DEVELOPMENT PROGRAM ON MINOR ACTINIDES BEARING BLANKETS AT CEA

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SUMMARY

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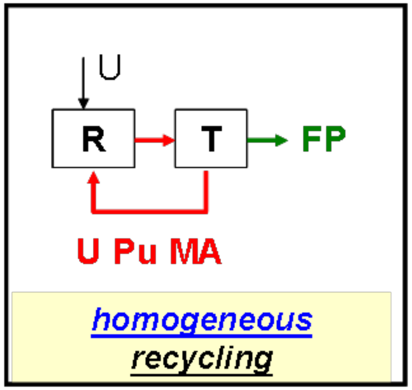
- ✓ **Introduction: current studies on minor actinides transmutation**
- ✓ **Minor Actinides Bearing Blanket concept – MABB**
  Description of the concept
- ✓ **Outline of development program on MABB**
- ✓ **Phase 1: Fuel selection**
- ✓ **Phase 2: Feasibility – first analytical experiments in MTR (Material test reactor)**
- ✓ **Phase 3: Optimization – semi-integral irradiation projects**
- ✓ **Phase 4: Qualification**
- ✓ **Conclusion**

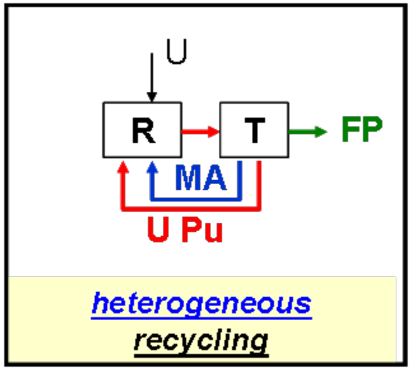
AFAQ ISO 9001

Several options studied for minor actinides transmutation in GEN IV fast reactor or dedicated systems



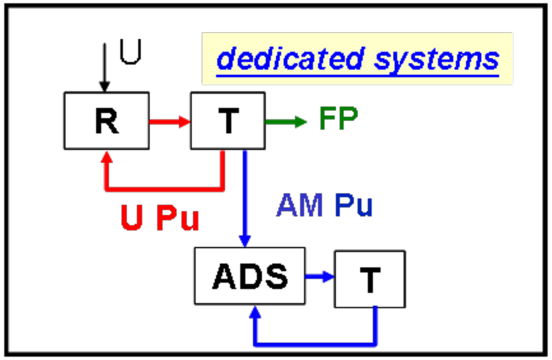
✓ **Homogeneous recycling:**

low amount of MA diluted in standard fuel (< 5 %)



✓ **Heterogeneous recycling:**

- Transmutation targets with inert matrix support (MgO, Mo, $ZrYO_2$, …)
- MA bearing blanket with UO_2 support – $(U, MA)O_{2-x}$
- 10 to 20 % MA



✓ **Dedicated systems ADS**

- Uranium free fuels
- Metallic, nitride and oxide fuels: composite $(Pu, MA)O_2$ – MgO or Mo
- High TRU content: up to 50 %

Present knowledge

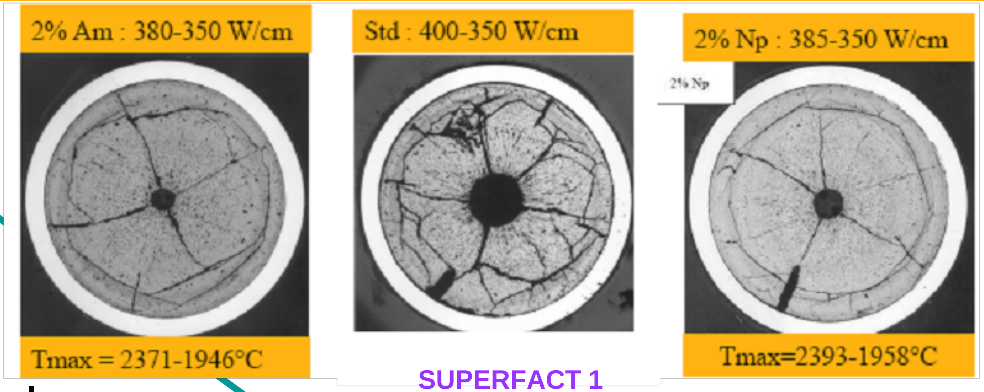
✓ Homogeneous recycling:

