



AREVA

FRENCH UMo GROUP DEVELOPMENT PROGRAM

STATUS AS OF MARCH 2004



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The French UMo Development Program Status as of March 2004

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- ◆ Manufacturing capability
- ◆ Irradiation experiments
 - RESULTS OF FIRST IMPORTANCE
- ◆ Thermo-Mechanical UMo Modeling with MAIA
- ◆ Reprocessing demonstration
- ◆ Further steps and conclusions
 - A NEW CHALLENGE

French UMO Group Development program Distinctives Features

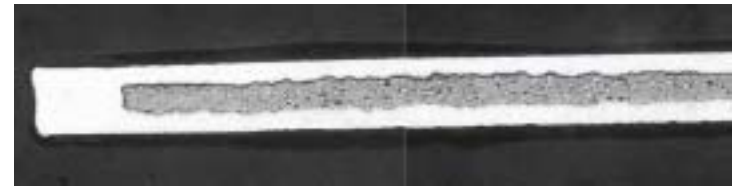
- ▶ Based on the RERTR results, as regard LEU conversion of RR and the choice of UMo to achieve high density of $U.cm^{-3}$ and reprocessing ability, the French UMo Group started its development program in 1999.
- ▶ F.UMo.G takes benefit from :
 - ◆ CEA, on the R&D side and AREVA, on the industrial side

- ▶ The F.UMo.G development program has unique features encompassing :
 - ◆ manufacturing aspects,
 - ◆ irradiations experiments and PIE on full-sized plates,
 - ◆ reprocessing demonstration,
 - ◆ advanced fuel characterization and modeling.

It is dedicated to develop a high performance LEU UMo dispersion fuel : U-7%Mo, with a density up to 8 gU/cm⁻³.

- ▶ This program intends to contribute to the global effort of LEU UMo conversion and to offer global industrial solutions to the MTR community.

- ▶ **Development steps managed by CERCA**
 - ◆ <2001 : use of milled powder (mechanical process)
 - ◆ >2001 : use of atomized powder
- ▶ **Use of advanced process : to make UMo–Al mixing to manufacture plates**
 - ◆ Manufacturing experience of high density U_3Si_2 fuel (5.8 – 6 g/cm³) since 1992
 - ◆ Mastery of homogeneity and dogbone effect
- ▶ **Detailed characterization of non irradiated fuel**
 - ◆ UMo alloy composition, density, powder granulometry, homogeneity,
 - ◆ Cladding thickness, fissile zone dimensions and thickness
- ▶ **First UMo plates manufactured in 1999**
- ▶ **Several sets of full-sized plates already supplied by CERCA**



► Irradiation Conditions

	Standard conditions			Envelope cond.
	Low clad temp.	High clad temp.		
Experiment	IRIS 1 OSIRIS	UMUS HFR	IRIS 2 OSIRIS	FUTURE BR2
Max. surfacic power BOL	140 W/cm ²	170/250 W/cm ²	240 W/cm ²	340 W/cm ²
Max. cladding Temperature	75 °C	90-110 °C	100 °C	130 °C
Max. Burnup	67%	<20%*	40%	33%
Status of irradiation	complete	* early termination	suspended after 4 cycles	suspended after 2 cycles
Status of PIE	complete	complete	intercycle examination done	underway

▶ **Non destructive examinations**

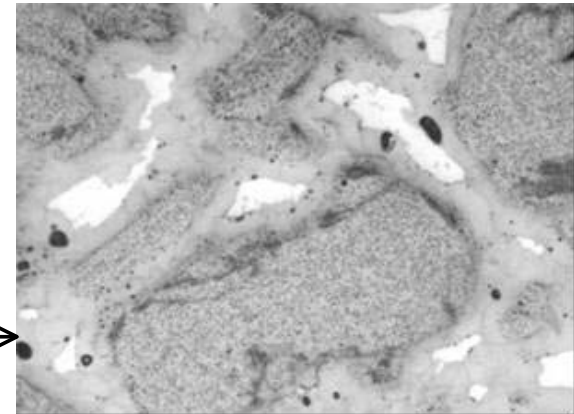
- ◆ Visual inspection
- ◆ Gamma scanning
- ◆ Thickness measurements

