda

3 Pillars for cross cutting fuel R&D:

1. **Properties of MA fuel**
2. **Multi-purpose Irradiation experiments**
3. **Separate effects and Modelling**

1. Properties of MA bearing Fuels

GACID (F,US,J): GIF Project

In Europe:

FP7 SFR project "ESFR" (CEA, JRC, NRG)

- Homogeneous MA recycle

Fabrication of (U,Pu, Am)C

(U,Pu, Am)N

Vaporisation behaviour

- Heterogeneous recycle

Fabrication of $(U,Am)O_{2-x}$

Vaporisation behaviour, Melting point, Thermal conductivity

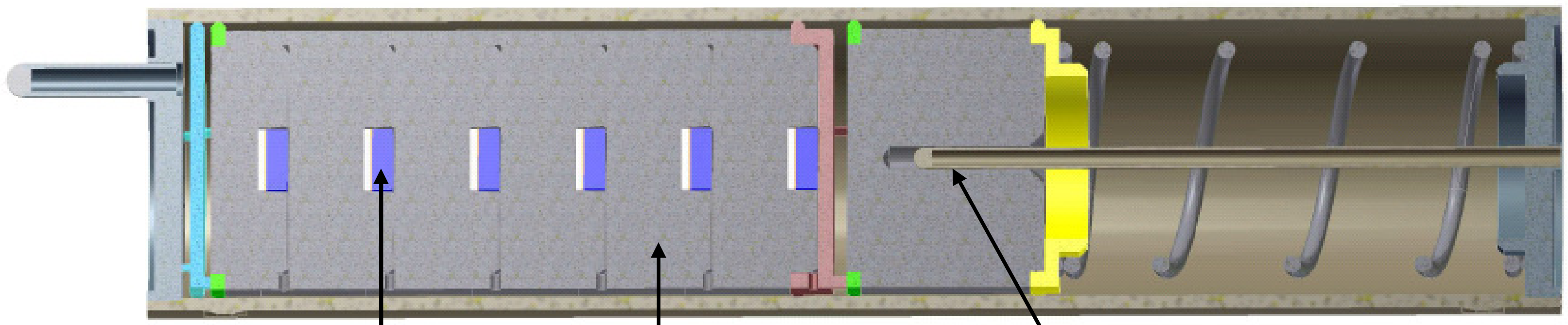
2. Multipurpose Irradiation Experiments starting 2010-2011

FP7 Project FAIRFUELS-MARIOS (CEA/JRC/NRG)

Behaviour of He in (U,Am)O_{2-x} (Heterogeneous recycle)

Samples as disks

Irradiation in HFR Petten



2. Multipurpose irradiation experiments starting 2010-2011

FP7 Project FAIRFUELS-SPHERE (JRC/NRG)

Comparison of (U,Pu,Am)O_2 irradiation behaviour (Homogeneous recycle)

