IRIS3 experiment – Status and results of thickness increases

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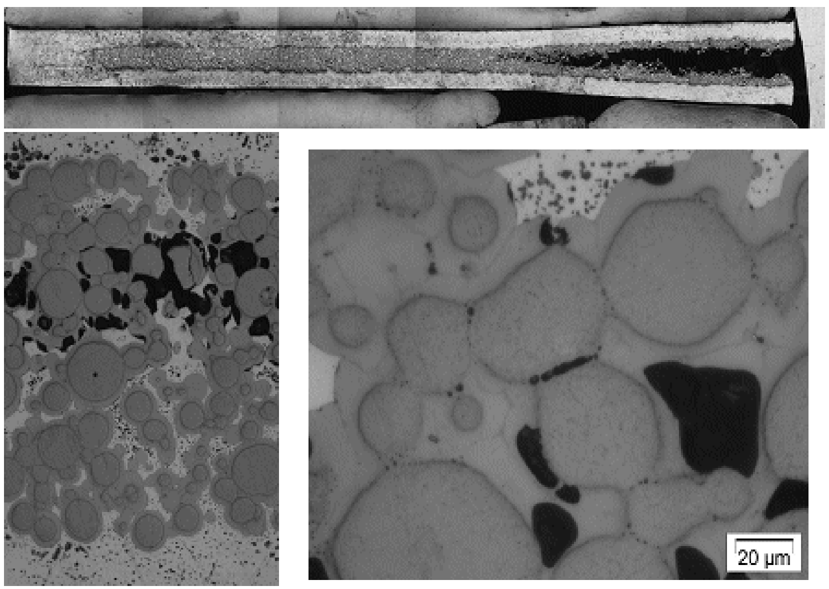
The IRIS3 experiment

- Introduction
- Objective
- Irradiation configuration (IRIS device)
- Irradiation conditions
- Thickness measurements
- Discussion of the Si effect
- Conclusion

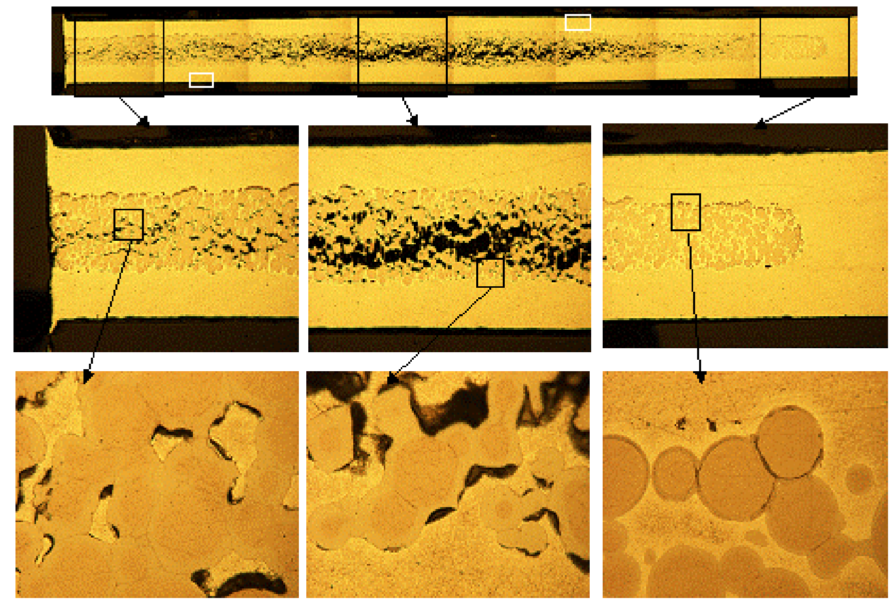
Flashback on early 2000's UMo/Al full-size tests

Past in-pile experiments have shown that atomised UMo fuel dispersed in Al matrix does not withstand high operating conditions.

