Instrumented fuel plate for IRIS irradiation program

CEA Saclay (France)

E-mail : patricia.boulcourt@cea.fr

Outline

- Context (fuel qualification)
- IRIS device and its associated equipments
- The « Instrumented IRIS device »
- Tests performed in April 2004
- Results

Context

- CEA engaged in fuel qualification for research reactors → tool: IRIS device

- Initially, IRIS devices have been designed for heat flux greater than 275 W/cm²
  → limited to 231 W/cm²

☞ For higher heat flux, the french regulator required that CEA completes the qualification of thermal hydraulic computer codes for steady states and transients

IRIS device

Material : AG3NET

Dimensions :

- section 82,2 x 82,4 mm (as a standard fuel element in OSIRIS)
- total height : 950 mm

Content :

- 4 full-sized fuel plates
- 4 crimped aluminum plates

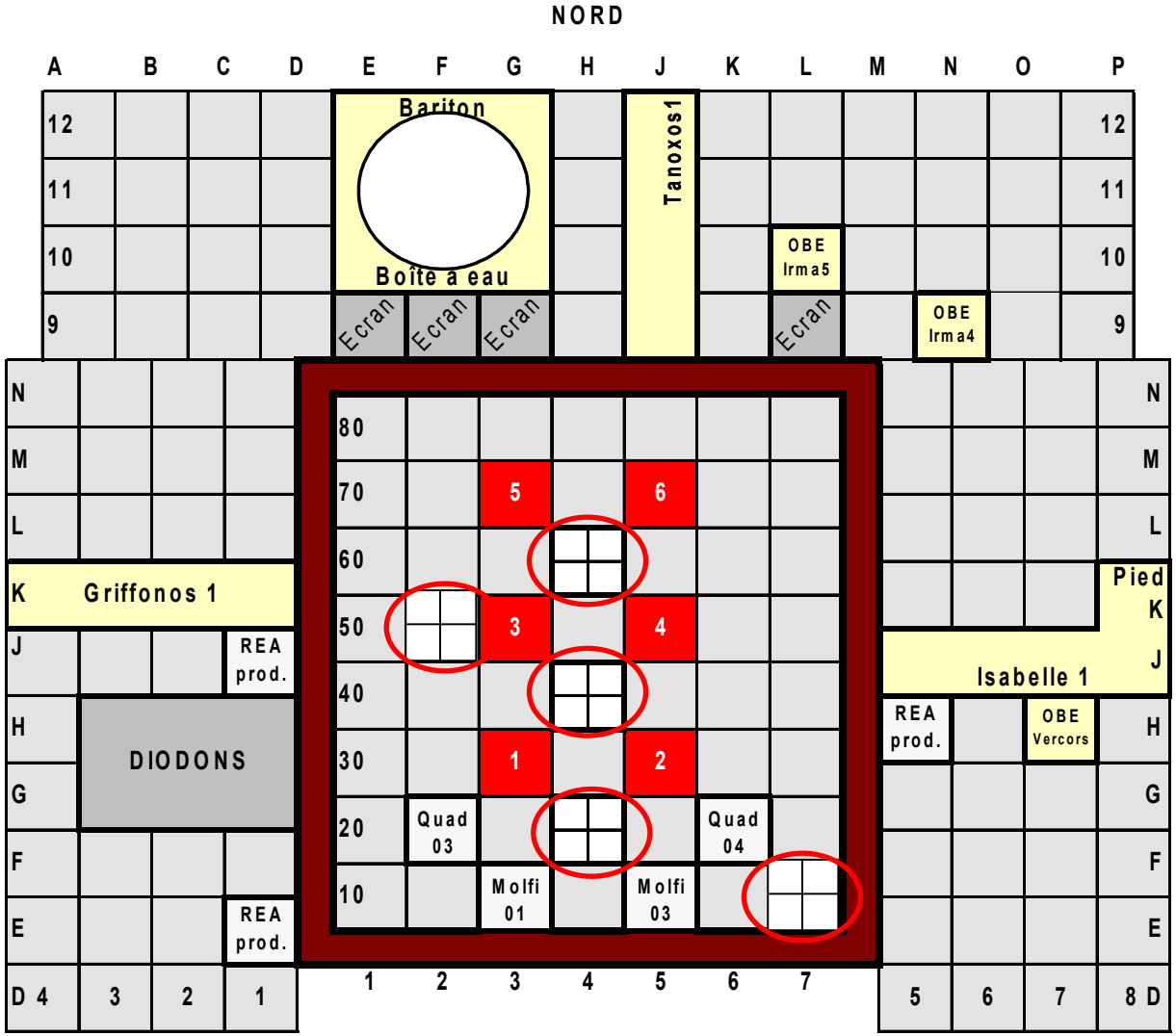
Dimensions of the fuel plates :