- Several important results:

  SUPERFACT 1 in Phénix➔

  AM1 in JOYO

  AFC-2.C.D in ATR (on going)



Next step: pin scale and assembly scale demonstrations planed in MONJU in the frame of GACID

✓ Heterogeneous recycling:

- Transmutation targets with inert matrix support (MgO, Mo, $ZrYO_2$, …)
- Wide knowledge: MATINA, ECRIX, CAMIX-COCHIX experiments in Phénix very good behavior of $MgO-AmO_2$ targets

Most promising options for MA recycling in future GEN IV SFR reactors

✓ Dedicated systems ADS

- FUTURIX FTA program in Phénix
- HELIOS Experiment in HFR

  ➔ First PIE results foreseen in 2011 and 2012

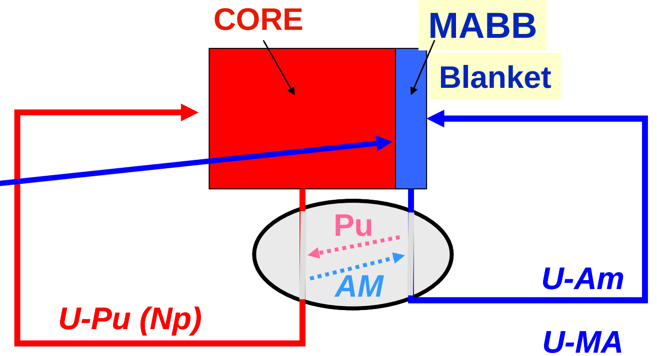
✓ Heterogeneous recycling:

- MABB: very few data available for this concept
- Important need of irradiation experiments

MABB: DESCRIPTION OF THE CONCEPT

MABB concept: **$(U,MA)O_2$ pellets**

Incorporating a large amount of MA (10 to 20 w%) irradiated for a long time (4,100 EFPD) in radial blanket on the periphery of the outer core



Use of the substantial neutron flux that escapes from the SFR core to:

- **Create Pu by using depleted UO_2 blankets (breeding)**
- **Burn minor actinides within the blankets (transmutation)**

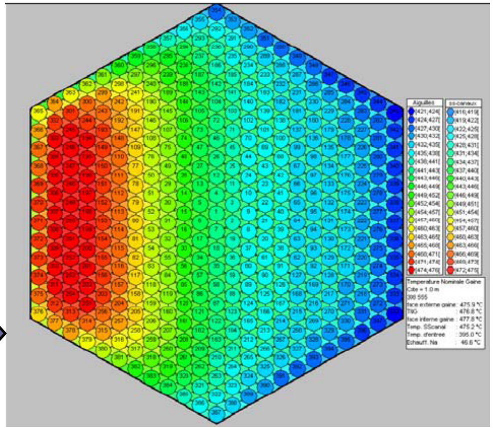
Low impact on the reactor operating parameters and core safety

Multirecycling scenario

Compatible with PUREX type process and the standard flow of spent MOX fuel at the reprocessing plant

