Minor-Actinides transmutation in an Accelerator Driven System prototype: results from fuel developments within the European integrated program EUROTRANS.

F. Delage, *R. Belin, J.P. Ottaviani (CEA)*
X.-N. Chen, W. Maschek, A. Rineiski (KIT)
E. D'Agata, A. Fernandez, J. Somers, D. Staicu (JRC)
F. Klaassen, S. Knol (NRG)
V. Sobolev (SCK• CEN)
R. Thetford (Serco for UK-NNL)
J. Wallenius (KTH)
B. Wernli (PSI)

OUTLINES:

Objectives & background

Items addressed

In-pile tests results

Major outcomes

Objectives & background for fuel developments

- Objectives of domain AFTRA:

→ Ranking of ADS fuel concepts for European Facility for Industrial Transmutation (400 MWth, U-free fuel, Pb coolant) according to in-pile behaviour, out-of-pile properties, predicted behaviour in normal operating conditions and safety performance

→ Recommendations for the most promising fuel

- Fuel candidates:

  - Emphasis in Europe on oxide-based fuels
    - **reference**: CERCER (Pu, MA)O_2 + MgO and CERMET (Pu, MA)O_2 + ^{enr}Mo
    - solid-solution (Pu,MA,Zr)O_2 as an alternative
    - First development in the frame of the FP5 - FUTURE program: best candidates according to performance, safety and fabricability criteria + synthesis of oxide compounds + out-of-pile characterisation
    - Strong synergy with transmutation target programs (ex: ECRIX-H)
    - Large industrial experience on oxide fuel fabrication for critical reactors
  - Nitride-based fuels (Pu,MA,Zr)N as a backup
    - Development by JAEA (EUROTRANS partner): JAEA ADS fuel compo. ~$Pu_{0.2}Am_{0.3}Zr_{0.5}N$
    - Development in the frame of the FP5 - CONFIRM program: (Am,Zr)N synthesis, irradiation of (Pu,Zr)N pellets in HFR, out-of-pile measurements

Items addressed within AFTRA

SIXTH FRAMEWORK PROGRAMME

- CERCER & CERMET fuel element design and performance assessment:
  - **Pu/MA ratio, IM content, size & configurations of pellets, pins and SAs**
  - **Neutronic and thermo-mechanical behaviour from BOL to EOL**

- Safety Analysis:
  - **transients conditions: ULOF, UTOP, …**
  - **severe accidents**

- In-pile experiments:
  - **PIE on one pin of ADS fuel precursor ($Pu_{0.3}Zr_{0.7}N$), irradiated in HFR ($480W.cm^{-1}$, 10.4at%) within CONFIRM program**
  - ***FUTURIX-FTA test in PHENIX***
  - ***HELIOS test in HFR***
  - ***BODEX test in HFR and Post Irradiation Examinations***

- Out of pile experiments:
  - **Thermal and mechanical properties of CERMET, CERCER fuels**
  - **Chemical compatibility : fuel/clad, fuel/coolant, TRU compounds/Inert Matrices**
  - **Oxygen potential**
  - **Pu-Am-O phase diagram**

Futurix-FTA experiment

- Comparison of irradiation behaviour in EFIT representative conditions for 3 fuel types :

  oxides (european development), nitrides (JAEA development), metallic fuels (US development)