	UMo 7	UMo 9
Bu_{max} (%)	67,5	55
Swilling Δe (%)	5,9	4,4

▶ **Destructive examinations**

- ◆ Metallographic examinations
- ◆ Electron probe microanalysis

UMo 7 microstructure middle of the plate BU=61%

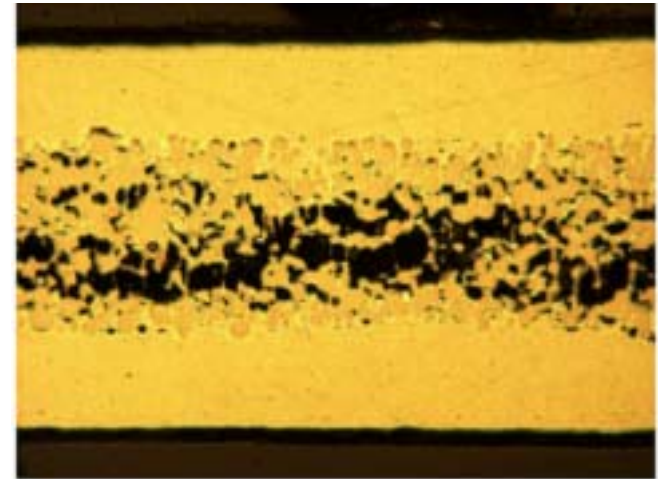
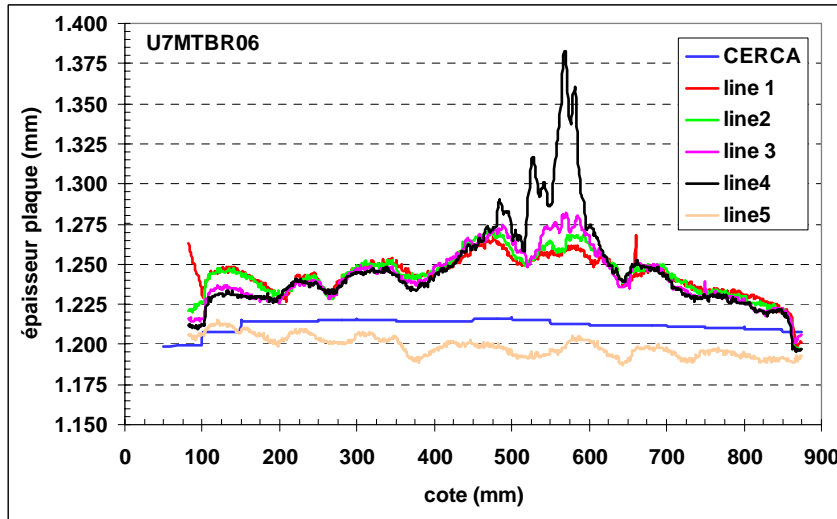


- ▶ Large interpretation of UMo behavior under IRIS 1 conditions.
- ▶ New understanding of the (U-Mo)Al_x structure in the interaction layer

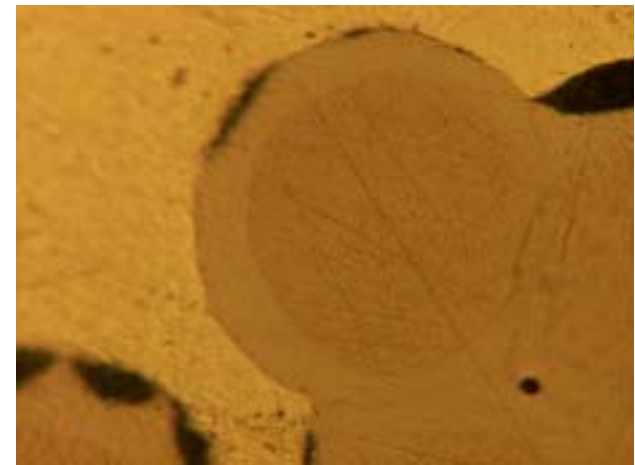
- ▶ Two UMo plates, density 8g U /cm³
- ▶ Irradiation was discontinued after local abnormal swelling was measured at end of cycle 2
- ▶ Destructive examinations were decided on one plate
 - ◆ Corrosion is low
 - ◆ Cladding is intact
 - ◆ Void in the meat was observed on swollen area



- ▶ PIE have been completed by SCK/CEN
- ▶ The large increase of the plate thickness is due to a pillowing effects as the result of large porosities which have coalesced in the center of the meat.



