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THE FRENCH UMo GROUP CONTRIBUTION TO NEW LEU FUEL DEVELOPMENT

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RRFM 2005 – BUDAPEST – April 11-12 2005

The French UMo Group Contribution to New LEU Fuel Development

CONTENT

- F.UMo.G Initiative
- Technical features of the Development Program
- Main Issues

Necessity to reroute the UMo development program

- The French UMo Extended Program

The French UMO Group Initiative

- **This initiative took place :**
  - **On the basis of RERTR program available results**
  - **With the choice of UMo to achieve high density of U.cm^{-3} and offer reprocessing capabilities**
  - **With a starting point of the development program early in 1999**

- **The F.UMo.G initiative :**
  - **Has motivated a close collaboration between CEA, on the R&D side, and AREVA, on the industrial side**
  - **Was dedicated to develop a high density LEU UMo dispersion fuel :**

    U-7%Mo, with a density up to 8 gU/cm^{-3}
  - **Intended to deliver industrially a high performance LEU UMo fuel suitable for a wide range of Research Reactors, and covering the expected needs for MTR next generation**

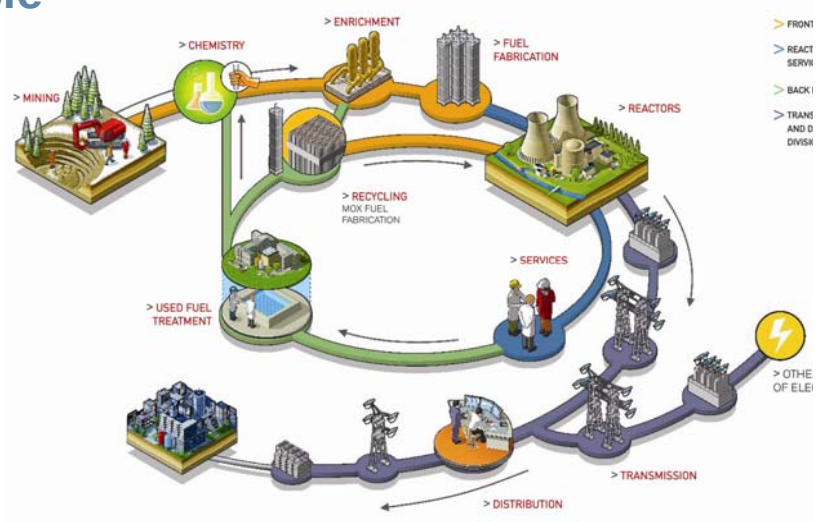
- **During the last five years, this program has provided a major contribution as part as the international effort to develop a new LEU UMo fuel**

A Global approach

The F.UMo.G initiative :

Intended to cover the whole fuel cycle

- **Manufacturing**
- **Irradiation of full-sized UMo plates**
- **Characterization of irradiated fuel**
- **Numerical code development for modelling the behaviour of UMo dispersion fuel**
- **Reprocessing validation**



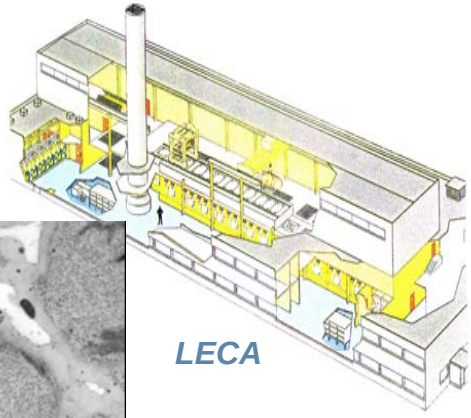
The F.UMo.G development program was based on unique technical features to encompass a global qualification route