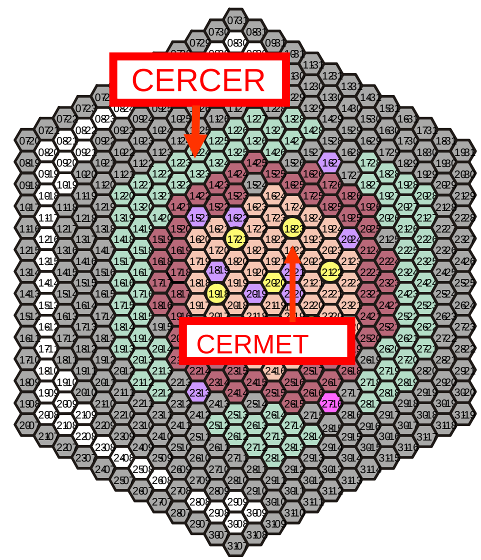
  Collaboration DOE-JAEA-ITU-CEA

- Investigation on MgO-CERCER and Mo-CERMET fuels under EUROTRANS umbrella

Pin nb	composition	Am (g/cm3)	TRU (g/cm3)
5	$Pu_{0.8}Am_{0.2}O_{2-x}$ + 86%vol Mo	0.3	1.3
6	$Pu_{0.23}Am_{0.25}Zr_{0.52}O_{2-x}$ + 60%vol Mo	1.0	1.8
7	$Pu_{0.5}Am_{0.5}O_{2-x}$ + 80%vol MgO	1.0	2.0
8	$Pu_{0.2}Am_{0.8}O_{2-x}$ + 75%vol MgO	1.9	2.5

Test successfully completed in March 2009 after 235 EFPD

- CERMET fuel capsule:
  - Pin 5: LHR ~130W/cm & BU~18at%
  - Pin 6: LHR~130W/cm & BU~13at%
- CERCER fuel capsule:
  - Pin 7: LHR~100W/cm & BU~9at%
  - Pin 8: LHR~90W/cm & BU~6at%



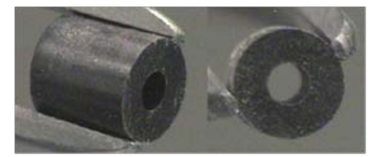
PIE scheduled in FP-7 FAIRFUELS project

HELIOS experiment

SIXTH FRAMEWORK PROGRAMME

- Role of microstructure and T° on fuel swelling as well as helium build-up & release:
  - Pin 1: Am pyrochlore particles (~5-50µm) dispersed in MgO matrix with tailored open porosity
  - Pins 2&3 (T° instrumented): AmO_2 in Yttrium stabilised ZrO_2 crystal lattice w/o Pu
  - Pins 4&5: beads (>65µm) embedded in Mo w/o Pu

Pin nb	composition	µ-structure	Am (g/cm3)	Pu (g/cm3)	Max. T° (°C) estimation
1	$Am_2Zr_2O_7$ + 80 vol%MgO	CERCER		/	650
2	$Zr_{0.80}Y_{0.13}Am_{0.07}O_{2-x}$	Solid-solution			620
3	$Pu_{0.04}Am_{0.07}Zr_{0.76}Y_{0.13}O_{2-x}$		0.7	0.39	1390
4	$Am_{0.22}Zr_{0.67}Y_{0.11}O_{2-x}$ + 71 vol%Mo	CERMET		/	620
5	$Pu_{0.80}Am_{0.20}O_{2-x}$ + 84 vol%Mo	CERMET		1.2	1120