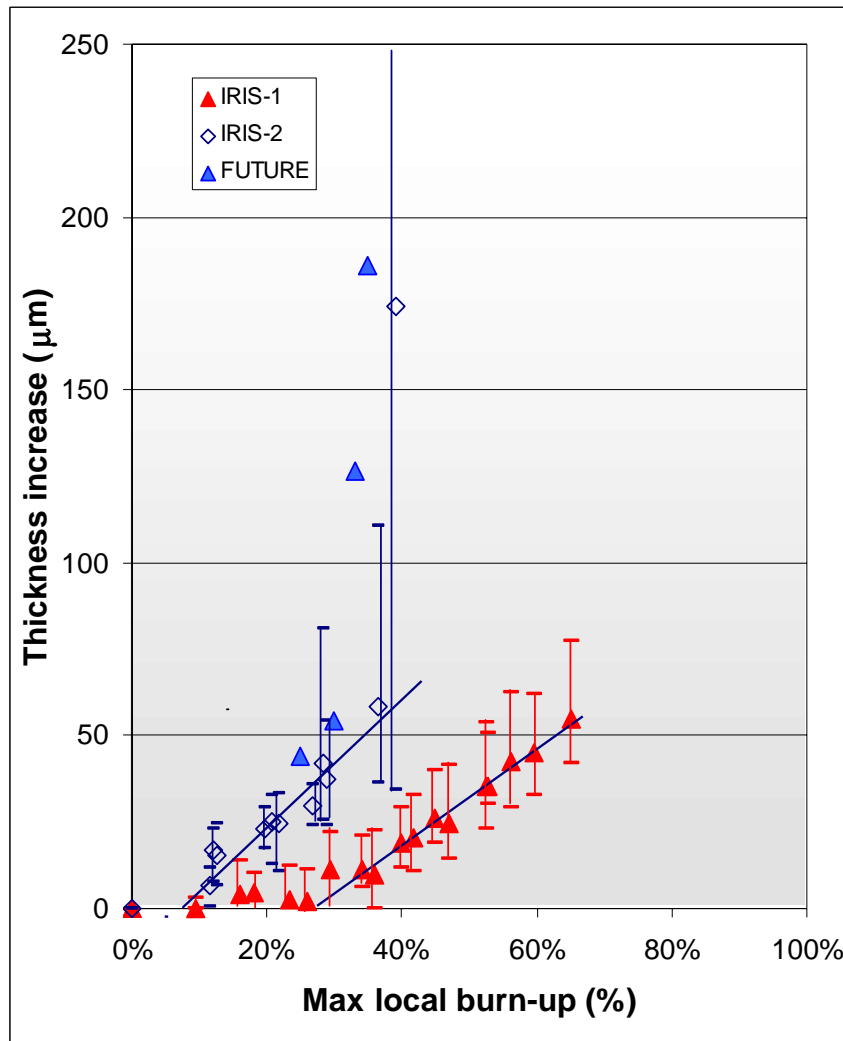
- ▶ **The large increase of the plate thickness is due to a pillowing effects as the result of large porosities which have coalesced in the center of the meat.**



- ▶ Four UMo plates, density 8g U /cm³
 - ▶ Plate thickness is measured after each cycle
 - ▶ Thickness increase satisfactory after the first 3 cycles
- ▶ **Abnormal change in the thickness of all plates after the fourth cycle (max BU of 40%) in spite of less severe operating conditions the FUTURE ones.**
- ▶ Irradiation experiment definitively stopped.



Full-sized plates irradiation Results of First Importance



► For IRIS 1 with low operating conditions the plate swelling is moderate up to 70% burn-up.

► For FUTURE and IRIS 2 a severe and unstable swelling has affected all the plates for 35-40% burn-up.

► Performance limitations have been discovered for UMo dispersion fuel.