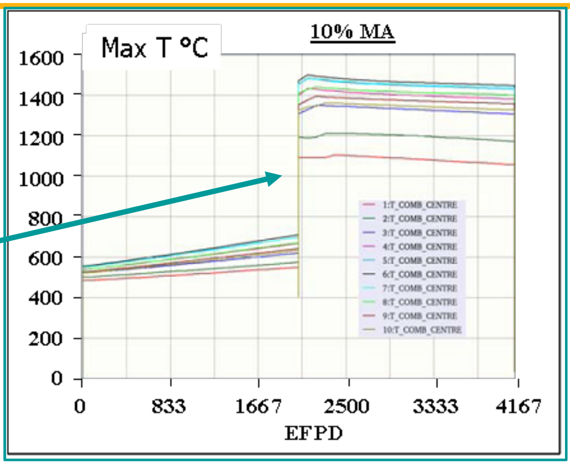
Strong radial variation in the neutron flux inside subassembly located in radial blanket
⇒ very different operating conditions for MABB pins in a same subassembly (S/A)

Temperature range between ~500 – 1500°C



MABB : CURRENT STATE OF KNOWLEDGE

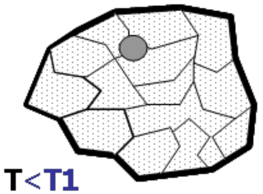
High production of He due to transmutation of ^{241}Am
Possible gas swelling for MABB pellets



To homogenize the Burn-Up of the pins
of the MABB S/A and
the cladding damage

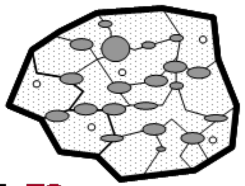
➔ 180° S/A rotation at mid-life
⇒ Significant temperature transient
which can result in additional gas swelling

Simplified assumption of behavior and swelling under irradiation



T<T1
500 à 700°C
He Implantation and annealing tests

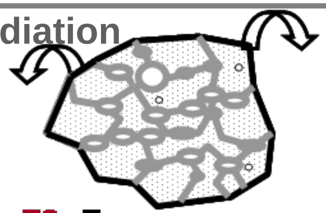
- ***Low He swelling (He atoms isolated in small size defects)***