Advanced R&D means

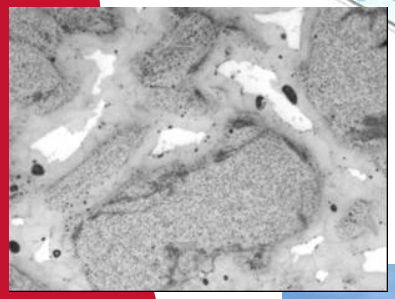
CERCA

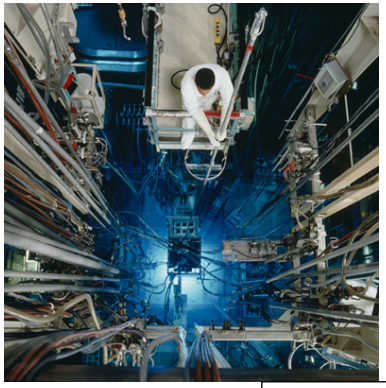
- **Advanced R&D facilities has been dedicated to the F.UMo.G Development Program :**
  - **CERCA R&D and manufacturing capabilities**
  - **CEA facilities**

IRIS



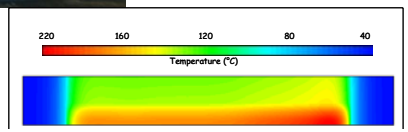
LECA





OSIRIS

ATALANTE

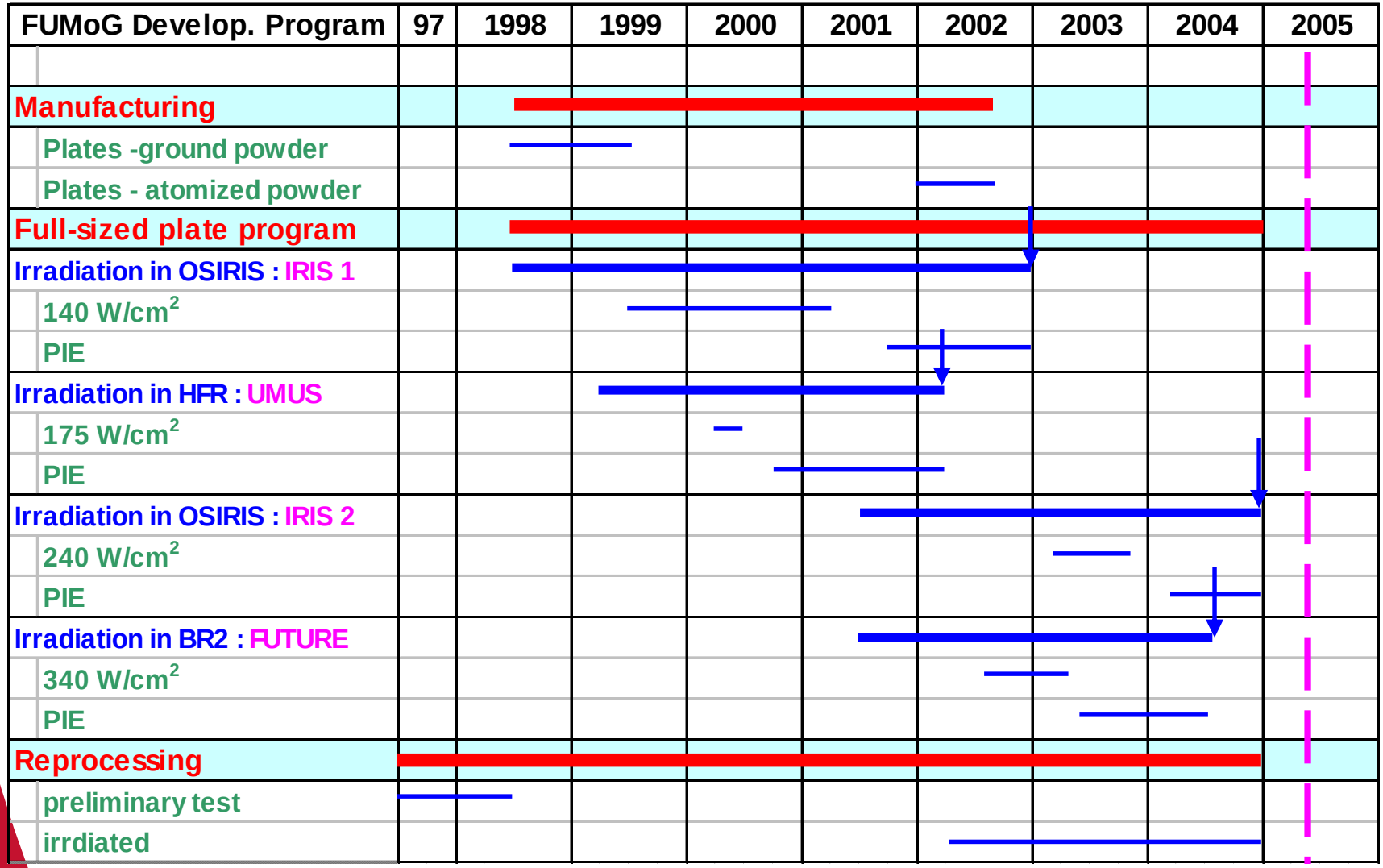


- **with the additional contribution of HFR and BR2 facilities in Europe**

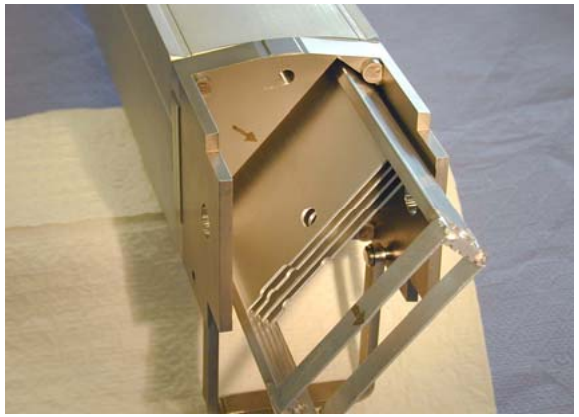
HFR

BR2

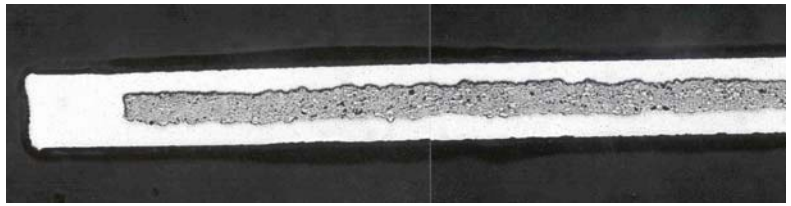
The F.UMO.G Development Program
A sustained Effort



Main Issues - Manufacturing



- Manufacturing development program managed by CERCA
- Continuous adaptation of the advanced proprietary process along the program
- Based on the manufacturing experience of CERCA of high density U_3Si_2 fuel (5.8 – 6 g/cm^3) fabrication since 1992
- First UMo plates manufactured in 1999