641.9 x 73.3 x 1.27 mm

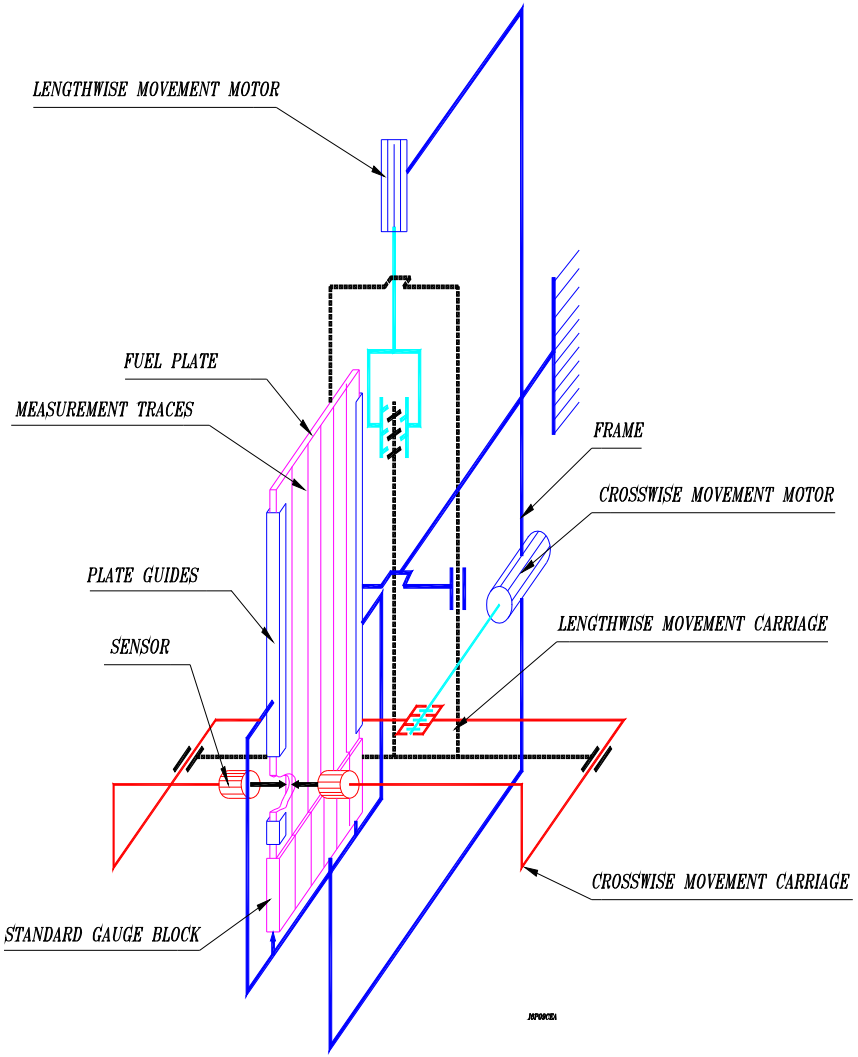
Maximum dimensions of the fuel zone :