Thermo-Mechanical Modeling of UMo with MAIA

▶ MAIA :

- ◆ 2D thermo-mechanical code using a Finite Element Method (FEM) dedicated to U-Mo/Al dispersion fuel

▶ Development in close collaboration between CEA and Argonne National Laboratory (ANL)

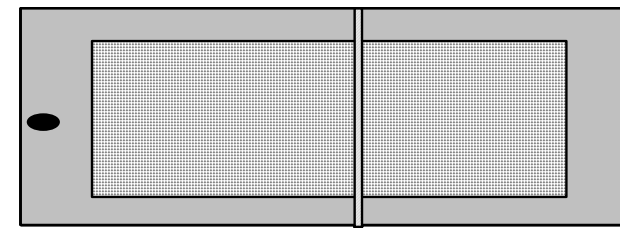
▶ Main Features

- ◆ Homogenization of meat thermal properties
 - evolution in time due to the growth of interaction layer and gaseous swelling in U-Mo
- ◆ Interaction layer growth and Fission product swelling
 - ANL correlations
- ◆ Porosity evolution
 - as-fabricated porosity is supposed to accommodate the swelling as long as it has not completely disappeared
- ◆ Cladding oxidation
 - Several correlations available
- ◆ Mechanical behaviour
 - elastic or viscoplastic model (plasticity in the meat and creeping in the cladding)

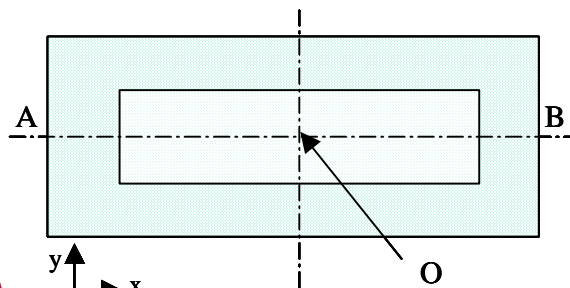
Thermo-Mechanical Modeling of UMo with MAIA

► Calculation of the FUTURE experiment

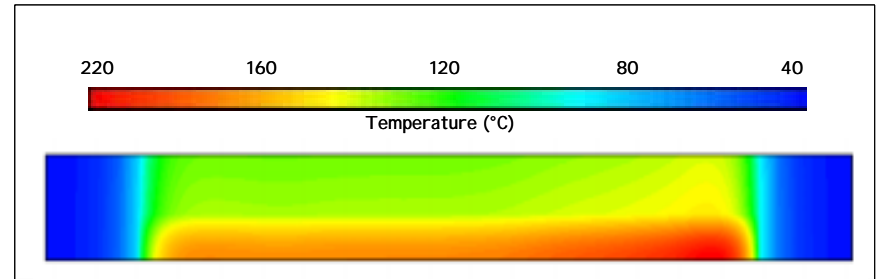
- ◆ The MAIA calculation has been made at the maximum flux plane (MFP)



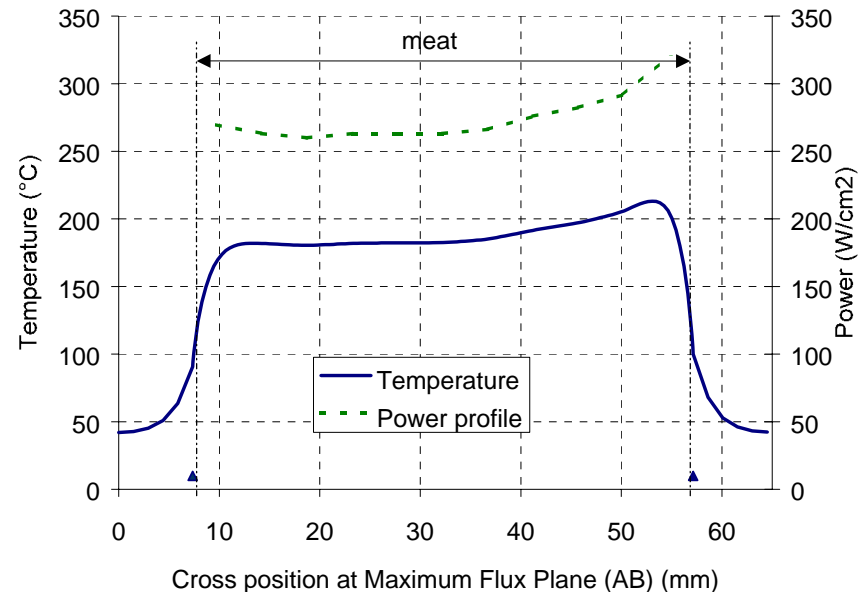
Position of the Maximum Flux Plane (MFP)