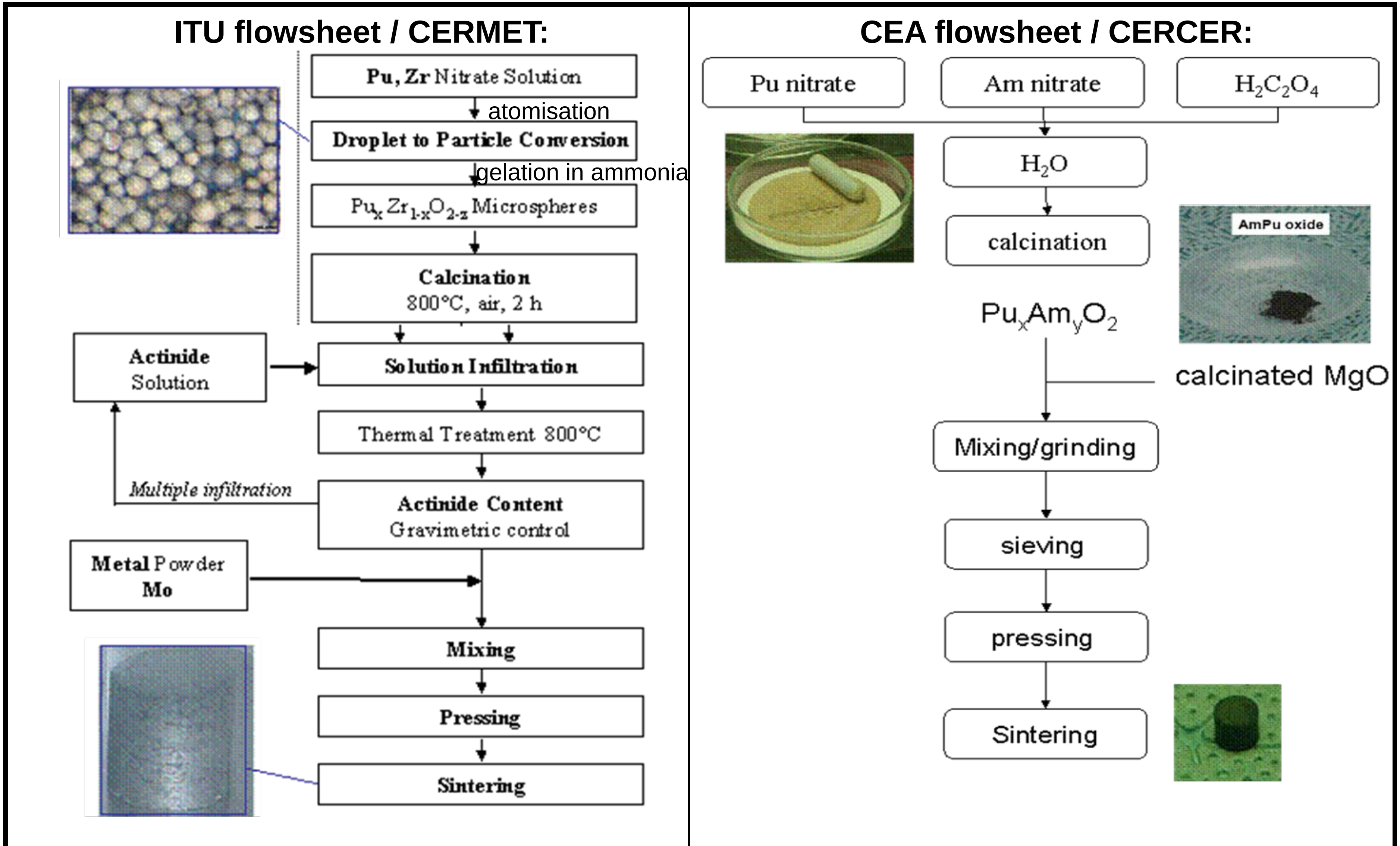


Irradiation test successfully completed on Feb. 19, 2010 after ~241 EFPD
& internal temperatures measured in pins 2&3 lower (~100°C) than expected

PIE under progress within FP-7 FAIRFUELS project

CERCER and CERMET pellets fabrication

- Steps: particle synthesis by 2 routes and then conventional powder metallurgy



BODEX experiment (1/5)

SIXTH FRAMEWORK PROGRAMME

- Investigation of He build-up and release mechanisms in Inert Matrices
  - ^{10}B surrogate of ^{241}Am to simulate He production: $^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li + ^{4}_{2}\alpha$
  - Advantages: few wt% of ^{10}B sufficient to be representative of He production, short irradiation time, easy fabrication and handling.

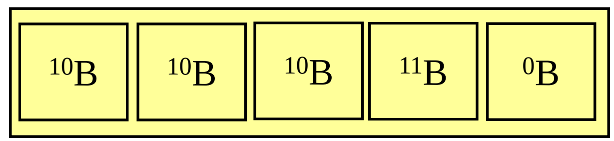
- Design:

✓ 3 matrices : Mo, MgO, ZrO_2	✓ 1 wt% B	✓2 T° : 800 - ~1200°C

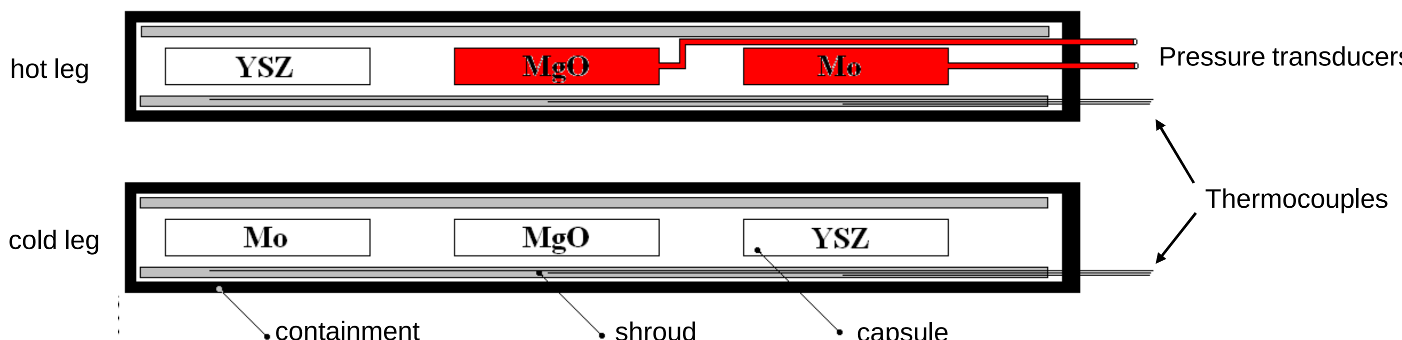
✓ 3 boron compounds :

Mo_2B / Mo	ZrB_2 / Y-ZrO_2	$Mg_3B_2O_6$ / MgO
density >90%	*density> 90%*	*density: 76-82%*

✓ 2x3 capsules : 3 pellets doped with ^{10}B + 1 pellet doped with ^{11}B + 1 undoped pellet



✓ 2 legs & on-line pressure measurements / 2 capsules



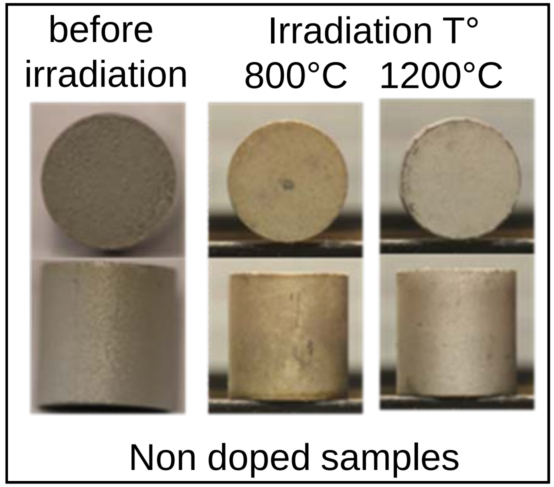
- HFR irradiation conditions: 57 EFPD - ^{10}B burn-up: ~65% - He production: ~6×10^{20} atoms/cm^3

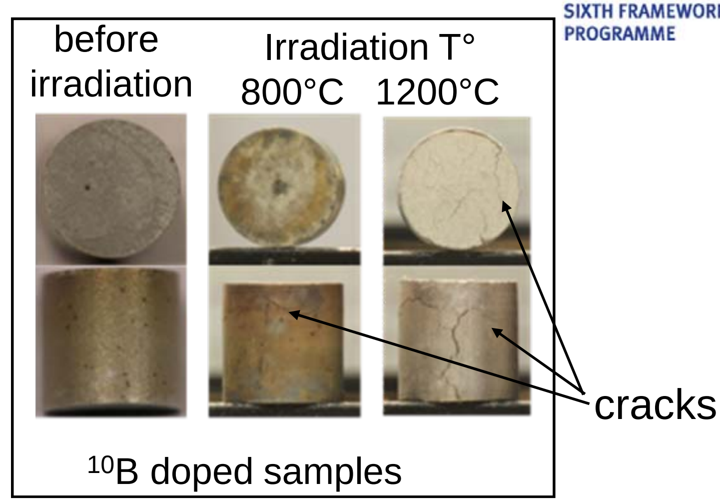
BODEX experiment (2/5)