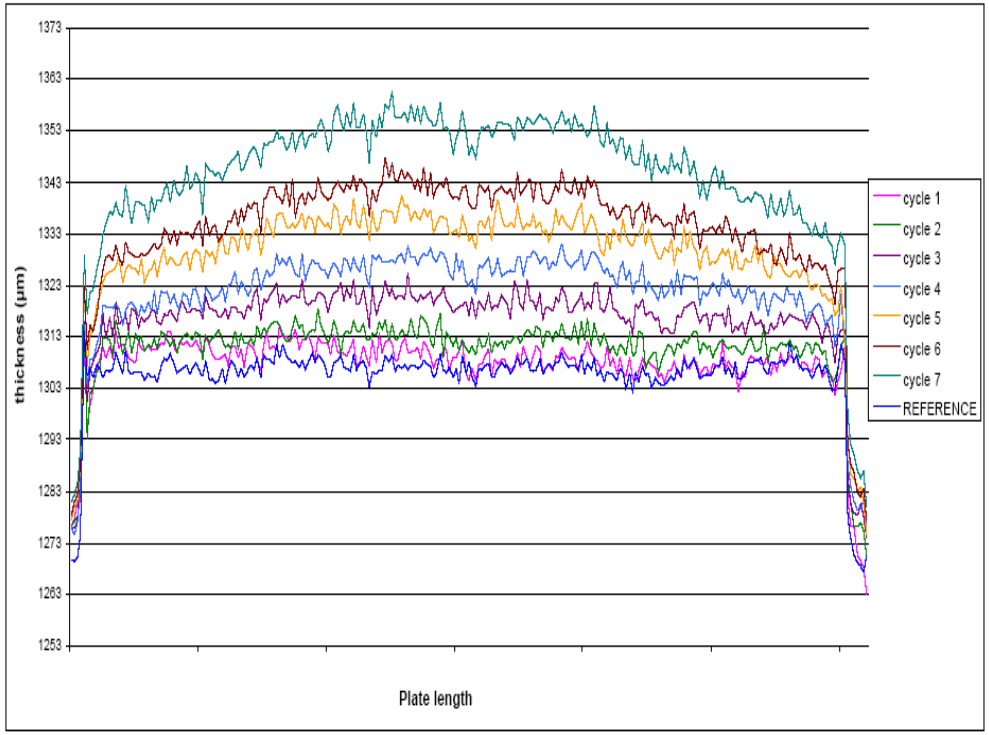
609.5 x 65.4 x 0.7 mm

IRIS location in OSIRIS



Measurement device

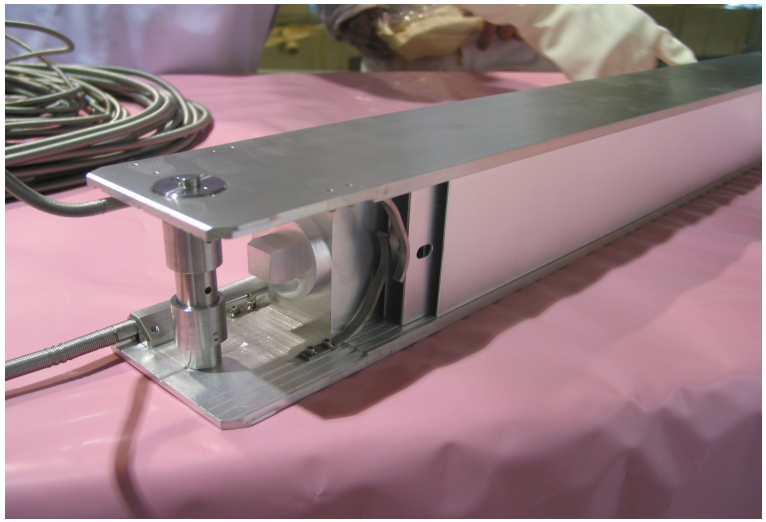


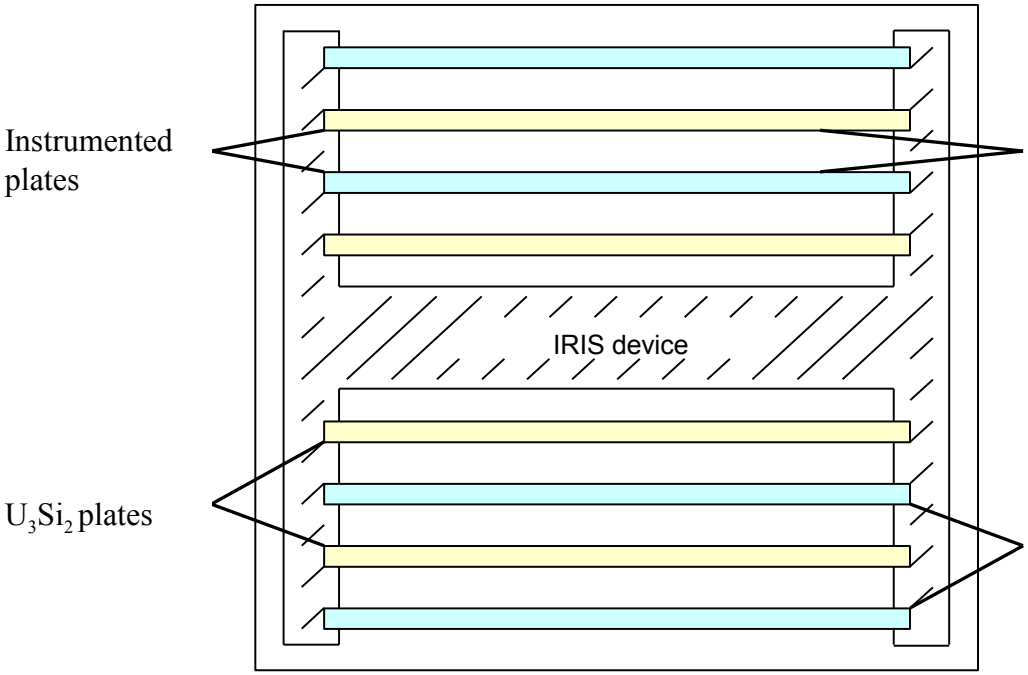


Thickness measurements

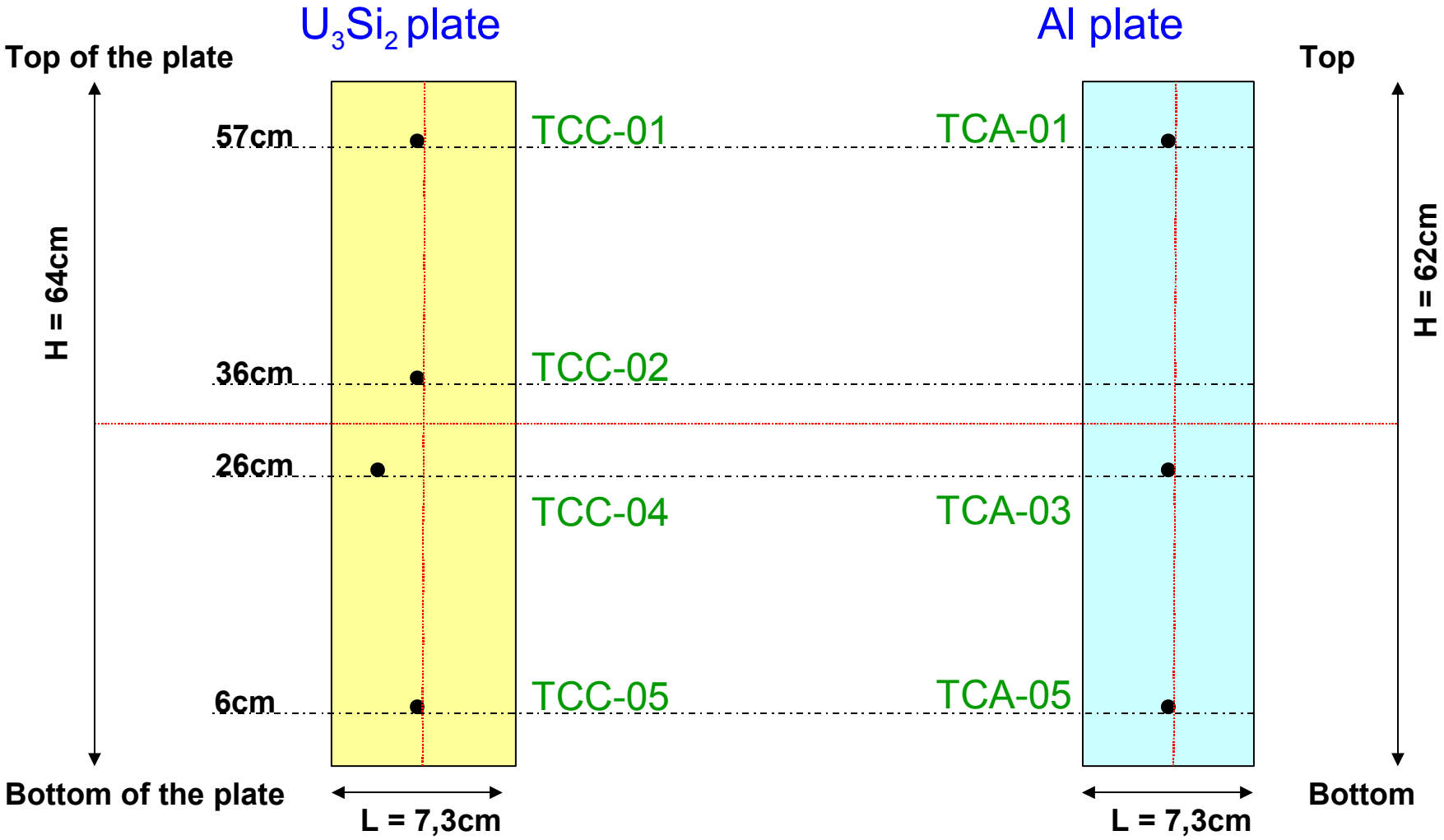
Instrumented IRIS device

- 4 U_3Si_2 plates (5 TC K-type)
  - ^{235}U enrichment = 19,75 %
  - Density = 4,8 gU_{tot}/cm^3
- 4 aluminum plates (3 TC K-type)





Thermocouples location in the plates



Safety authority request

- To complete the qualification of thermal hydraulic computer codes for steady states and transients