IRIS 2



FUTURE



Extensive porosity appeared in the interaction layer

- ➢unacceptable pillowing and/or swelling of the fuel plate
- ➢dispersed UMo/Al fuel has to be improved

IRIS 3: the objective

Objective:

- evaluate the influence of adding Si to the Al matrix on the in-pile irradiation behaviour of UMo dispersed fuel.

Previous out-of-pile observations:

- Boucher 1959, Chakraborty 1971 showed that addition of Si (from 0.1 to 6 wt%) in U-Al alloys stabilizes UAl_3 and prevents formation of UAl_4.
- Bierlein 1955, De Luca 1957, Green 1957 showed on U-Al and U-AlSi diffusion couples that the penetration coefficient of U into Al is reduced by 10 to 100 in presence of 12 wt% Si.
- The Si addition to Al matrix could be promising to solve UMo/Al interaction (Hofman, Kim 2003).

IRIS-3 full-size test

IRIS 3 experiment:

- 4 UMo/AlSi full-sized plates
- irradiated in the IRIS device of OSIRIS reactor

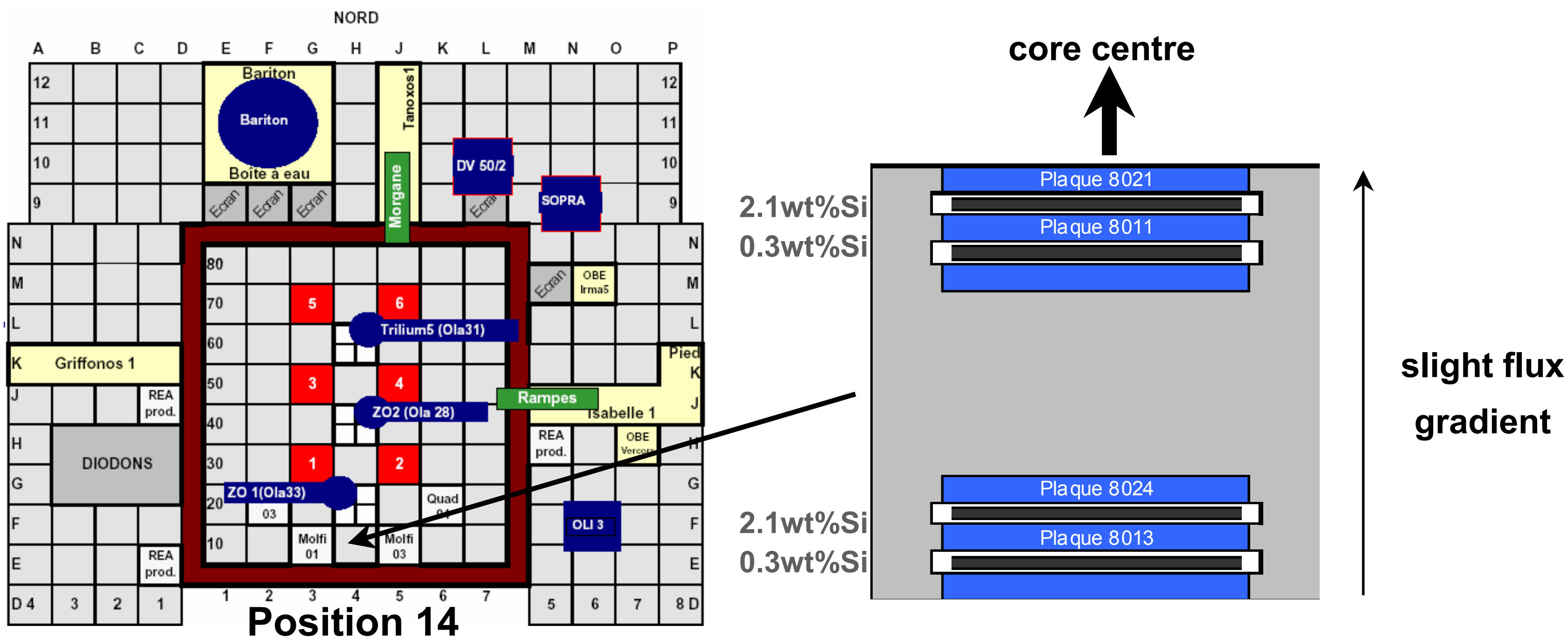
Plates manufacturing (CERCA):