Geometry of the MFP modelled with MAIA



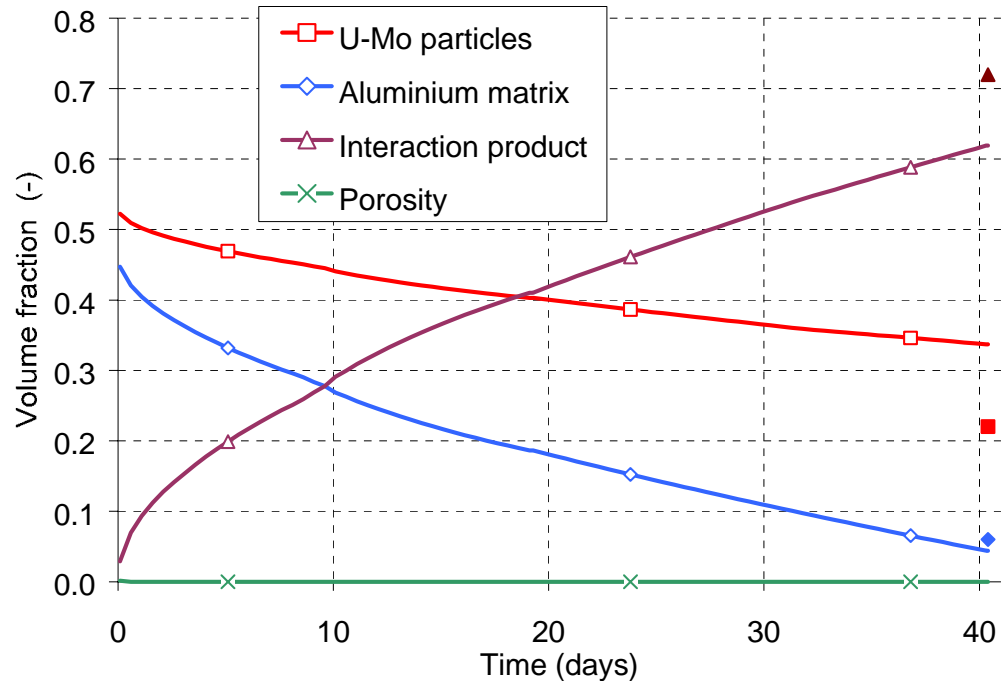
Temperatures of the plate at the end of irradiation (40 days)



Thermo-Mechanical Modeling of UMo with MAIA

▶ Calculation of the FUTURE experiment

- ◆ Validation in progress
- ◆ Helpful tool for interpretation of irradiation experiments
- ◆ Not a predictive tool for unexpected pillowing effects (not modeled) as observed in some regions of the FUTURE plate



Evolution of the calculated volume fractions in the centre of the meat (O) and comparison with PIE (full symbols)



▶ OBJECTIVE

- ◆ Ensure the reprocess ability of UMo fuel to overcome the lack of an available back-end solution for most users of U_3Si_2 fuel.