  - UMo produced by grinding before 2001, and by atomization after
- Characterization of non irradiated fuel mastered by CERCA



CERCA is ready to extend its manufacturing process to take into account the necessary evolution of UMo fuel

Main Issues - Irradiation experiments

Irradiation Conditions

	Standard conditions			Envelope cond.
	Low clad temp.	*High clad temp.*		
Experiment	**IRIS 1 OSIRIS**	**UMUS HFR**	**IRIS 2 OSIRIS**	**FUTURE BR2**
Number of plates	**3**	**4**	**4**	**2**
U-Mo powder	**grinded**	**grinded**	**atomized**	**atomized**
Max. surfacic power BOL	**140** W/cm²	**170/250** W/cm²	**238** W/cm²	**340** W/cm²
Max. cladding Temperature	**75 °C**	**90-110** °C	**93 °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	complete	complete

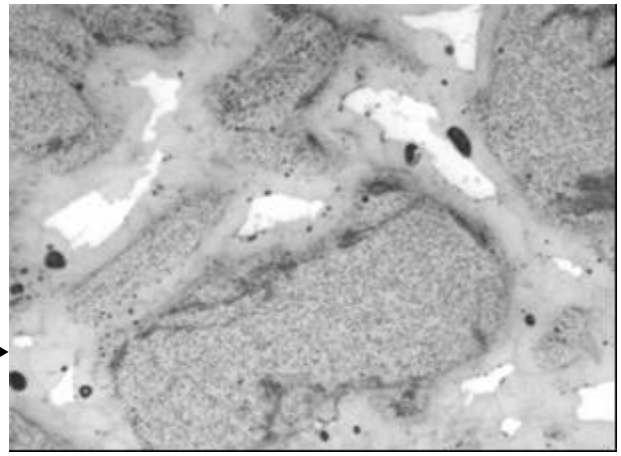
Main Issues – "IRIS 1" Irradiation

- **Good behaviour of UMo dispersion fuel for a high burn-up, but with rather low irradiation conditions**
  - **Acceptable swelling**