- Low Enriched Uranium < 20% $^{235}U/U$
- high uranium loading (~ 8 $g_U.cm^{-3}$)
- U-7 wt%Mo alloy atomised powder
- low porosity ~1-2%
- Si amount in Al matrix : 0.3 and 2.1 wt%

Irradiation configuration

IRIS device of OSIRIS reactor

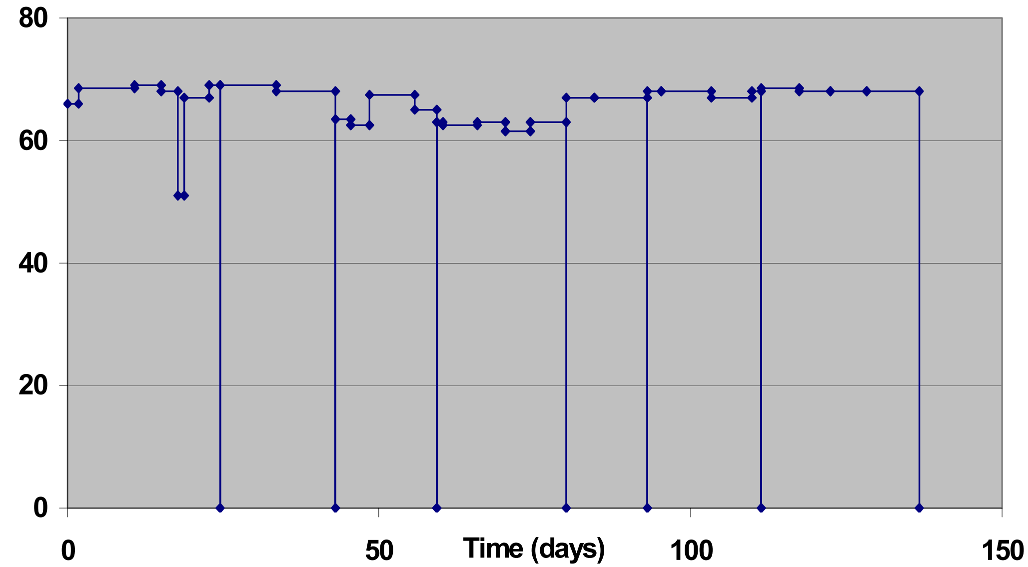
- 4 full-sized plates: 641x73x1.30mm^3 (meat thickness 0.51mm)
- plates removal after each reactor cycle
- associated to a in-pool plate thickness measurements device
- both transverse and longitudinal profiles recording



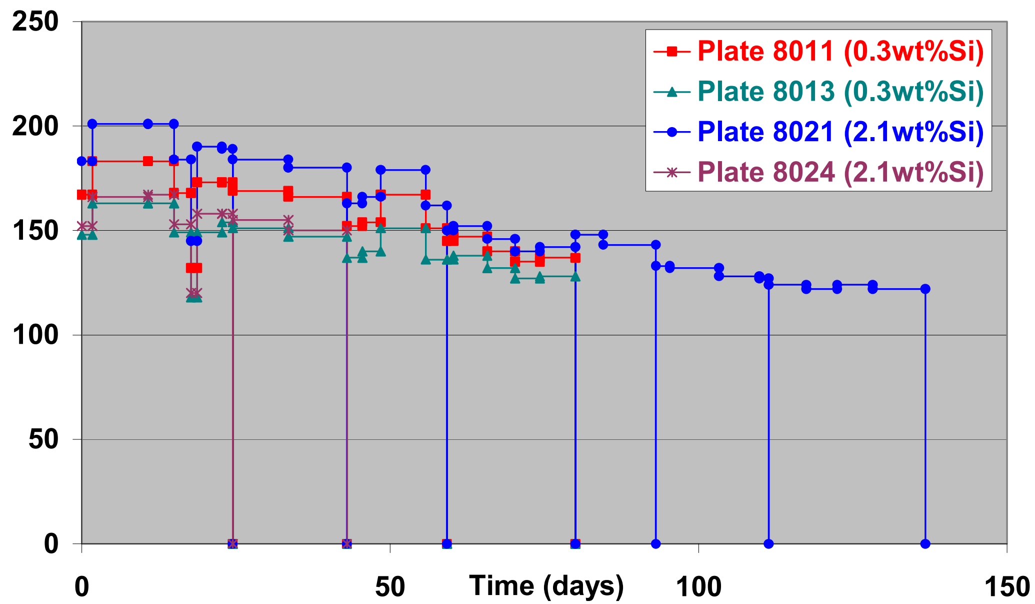
The irradiation began in January 2005 and ended in February 2006.