Samples as Pellets
SPHERE PAC

Irradiation in HFR

3. Separate Effects and Modelling

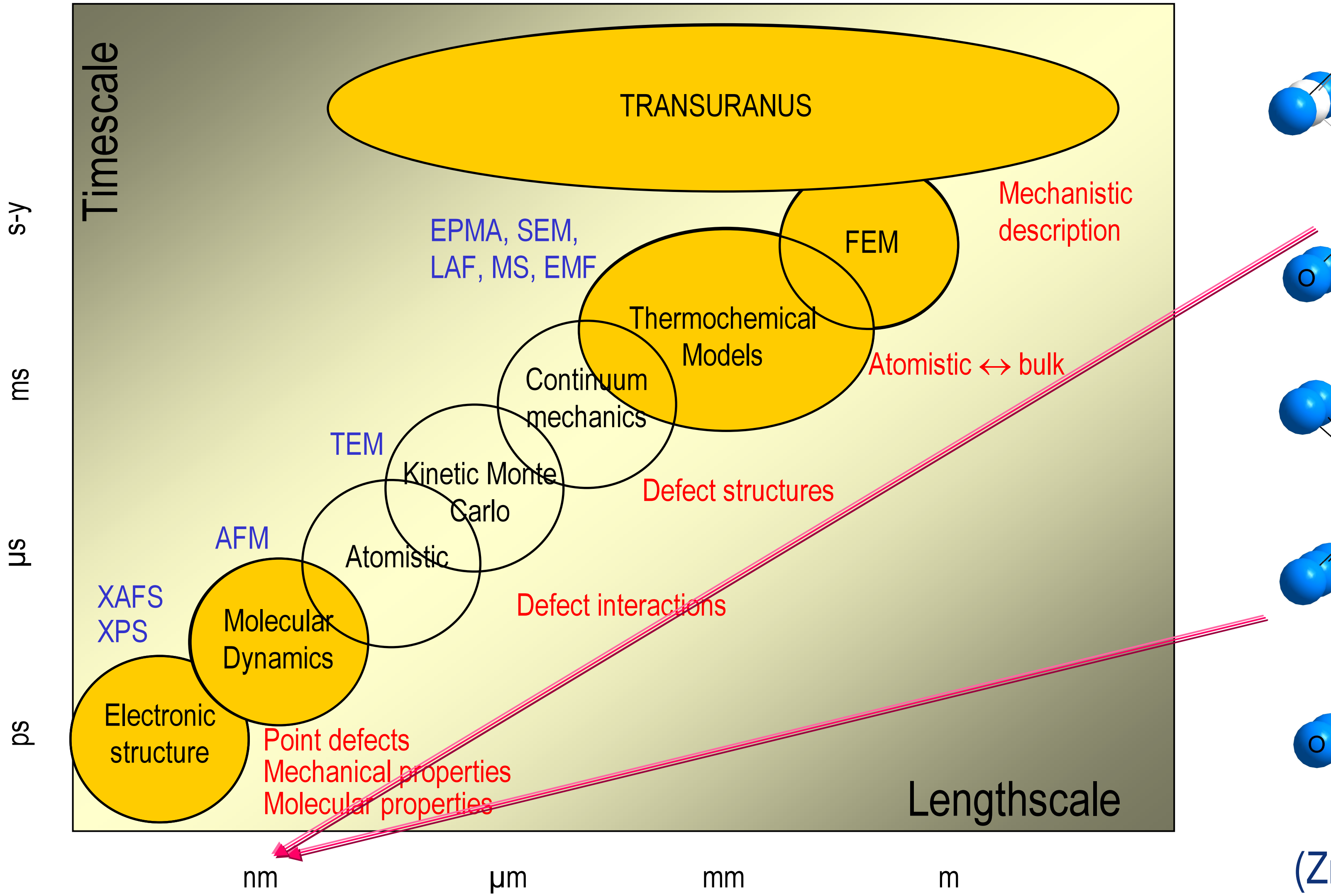
FP7 Project F-Bridge

Multi partner project encompassing

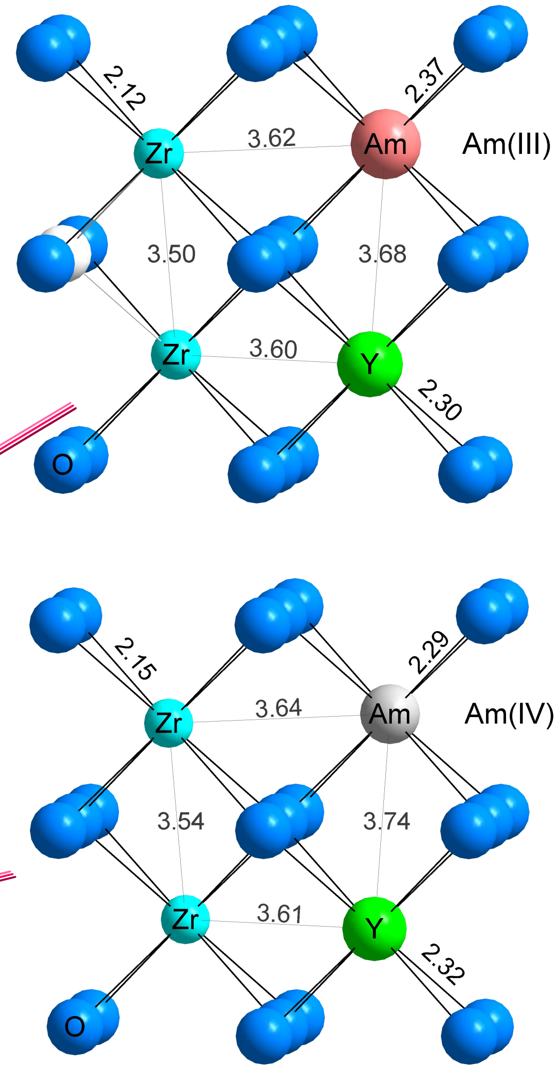
- Material fabrication
- Thermophysical, thermochemical and thermomechanical properties
- Multi scale modelling
  - (nm,ps) ➔ (m, y)
  - Science-driven fundamentals into engineering

Looking towards the Future

3. Separate Effects and Modelling



EXAFS Am(III) and (IV)



$(Zr_{0.67}Y_{0.14}Am_{0.19})O_{2-x}$

Conclusions

- SNETP SRA provides a target for cross-cutting FR fuel research
  - **Properties of MA fuel**
  - **Multi-purpose Irradiation experiments**
  - **Separate effects and Modelling (ab initio to engineering scale)**
- **In the recent past, research concentrated on U-free fuels**
- Today,priortity to fertile fuels in homogeneous or heteregeneous modes
  - **Oxides, nitrides carbides(metals in collaboration)**
- Cladding materials (T91, ODS, SiC)
- Long Lead Times
  - **Licensing, transient testing…**
  - **Need a determined campaign from now**