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

- **A large amount of Destructive examinations has been done**
  - **Metallographic examinations**
  - **Electron probe microanalysis**

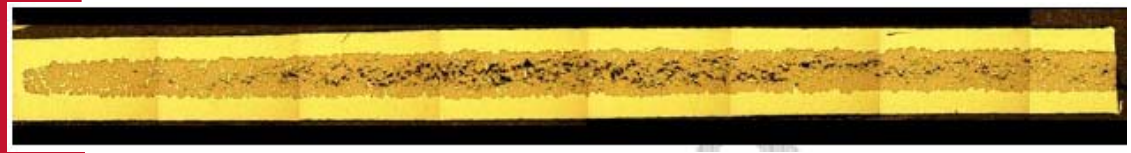
UMo 7 microstructure in the middle of the plate with a burn-up of 61%

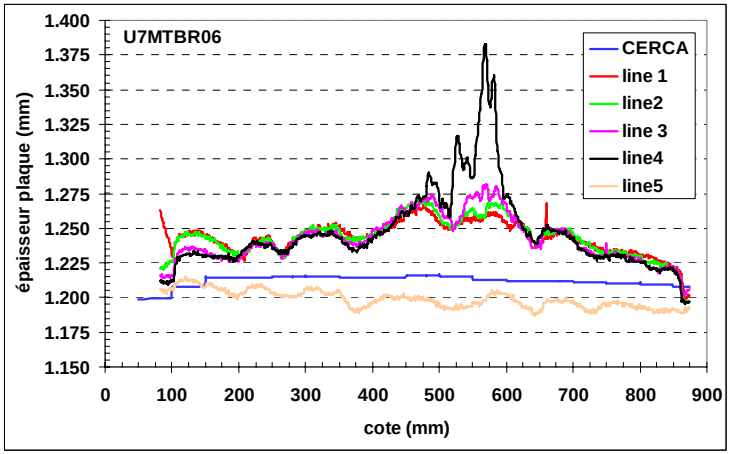


- **The IRIS 1 experiment has issued a new understanding of the $(U\text{-}Mo)Al_x$ structure in the interaction layer**

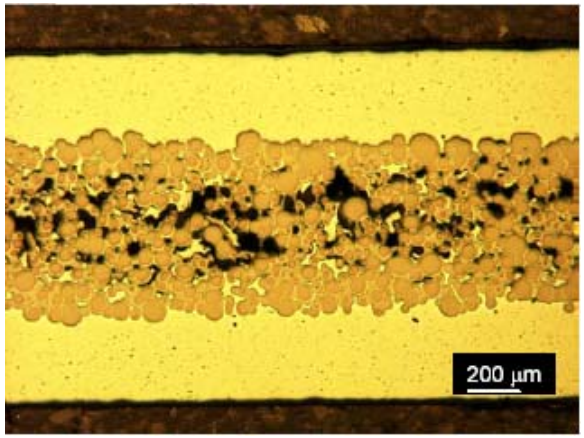
Main Issues - "FUTURE" Irradiation

- Two U-7%Mo plates, density 8g U /cm^3 under envelop irradiation conditions
- The experiment was discontinued after a local abnormal swelling was measured at end of 2nd cycle





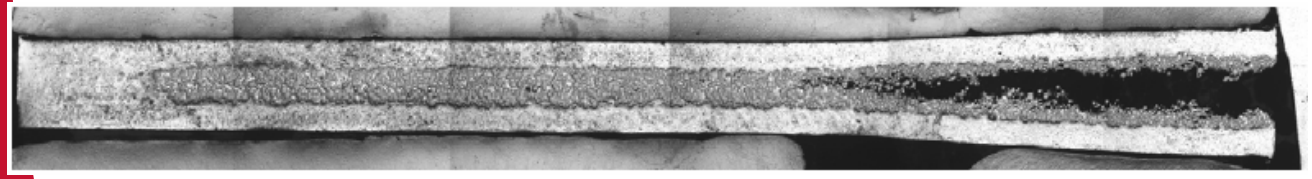
  - Corrosion is low
  - Cladding is intact
- Increase of plate thickness is due to a pillowing effect as the result of large porosities which have coalesced in the center of the meat.