Irradiation conditions

OSIRIS power history (MW)



Peak heat flux ($W.cm^{-2}$)

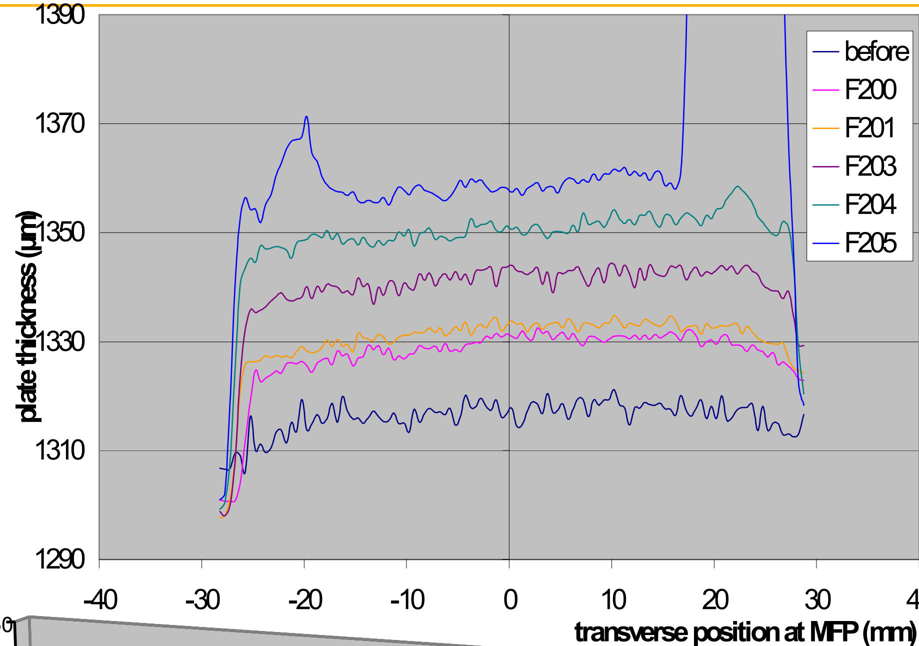


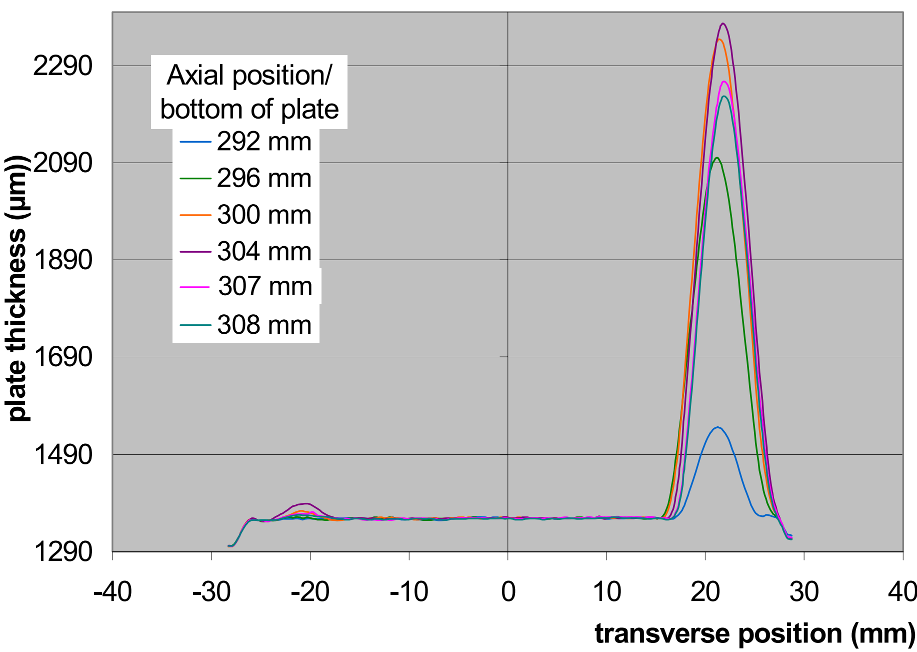
Thickness measurements: plate 8011 (0.3wt%Si)