T1<T<T2

- ***Potentially significant He swelling.***

MABB thermal conditions



T2<T
1100 à 1400°C
He Implantation and annealing
MOX annealing
SUPERFACT

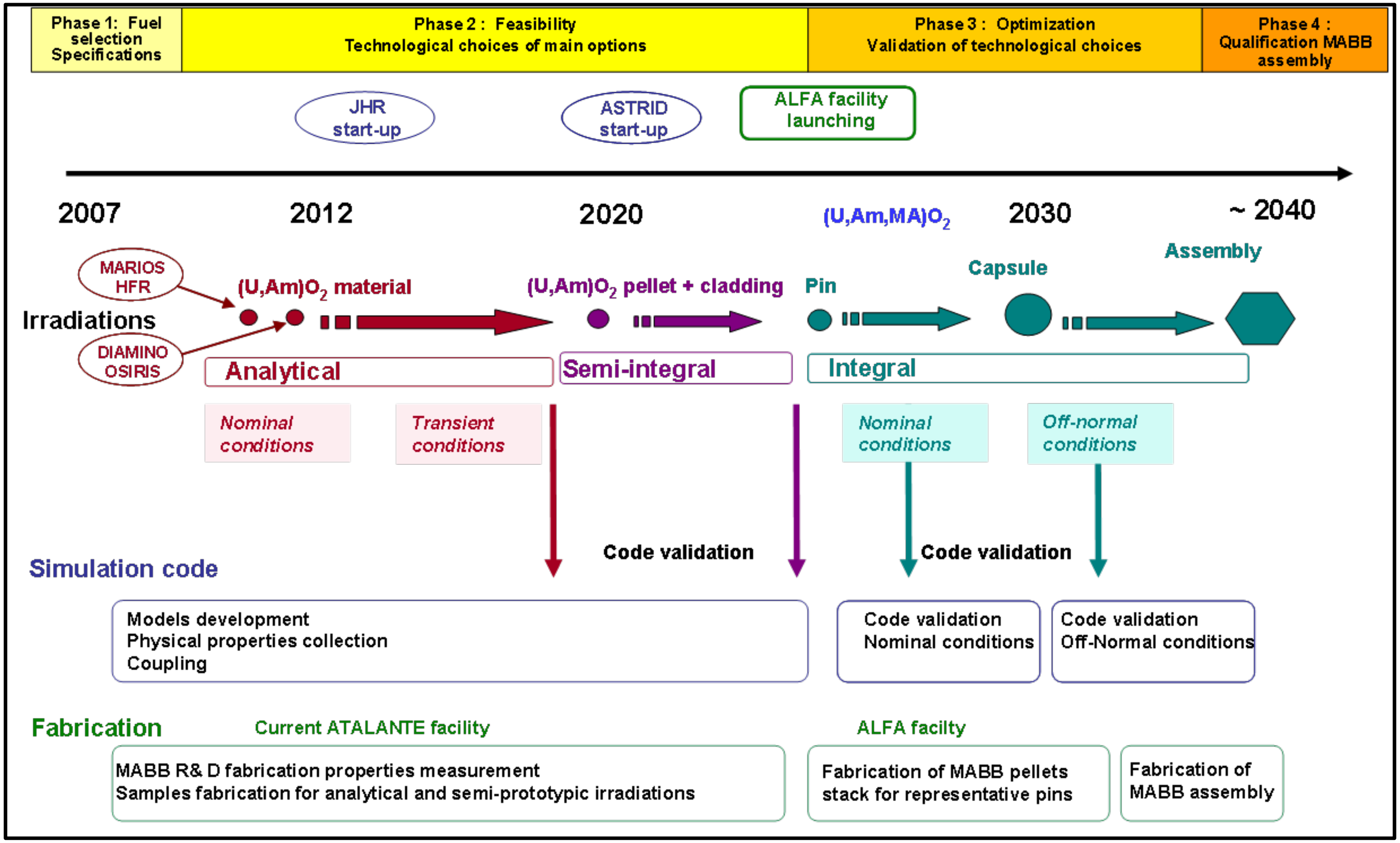
- ***Low He swelling because of significant release***

Potential swelling considering high production of He, moderate T° and operating transients
⇨ Risk of Fuel Cladding Mechanical Interaction (FCMI)

OUTLINE OF DEVELOPMENT PROGRAM

Schematic diagram of the development program for MABB concept:

Description of the main phases to be completed prior to qualifying a MABB S/A in the ASTRID demonstrator around 2040: prerequisite for MABB deployment in industrial-scale reactors



➔ **Implementation of new manufacturing and irradiations means required**

➔ **Rational irradiation program with respect to the available means**

PHASE 1: FUEL SELECTION

Started in 2007: compiling information for MABB pin and assembly specifications

- **Operating conditions in future SFRs: pins and S/A calculations**
- **Various requirements related to frontend (manufacturing, transport and handling)**
- **and backend (handling, transport and treatment)**

⇒ **Specifications ➔ to elaborate the preliminary design studies**

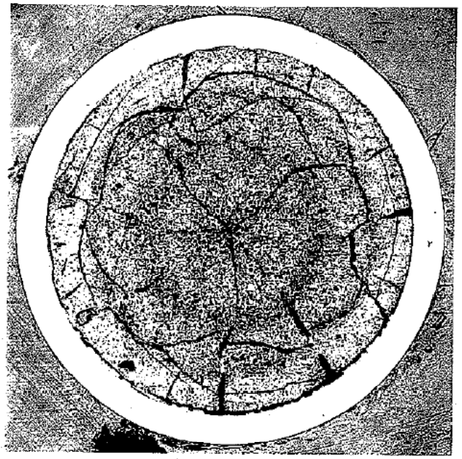
All available data that can help better understand and model the behavior of MABBs throughout their lifespan is analyzed during PHASE 1