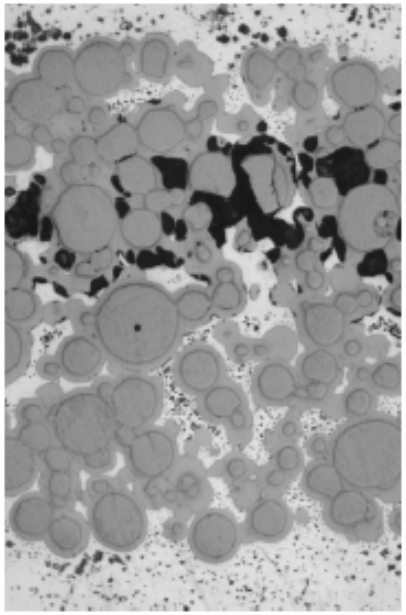
- This experiment revealed for the first time severe performance limitation of UMo dispersion fuel for higher irradiation flux

Main Issues - "IRIS 2" Irradiation

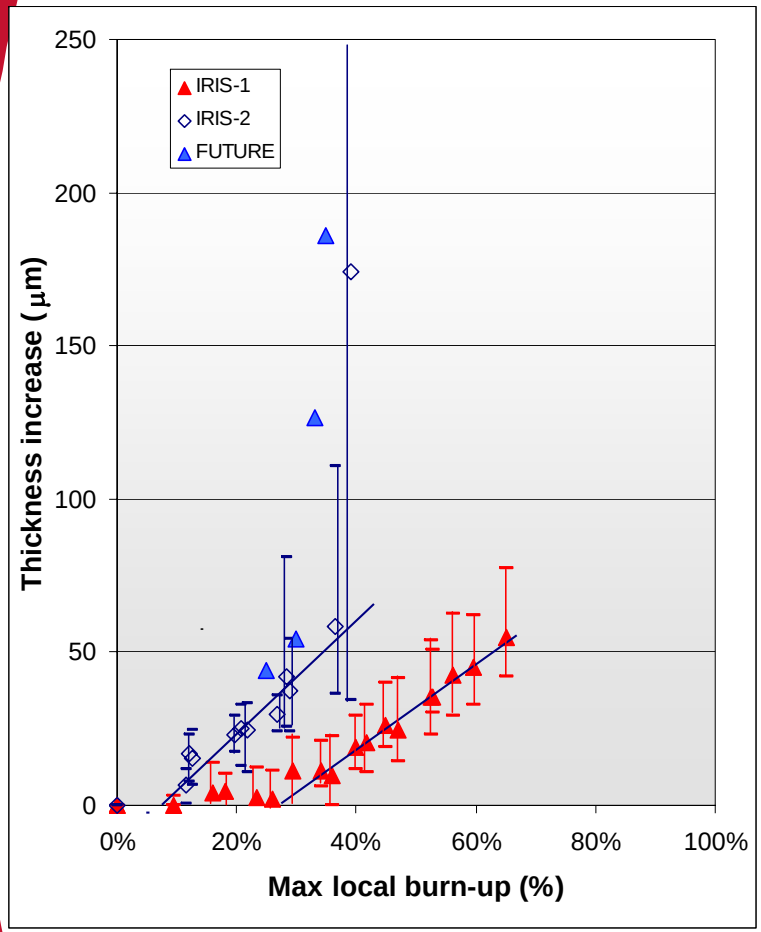
- Four U-7%Mo plates, density 8g U /cm^3
- Less severe operating conditions than the FUTURE ones
- Plate thickness is measured after each cycle
- Abnormal change in the thickness of all plates after the fourth cycle (max BU of 40%)



- Irradiation experiment definitively stopped
- Large amount of PIE, consistent with FUTURE
  - Large pore developments are observed in the interaction product, that induce the pillowing of the plates.