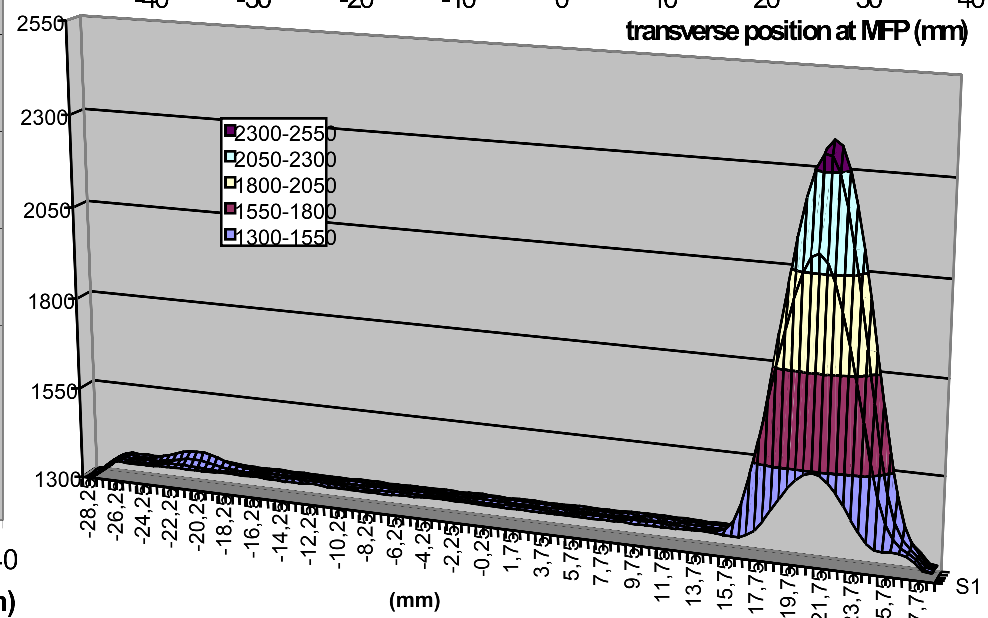
Classical swelling behaviour during the 4 first cycles, then sharp pillowing at ~ 2.8 10^{21}f.cm^{-3}

max thickness increase located at the Maximal Flux Plane is ~ 1 mm
>> 250 µm (admissible limit at OSIRIS)