SUPERFACT 1 experiment in Phénix is a useful source of experimental feedback

2 pins with ($U_{0.6}$, $Am_{0.2}$,$Np_{0.2}$)O_{2-x} pellets ➔ ➔ ➔ ➔

irradiated 382 EFPD inside the inner core

At relatively high linear power



SF6: 20%Am + 20% Np

Thermal simulation:

⇒ **Central pellet temperature > 1,500°C during irradiation**

Outside the nominal operating condition expected for MABB pellets in an SFR blanket

These high thermal conditions in SUPERFACT 1 pellets led to the full release of He

⇨ **Not the case for MABB in normal operating conditions**

PHASE 2: FEASIBILTY

➔To demonstrate the feasibility of the MABB pin concept to achieve the predicted transmutation performance while ensuring safe and reliable operation under all circumstances

At the end of this phase:

- Technological choices for MABB fuel element consolidated
- Reference manufacturing process for MABB pellets defined

Chronological order of this program:

- **First series** of analytical experiments (separate-effect tests) on MABB samples in available MTR such as OSIRIS, HFR or JHR (soon to be commissioned)
    - Study the behavior of MABB under irradiation (He swelling, gas release) within the temperature range of normal conditions [500 – 1500°C]
    - Correlate the irradiation behavior with MABB manufacturing process to optimize the microstructure
- **Second series** of ‘semi-integral’ experiment with fuel pellets and cladding
    - Understand the phenomena preventing high transmutation rate

      Mechanical and/or chemical interaction between cladding and MABB, neutron damages to the cladding, internal pressure, gas swelling during normal or incident transient

FIRST ANALYTICAL EXPERIMENTS IN MTR

TWO IRRADIATION EXPERIMENTS:

- **MARIOS in HFR Petten**
- **DIAMINO in OSIRIS Saclay**

Main objectives:

- **Rapid acquisition of first data on He swelling as a function of given temperatures**
- **Screening experiment on the impact of MABB microstructure**

COMPOSITION		TARGETED TEMPERATURE (°C)			
		600	800	1000	1200
$(U,Am)O_2$ (15 % Am)	Standard microstructure	X	X	X	X
	Optimised microstructure	X	X	X	X
$(U,Am)O_2$ (7.5 % Am)	Standard microstructure		X		
	Optimised microstructure		X		

MARIOS
Jan. 2011

DIAMINO
mid 2012

Low He production rate

Stable, well-controled and homogeneous temperatures → disc irradiation (with instrumentation)

Two microstructures:

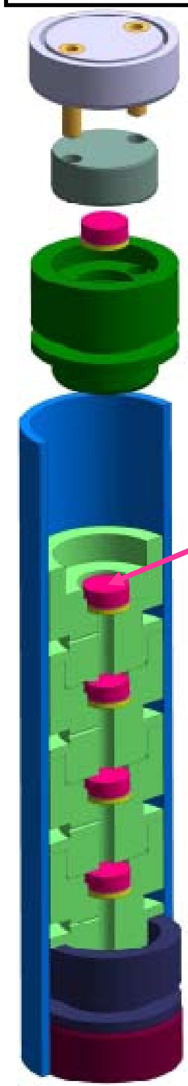
- **'Standard' microstructure with a high density (~ 92 % T.D.)**
- **Optimized microstructure with a lower density (~ 88 % T.D.) and tailored open porosity**

+ Test of the conservative effect of the increased He production rate on swelling