Full-sized plates irradiation Results of First Importance



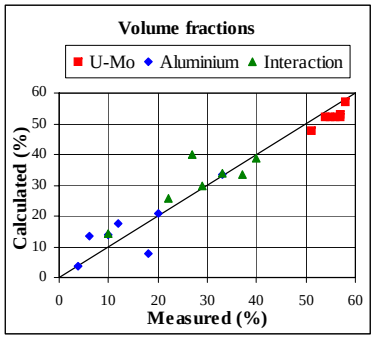
- **Unacceptable restrictive limitations for the UMo dispersion fuel, have been revealed for the first time with FUTURE and confirmed with IRIS 2 experiment**

- **FUTURE and IRIS-2 fission density limit of 2.10^{21} $f.cm^{-3}_{UMo}$**
- **For IRIS-1 with lower irradiation conditions and grinded particles no pillowing was observed**

- **The origin of the phenomenon is not completely established**
  - **Decrease of the aluminium content versus the increase of the temperature in the interaction compound**
  - **Role of the fission products**

Main – Issues
Thermo-Mechanical Modeling of UMo

- **MAIA :**
  - **2D thermo-mechanical code using a Finite Element Method (FEM) dedicated to the modelling of U-Mo/Al dispersion fuel behaviour**
- **Development in close collaboration between CEA and Argonne National Laboratory (ANL)**
  - **Including physical model of the DOE-ANL code PLATE as regards interaction layer growth and fission products swelling**
- **Improvements occurred in 2004 on interaction modelling and mechanical computations with validation exercises**



- **MAIA is a tool, gathering physical laws and numerical model that allows parametric thermo-mechanical studies on UMo dispersion fuel**

Main Issues - Reprocessing

OBJECTIVE

- Ensure the reprocess capability of UMo fuel to overcome the limitation as regards back-end solution for most users of U_3Si_2 fuel.

R&D PROGRAM and RESULTS

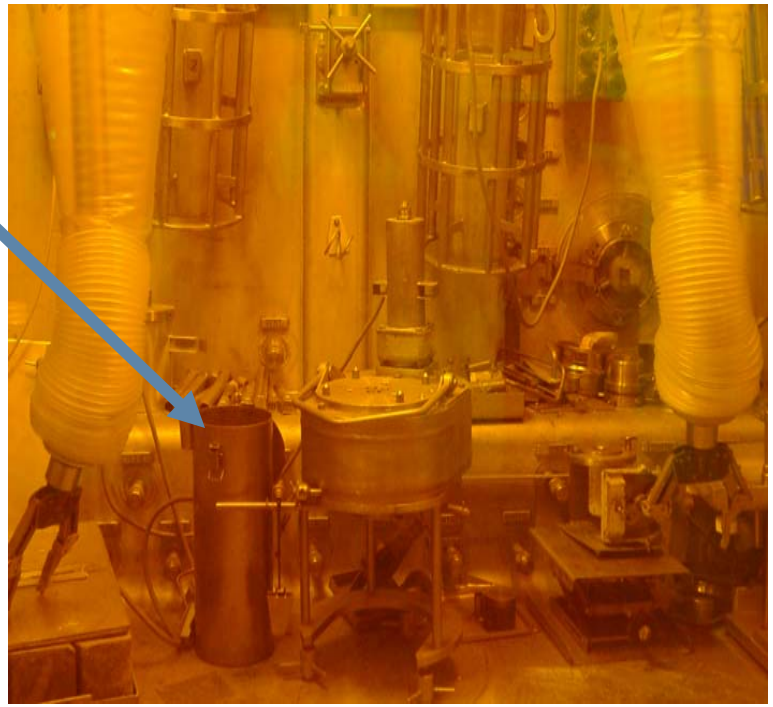
- Study of the solubility of Mo as a function of T, [U], [Al], [HNO_3]
- Only Al concentration affects significantly Mo solubility
- Interaction product $UMoAl_x$ does not affect dissolution kinetics

Reprocess of UMo has been demonstrated on irradiated plates at the ATALANTE Facilty (CEA Marcoule) in 2004

The industrial process ensures the total dissolution in nitric acid and allows the dilution in standard fuel dissolution solution and the compatibility with La Hague's Purex process

Main Issues - Reprocessing

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



- Validation of the reprocessing operating parameters for irradiated UMo fuel plates is one of the most important result issued by the F.UMo.G development program.
- This is the confirmation of the favourable properties of UMo fuels as regards back-end solution.