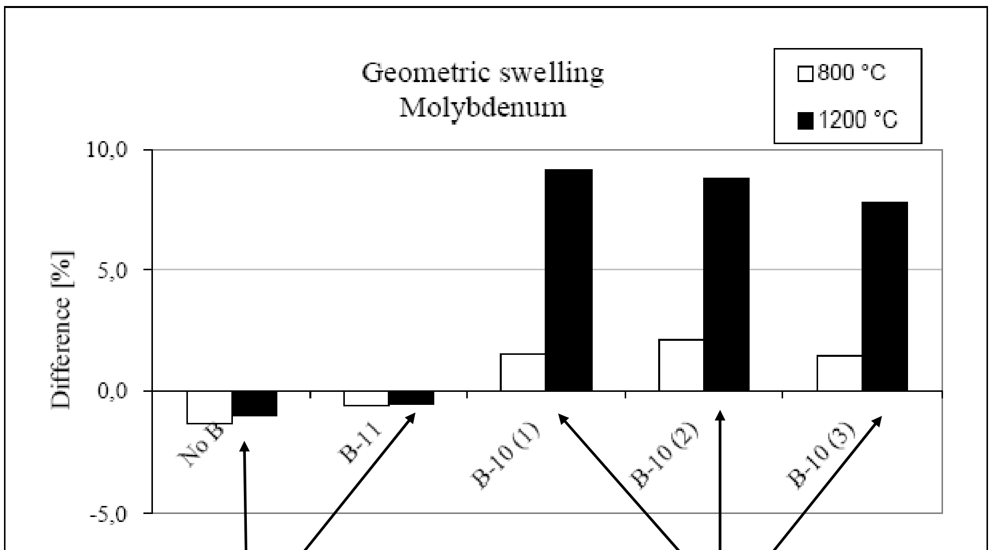
- Behaviour of Mo samples:

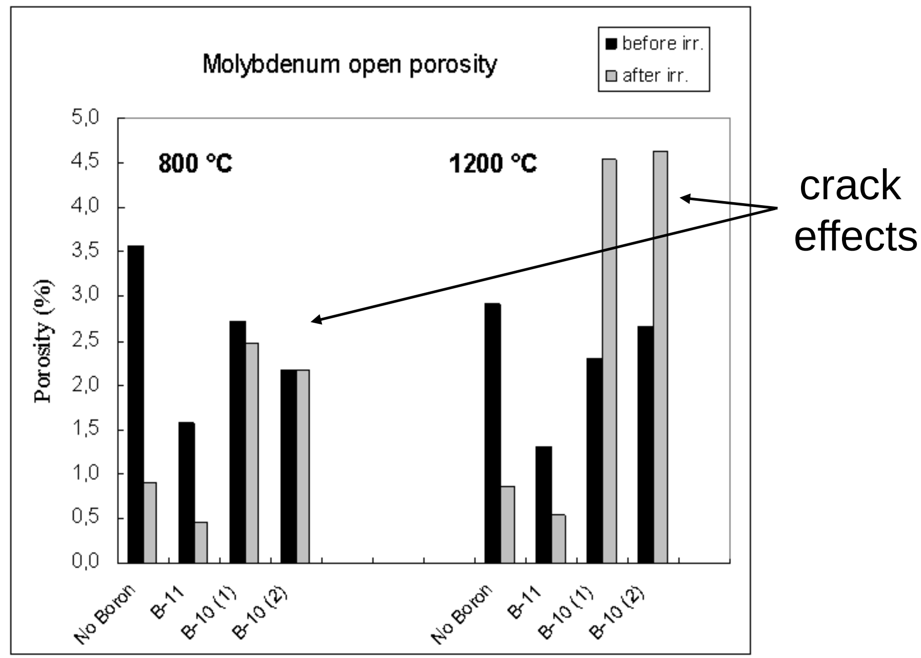
  (high density)

He release (1200°C): 9 %









Global stability at both T°

Vol. changes linked with ^{10}B & T° increase

BODEX experiment (3/5)

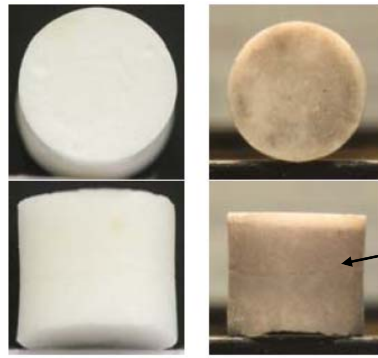
SIXTH FRAMEWORK PROGRAMME

- Behaviour of MgO samples:

  (high open porosity)