Only ^{241}Am: main responsible of the He production

DIAMINO IN OSIRIS

Mini pin with MABB discs

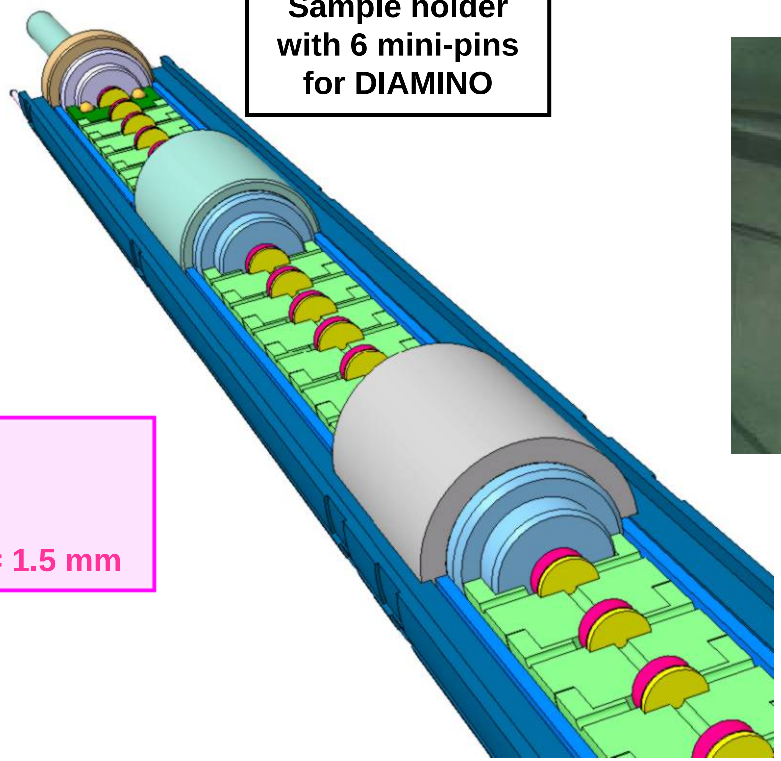


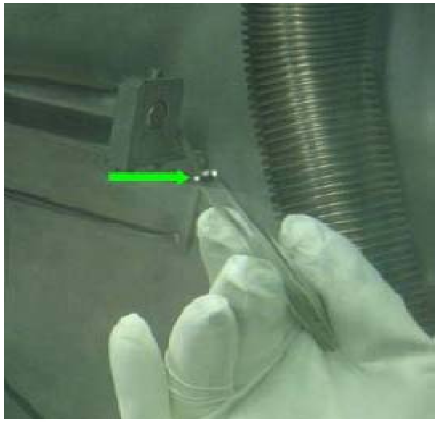
MABB disc

∅ = 4.5 mm

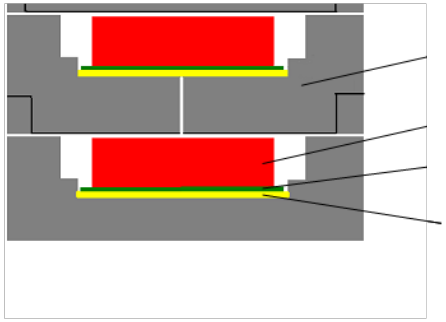
thickness = 1.5 mm

Sample holder with 6 mini-pins for DIAMINO





MABB disc fabricated at ATALANTE

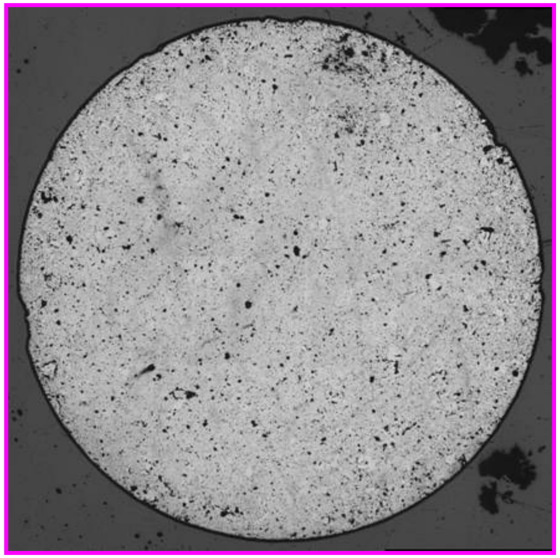


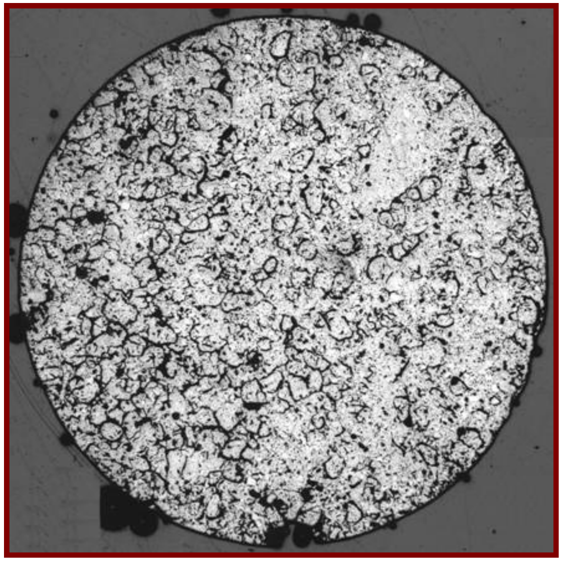
Radial and axial gas gaps