A Key Contribution to UMo Development Route

- A sustained R&D effort since 1999
- A global approach covering the whole fuel cycle
- Results of first importance
  - Mastery of UMo full sized plates manufacturing
  - Good behaviour of IRIS 1 experiment for low irradiation conditions
  - Parametric simulation with the MAIA code for UMo dispersion fuel
  - Validation of the reprocessing of UMo spent fuel
  - Evidence of an unexpected unstable swelling for UMo disperion fuel

    With FUTURE experiment for the first time, confirmation with IRIS 2 results
- Facing the results of the F.UMo.G program, the international effort to develop UMo fuel has to be definitively rerouted
  - A new Development program has been defined

CEA & CERCA UMo extended program

Context

- Low enriched UMo fuel was elected as the reference fuel solution for the CEA Jules Horowitz Reactor project –JHR-
- CEA and CERCA have always contributed actively to the RERTR program
- CEA and CERCA signed in 2004 a collaboration agreement for studying and developing a suitable UMo fuel solution
  - Dispersed and monolithic UMo solution selected
  - CEA competencies and skill -Out-of-pile investigations, code, irradiation and postirradiation programs- are shared with CERCAs manufacturing knowledge.

CEA & CERCA UMo extended program

Main Technical program

- Fundamental knowledge investigation by means of out of pile investigation
  - Thermodynamic studies to determine, through the U-Mo-Al ternary system, the phase equilibria at different temperatures;
  - Out-of-pile metallurgical studies on diffusion couples for further understanding the mechanisms of the U-Mo/Al interaction and for testing parameters which could prevent such reaction.
  - Simulation studies to take into account the effects of irradiation using high-energy ion irradiation (damage simulatation created by fission products).
- Irradiation experiments program
  - Sustained by the preliminary out of pile studies
  - Carried-out on full size plates
    - UMo dispertion plate up to 8 gU/cc –IRIS III and IV-
    - Monolithic UMo plates –IRIS V-

CEA & CERCA UMo extended program

CEA & CERCA program schedule

UMo fuel investigation program	2004	2005	2006	2007	2008
Out-of pile investigation					
Aluminium matrix study -Si-					
U-Mo-Al ternary diagram					
Microstructure investigation					
IRIS 3 Irradiation Al2%Si and Al0,3%Si matrix			***Irradiation in progress -2 cycles in OSIRIS reactor***		
Plates manufacturing **-achieved-**					
Irradiation **-In progress-**					
PIEs					
IRIS 4 irradiation UMo "coated" particles			***Preliminary test performed***		
Feasability studies and plate manufacturing					
Irradiation					
PIEs					
IRIS 5 Irradiation Monolithic UMo fuel -ANL and CERCA plates-			***Manufacturing feasability launched***		
Feasability studies and plate manufacturing					
Irradiation					
PIEs					

CEA & CERCA UMo extended program

Status as of April 2004

- Out of pile investigation
  - Investigation result states during this conference by S.Dubois (CEA)
- Plates manufacturing and irradiation program
  - IRIS III experiment –Dispersion fuel / 230 W/cm2 and 90°C-
    - 4 UMo fuel size plates were manufactured by CERCA using Al2%Si and Al0,3%Si aluminum matrix
    - These plates were introduced in CEA OSIRIS reactor at the beginning of 2005 (2 cycles already performed).
  - IRIS IV experiment –Dispersion fuel-
    - CEA and CERCA are being investigated a way to produce advanced modified UMo particles
    - 4 plates will be manufactured, and introduced in OSIRIS at the beginning of 2006

CEA & CERCA UMo extended program

Status as of April 2004

- IRIS V -monolithic fuel-
  - CEA & CERCAs manufacturing challenge*
    - A scanning of the bounding technique as well as UMo foils production have been performed
    - UMo foils
      - U8Mo ingot was already manufactured
      - UMo foils are being produced by means of cold and hot rolling
    - Bounding methode
      - As proposed by ANL FSW technique is considered for the preliminary plates production
      - Other techniques are evaluated simultaneously
  - US and French monolithic UMo full size plates will be introduced in the CEA OSIRIS reactor at the beginning of 2006

**In cooperation with TUM*