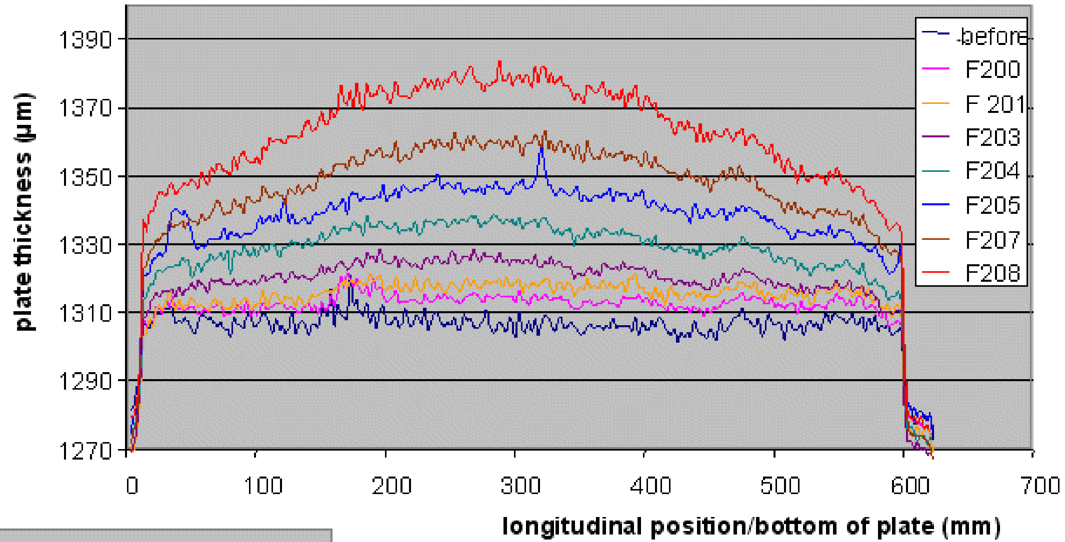
irradiation was stopped

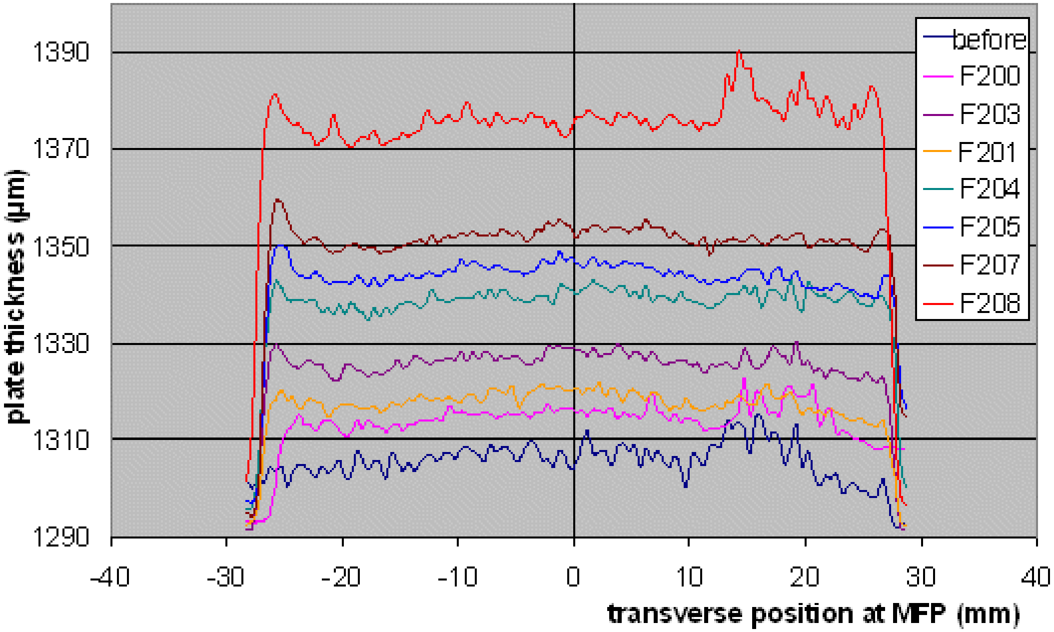






Thickness measurements: plate 8021 (2.1wt%Si)