→ free swelling of discs

FABRICATION OF MABB DICS

FOR MARIOS

Standard microstructure:	**Optimized microstructure with tailored open porosity:**
14 discs $(U_{0.85},{}^{241}Am_{0.15})O_{2-x}$	**14 discs $(U_{0.85},{}^{241}Am_{0.15})O_{2-x}$**





Fabricated in the ATALANTE Facility

Powder metallurgy process

Non organic pore former used for optimized microstructure

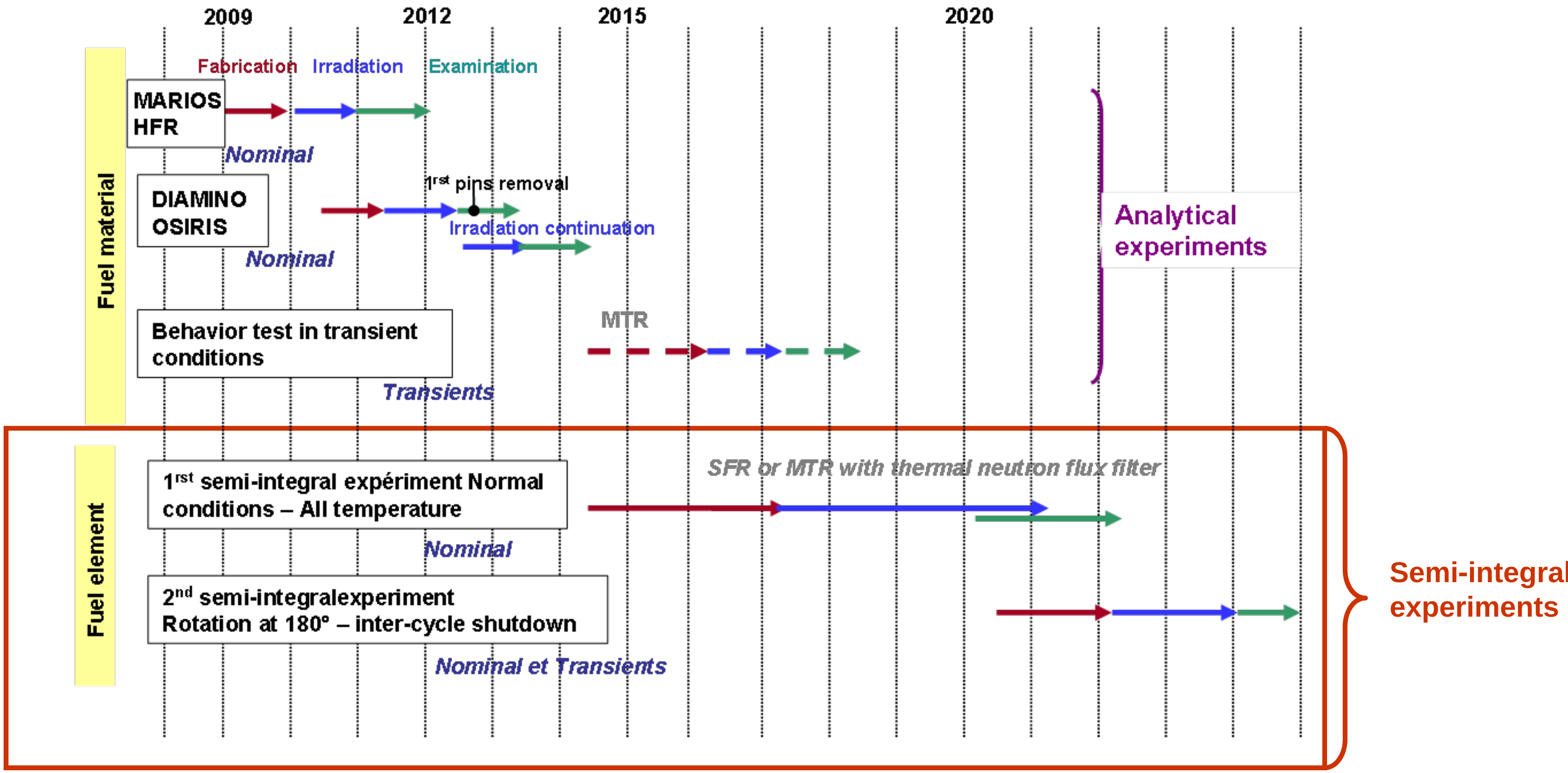
X-Ray diffraction analysis→ single fluorite-type phase