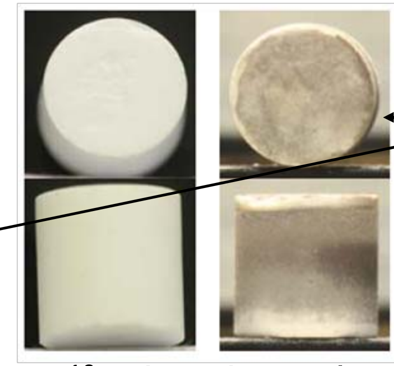
He release:
- 32 % (800°C)
- 35% (1200°C)

before irradiation | Irradiation T° 1200°C



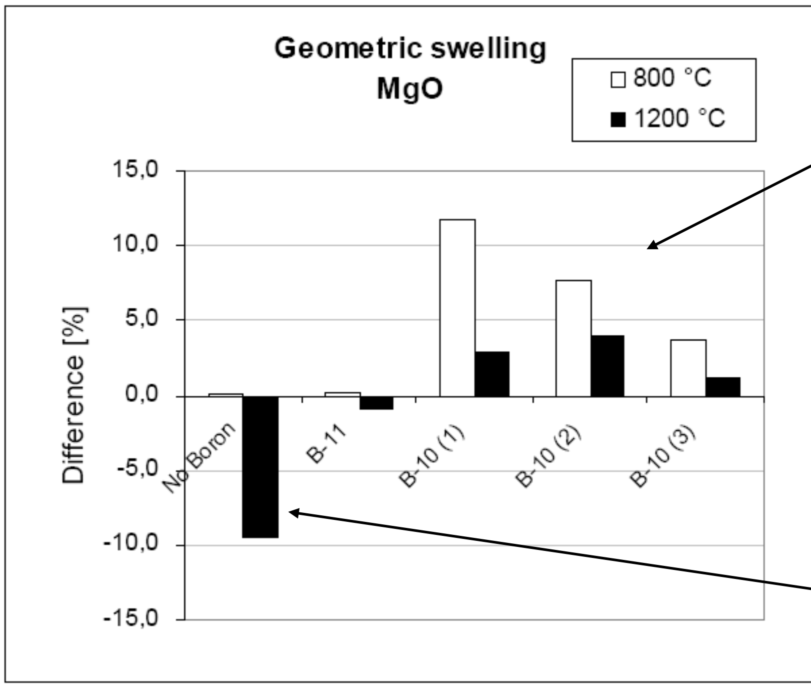
Non doped samples

before irradiation | Irradiation T° 1200°C



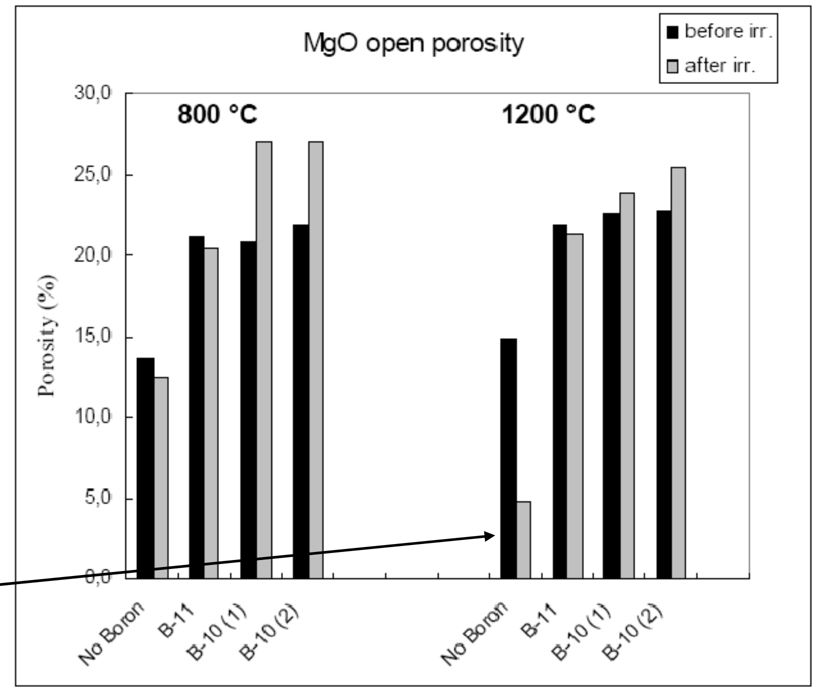
^{10}B doped samples

No cracks but very fragile materials



Swelling linked with ^{10}B
Spread results
Lower swelling at high T°

Extra-sintering of pure MgO at 1200°C



BODEX experiment (4/5)