▶ R&D PROGRAM

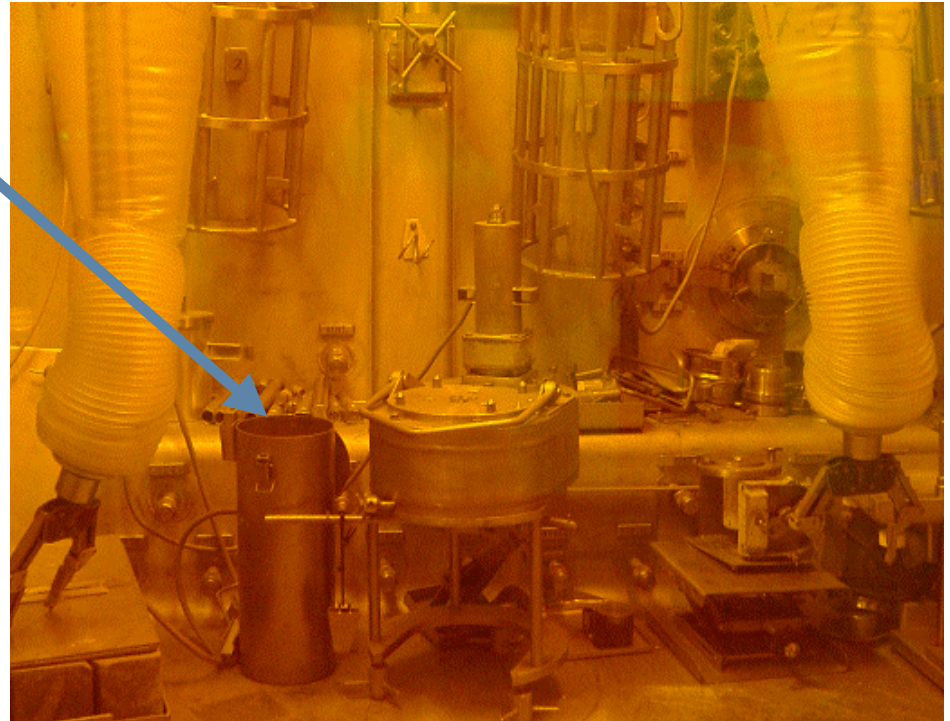
- ◆ Study of the solubility of Mo as a function of T, [U], [Al], [HNO₃]
- ◆ Only Al concentration affects significantly Mo solubility
- ◆ Interaction product $UMoAl_x$ does not affect dissolution kinetics

▶ **Reprocessibility of UMo is demonstrated on fresh plates**

▶ **IRIS 1 Irradiated plates will be reprocessed at the ATALANTE facility (CEA Marcoule).**

- ◆ Tests are in progress and they will be completed in 2004.

- ▶ **First Irradiated UMo plates in hot cell at the ATALANTE facility (CEA Marcoule)**



- ▶ **Industrial treatment**

- ◆ **Ensuring the total dissolution in nitric acid allows the dilution in standard fuel dissolution solution and the compatibility with La Hague's Purex process**