NEXT STEP: SEMI INTEGRAL IRRADIATION EXPERIMENTS

- ✓ Test the whole fuel element: MABB pellets + cladding in a suitable geometry
- ✓ Reproduce the different temperatures and the thermal gradient in the fuel
- ✓ Study the migration of species, fuel restructuring, oxide-cladding interaction

Where possible irradiation in a fast reactor

Otherwise in MTR with screening of the thermal component of the flux



PHASE 3: OPTIMIZATION

- ✓ Optimize the reference concept and improve performance level
- ✓ Prepare the finals specification for industrial partners and regulatory reports for the Safety Authority
- ✓ Validate modeling for off-normal conditions
- ✓ Guarantee control over the process in the pilot facility: reproducible characteristics according to specification

INTEGRAL IRRADIATION EXPERIMENTS:

True geometry of MABB fuel element under representative conditions

Irradiation in the ASTRID prototype reactor

⇒ Special irradiation rig to be designed

Pins fabricated in the ALFA Facility commissioned in ~2025

- Normal operating conditions
- Incidents and accident transients

Code develop to model the behavior of MABB fuel element validated for normal and off-normal conditions

PHASE 4: QUALIFICATION

- ✓ Demonstrate the manufacturing process on an industrial scale:
  fuel ➔ MABB S/A
- ✓ Qualify the production line
- ✓ Confirm the correct behavior of the S/A in incident and accident conditions
- ✓ Demonstrate core safety

Test of a whole MABB S/A in the ASTRID prototype reactor

In radial blanket position

Qualification ⇒ Irradiation performed up to levels exceeding the nominal conditions targeted for this technology

+ Specific monitoring program to be set up for S/A qualification operation

CONCLUSION

Complete development program to study and qualify the MABB concept
From the fuel material to the whole MABB subassembly

First analytical irradiation experiments currently being prepared in HFR and OSIRIS with European partners JRC- IE and NRG

Fabrication of MABB samples in the hot lab of ATALANTE
With two different microstructures

Beginning of the MARIOS experiment early 2011
and DIAMINO experiment mid-2012

First post-irradiation examinations expected early 2012

Next step: semi-integral irradiation experiments
MABB pellets + cladding → 2013

In parallel: development of a specific code to model the behavior of MABB fuel element in normal and off-normal conditions

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Thank you for your attention