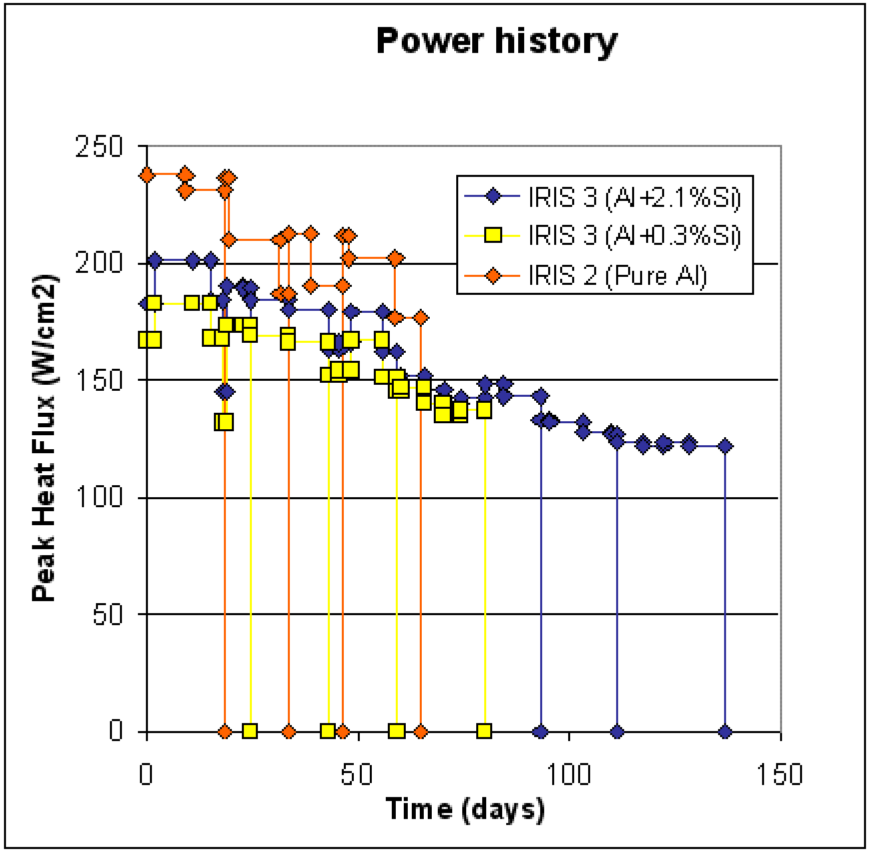


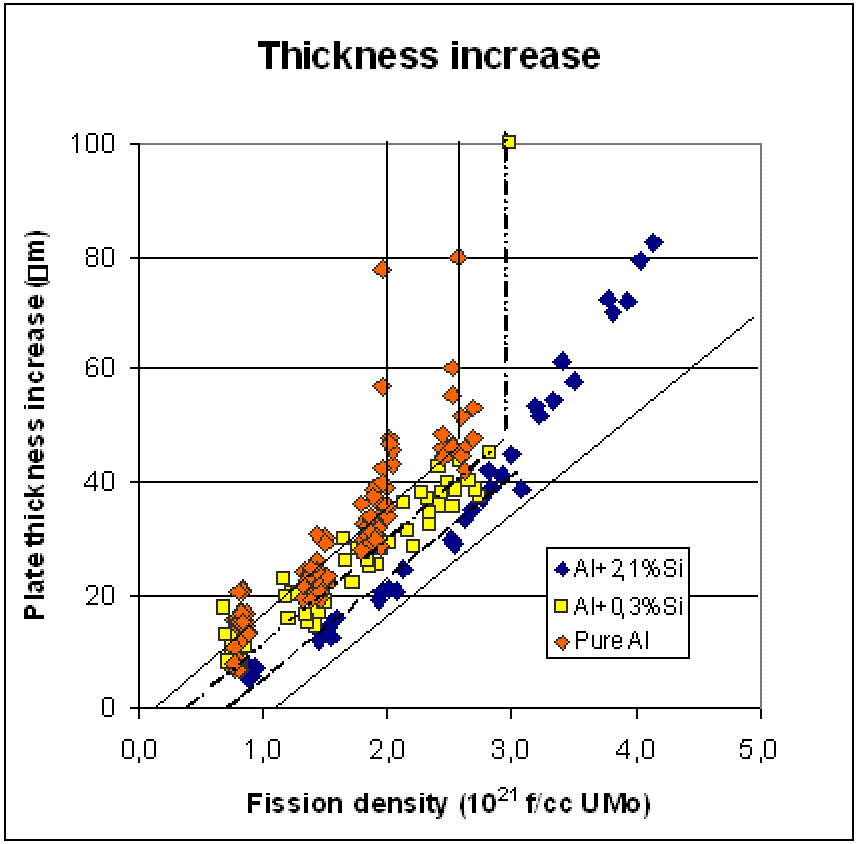
up to the end of irradiation ($4.1\ 10^{21}$ f.cm^{-3} at cycle F208, peak burn-up 60 ^{235}U%), no pillowing occurred