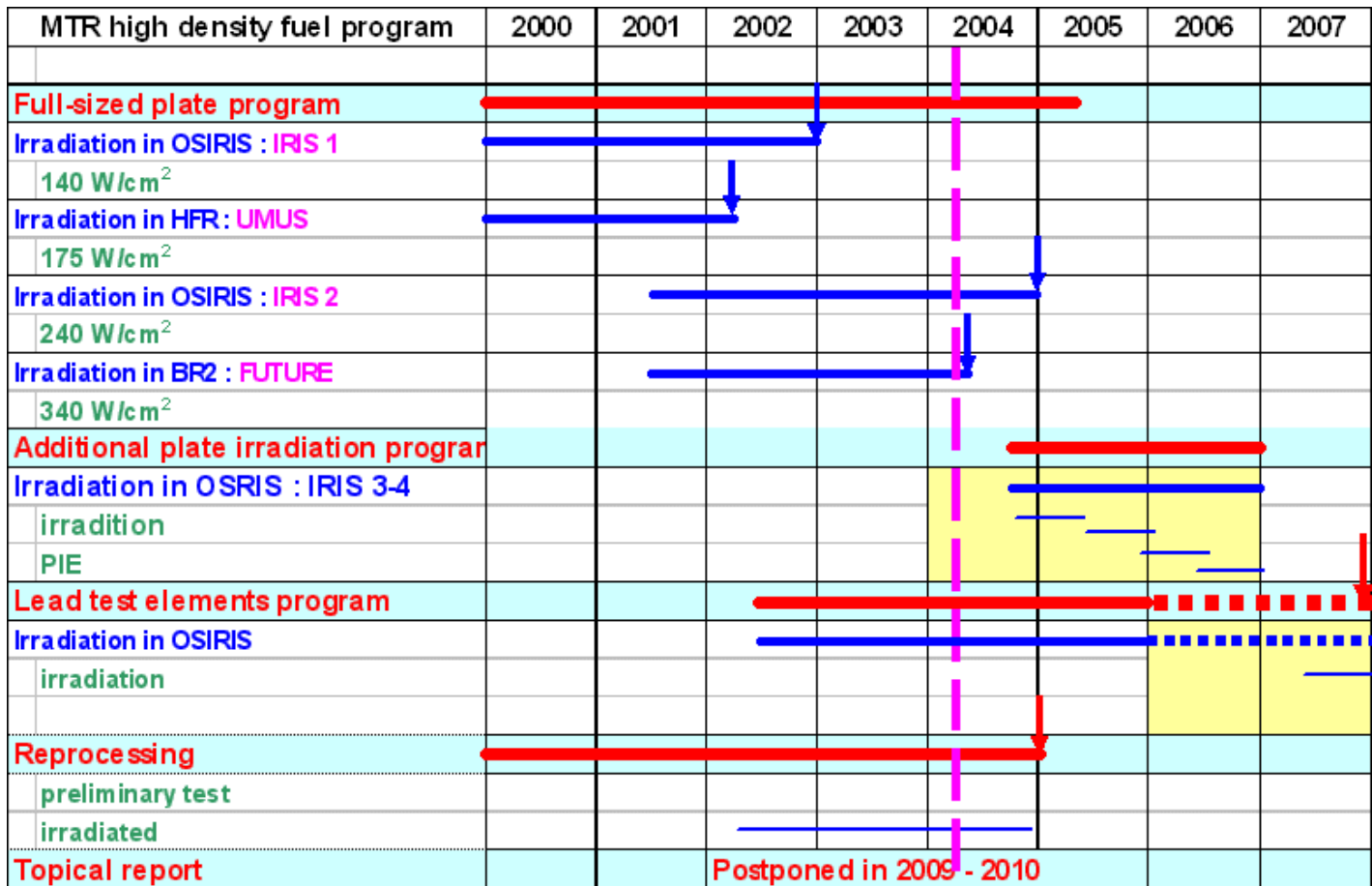
UMo Development Program

Next Steps

- ▶ **The priority is to understand the cause of the observed unstable swelling effect**
 - ◆ **Two main possible routes have to be investigated**

- Excessive formation of the interaction product $UMo(Al)_x$, with an unexpected metallurgical behaviour
 - Effect of fission gas release in the dramatic increase of the porosity
 - ◆ **Possible connection between the two phenomena**
- ▶ **Reduce the interaction between the UMo particles and the AL matrix**
 - ◆ **Evaluate the more promising options : adding Silicon in the AL matrix ?...**
- ▶ **New irradiation experiments of full-sized plates in OSRIS**
 - ◆ **IRIS-3 : with optimised dispersion**
 - ◆ **IRIS-4 : with monolithic fuel (dedicated for high performance)**
- ▶ **Lead test elements irradiation has to be postponed until the issue of the IRIS 3-4 results.**

UMo Development Program Time Schedule



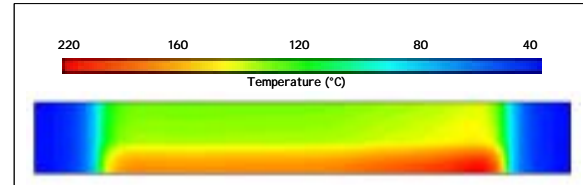
A sustained effort will be spent by the F.UMo.G to adapt the program according the result of the necessary modification of the dispersion fuel.

- ▶ **Results of first importance have been issued by the F.UMo.G**
 - ◆ Evidence of an unstable swelling in connection with an excessive formation of the $UMo(Al)_x$ interaction compound
 - ◆ Results recently confirmed by ANL with a new analysis of the past RERTR 3-4 experiments.

- ▶ **A loss of R&D effort avoided**

- ▶ **An adaptation of the international development route of UMo dispersion fuel appears necessary :**
 - ◆ to reduce drastically the interaction between UMo and the Al matrix : addition of Silicon ?...

- ▶ **The F.UMo.G will face this new challenge**
 - ◆ And adapt its program among a fruitful international synergy, on the basis of the new technical results that will be issued from parametric irradiation of plates in the next two years



Temperatures of the plate at the end of irradiation (40 days)

► **Dedicated tools will be involved to ensure the issue of the R&D program and the availability of industrial solutions as regard the needs of the RR community.**