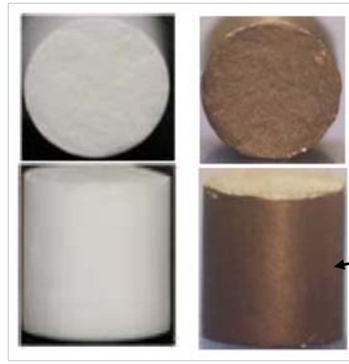
SIXTH FRAMEWORK PROGRAMME

- Behaviour of ZrO_2 samples:

(high density)

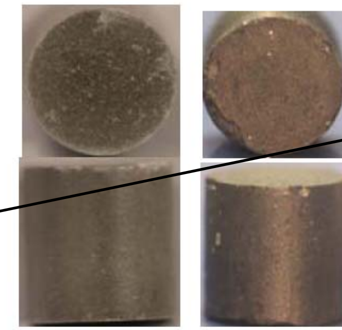
He release (1200°C): 27%

before irradiation	Irradiation T° 1200°C



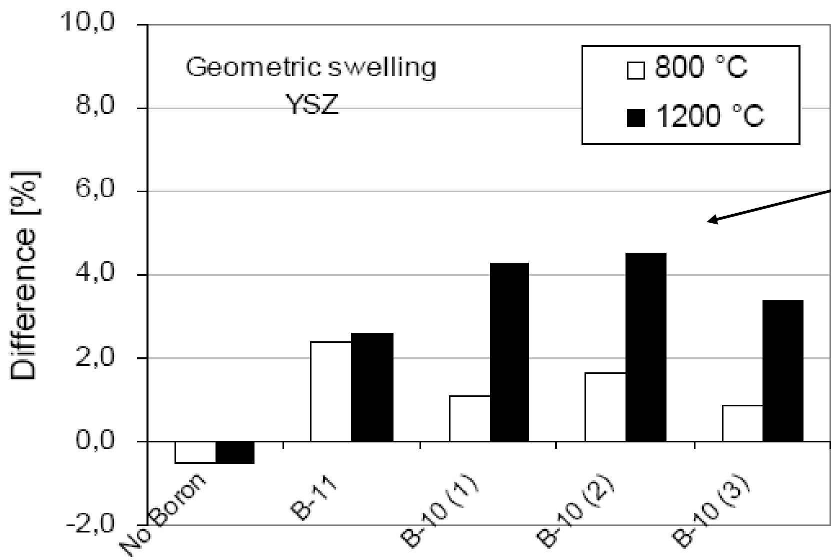
Non doped samples

before irradiation	Irradiation T° 1200°C



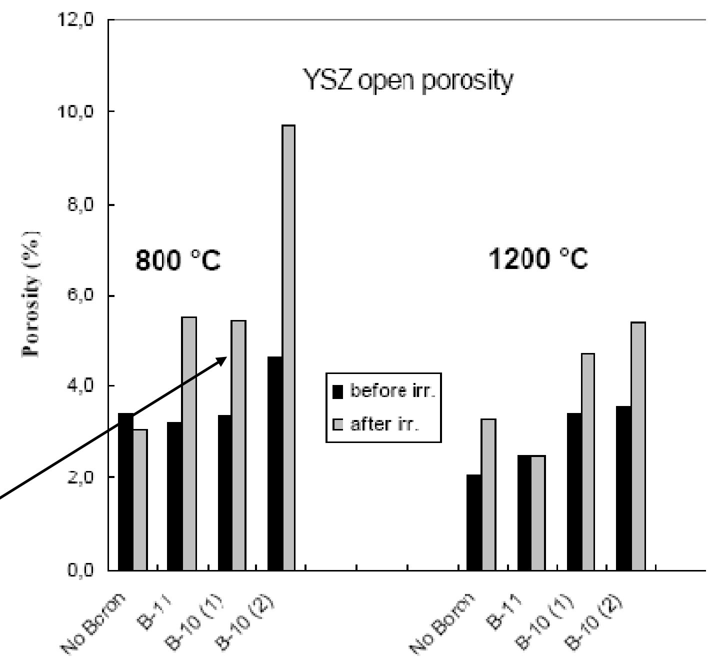
[10]B doped samples

No cracks but fragile materials



Limited swelling

Higher ΔPo at 800°C



BODEX experiment (5/5)