Effect of the Si addition to the Al matrix

Plate with 0.3 wt%Si → pillowing of ~1 mm at ~ 2.8 10^{21}f.cm^{-3}.
quite similar to the IRIS2 (pure Al matrix) behaviour

Plate with 2.1 wt%Si → max thickness increase < 85 µm up to 4.1 10^{21} f.cm^{-3}





Effect of the Si addition to the Al matrix

IRIS 3 results consistent with recent observations:

- Addition of Si in the Al matrix of UMo/Al-Si diffusion couples induces a modification of the interaction size, its composition and formation kinetics [Mirandou 2004].
- Palancher made the same observations in heavy ions irradiation studies (this conference).
- RERTR-6 showed same effect on U-7Mo mini-plates but studies on U-10Mo to be completed (this conference).

Conclusion

- ➢4 full-sized VHD U-7Mo/AlSi LEU plates up to 130.3 EFPD in OSIRIS
- ➢First worldwide in-pile experiment confirming the positive effect of 2.1% Si addition to Al matrix on atomised U-7wt%Mo dispersion fuel behaviour
- ➢First worldwide successful experiment on full-sized UMo/AlSi industrial plates at medium power (peak of 200 $W.cm^{-2}$) up to ~ 60 ^{235}U % burn-up.
- ➢Too weak effect of 0.3wt% Si addition to Al matrix.

✓For operational use, the Si addition to the Al matrix should be tested at higher irradiation conditions (flux and BU).

✓ destructive PIEs (optical µscopy, XRD, EPMA) needed for a further understanding of the phenomenology in the U-Mo-Al-Si system (interaction layer fraction, composition…) and planned by the end of 2006.

Irradiation conditions (2)

			Plate 8011			Plate 8013			Plate 8021			Plate 8024		
			Al+0.3wt%Si			Al+0.3wt%Si			Al+2.1wt%Si			Al+2.1wt%Si		
N°	Cycle	EFPD	F_d	BU	PHF	F_d	BU	PHF	F_d	BU	PHF	F_d	BU	PHF
1	F200	24	**0.81**	**11.8**	**183**	0.71	10.3	163	**0.88**	**12.8**	**201**	0.74	10.7	167
2	F201	42	**1.4**	**20.2**	**169**	1.2	17.8	151	**1.5**	**21.7**	**184**	1.3	18.5	155
3	F203	57	**1.9**	**27.3**	**167**	1.7	24.1	151	**2.0**	**29.15**	**179**	**Irradiation was stopped**		
4	F204	76	**2.4**	**35.2**	**147**	2.2	31.7	138	**2.6**	**37.2**	**152**			
5	F205	88	**2.8**	**40.2**	**144**	2.5	36.5	137	**2.9**	**42.2**	**148**			
6	F207	106	**Irradiation was stopped (pillowing)**			**Irradiation was stopped**			**3.3 (peak=3.5)**	**48.5 (peak=51)**	**133**			
7	F208	130							**3.9 (peak=4.1)**	**56.5 (peak=59.3)**	**124**			

$T_{max\ BOL}$ (clad) = 83°C

F_d (fission density in 10^{21} fissions.cm^{-3} UMo) and BU (burn-up in ^{235}U at. %) are average values at Maximal Flux Plane

PHF stands for Peak Heat Flux (in W.cm^{-2}) and EFPD for Equivalent Full Power Day