SIXTH FRAMEWORK PROGRAMME

- Summary:

^{10}B- doped samples	Average swelling (%)	Open Porosity (%)		He release (%)	Visual inspection
		BOI	EOI		
Mo-800°C	2	2.4	2.3	N/A	cracks
Mo-1200°C	9	2.5	4.6	9	
MgO-800°C	8	21.3	27.1	32	fragile
MgO-1200°C	3	22.7	24.7	35	
YSZ-800°C	1.2	4.0	7.6	N/A	
YSZ-1200°C	4.1	3.5	5.1	27	

- Conclusion:
  - **Molybdenum (high density):** low helium release – significant swelling at 1200°C - very good performance at 800°C
  - **MgO (high porosity):** large He release – significant swelling at 800°C – possible extra-sintering at 1200°C
  - **YSZ (high density):** large He release - low swelling at both temperatures

→ Swelling ranges are manageable in all cases

Major Outcomes on CERCER and CERMET fuels (1/2)

SIXTH FRAMEWORK PROGRAMME

- **Fabrication of Am bearing fuels:** demonstrated at laboratory scale with
  - Am content up to 36 wt% (1.9 g/cm^3)
  - TRU-oxide fraction up to 40 vol%
- **Fuel behaviour under irradiation:**
  - first irradiation tests completed on ADS type fuels: FUTURIX-FTA & HELIOS
  - results gained in BODEX: swelling of Mo & MgO manageable
- **Physical-chemical properties:**
  - accurate data on thermal properties: heat capacity, thermal diffusivity, oxygen potential and high T° species
  - first results on mechanical properties for $(Pu,Am)O_2$: creep rate
  - chemical compatibility (normal operation T° conditions and short time) for
    - MgO and Mo / PuO_2 and $Pu_{0.5}Am_{0.5}O_2$
    - Pb / TRU-oxides, MgO and Mo
    - T91 / $Pu_{0.8}Am_{0.2}O_{2-x}$, T91/Mo and T91/MgO, T91 / CERMET samples
  - phase diagram investigation: Am drives the crystallographic structures of $(Pu,Am)O_{2-y}$
    - Am rich systems: hexagonal Am_2O_3 type structure
    - Pu rich systems: strong modifications with Am increase from fcc PuO_2 to bcc Am_2O_3 structures

Major Outcomes on CERCER and CERMET fuels (2/2)

SIXTH FRAMEWORK PROGRAMME

- **Neutronic & transmutation performances under normal operation conditions**:
  - **fuel element configurations found to meet EFIT core specifications given by designers**
  - **similar performances with MgO-CERCER and ^{enr}Mo-CERMET fuels**

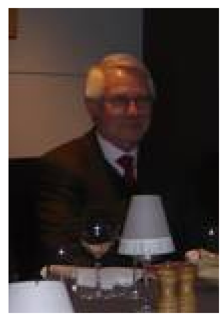
- **Thermo-mechanical performances under normal operation conditions:**
  - **description of fission gas behaviour in heterogeneous media improved in models**
  - **good behaviour calculated (MACROS, TRAFIC) of both fuels**

- **Safety analysis:**
  - **sufficient safety margins for MgO-CERCER fuel**
  - **larger margins for Mo-CERMET fuel**
  - **T91 clad failure limits pose main restriction on safety (and design)**

Reinforced interest for both ^{enr}Mo-CERMET and MgO-CERCER for EFIT

Ranking between the 2 primary candidates seems premature without at least results of FUTURIX-FTA & HELIOS PIE scheduled in FP7-FAIRFUELS program (2009-2013)

Thank you for your attention



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