$$P_{\max}^{before\_transient} = \min\left[P_{231W/cm2}^{reactor}, P(T_{transient}^{standard.elt} \le T_{70MW}^{standard.elt}) \right]$$

- <u>One condition</u> :
  - Check during steady states that $T_{calculated} \approx T_{measured}$ otherwise, stop the experiment before the transient
  - One TC among TC 2 and 3 and one among TC 1,4,5

Procedure of the tests
2 days (52nd an 17th location in OSIRIS)

- Before experiment : calculation of cladding temperatures
- Increase of the power by steps of 10 MW,
- Thermal balance at 40 and 63 MW
- Comparison with calculated temperatures
- Stop of the 3 primary pumps
  - Drop of control rods
  - Opening of natural convection valves
- All along the experiment, recording of thermal hydraulic parameters (Q, T, P every second during steady states and every 0,1 s during the transient)

Measured and calculated temperatures during the steady state phase

TC n°, Reactor power (MW)	
Tm+ΔT	Tc (P+10 %, Q-8%)
Tm	Tc (FLICA b.e.)

Results in the 52nd location of the core :

TC2, 40 MW	
63,1	64,2
61,9	59,7

TC2, 63 MW	
83,6	86,8
82,4	80,1

TC1, 40 MW	
53,5	56,3
52,3	52,7

TC1, 63 MW	
69,6	75,2
68,4	69,9

Results in the 17th location of the core :

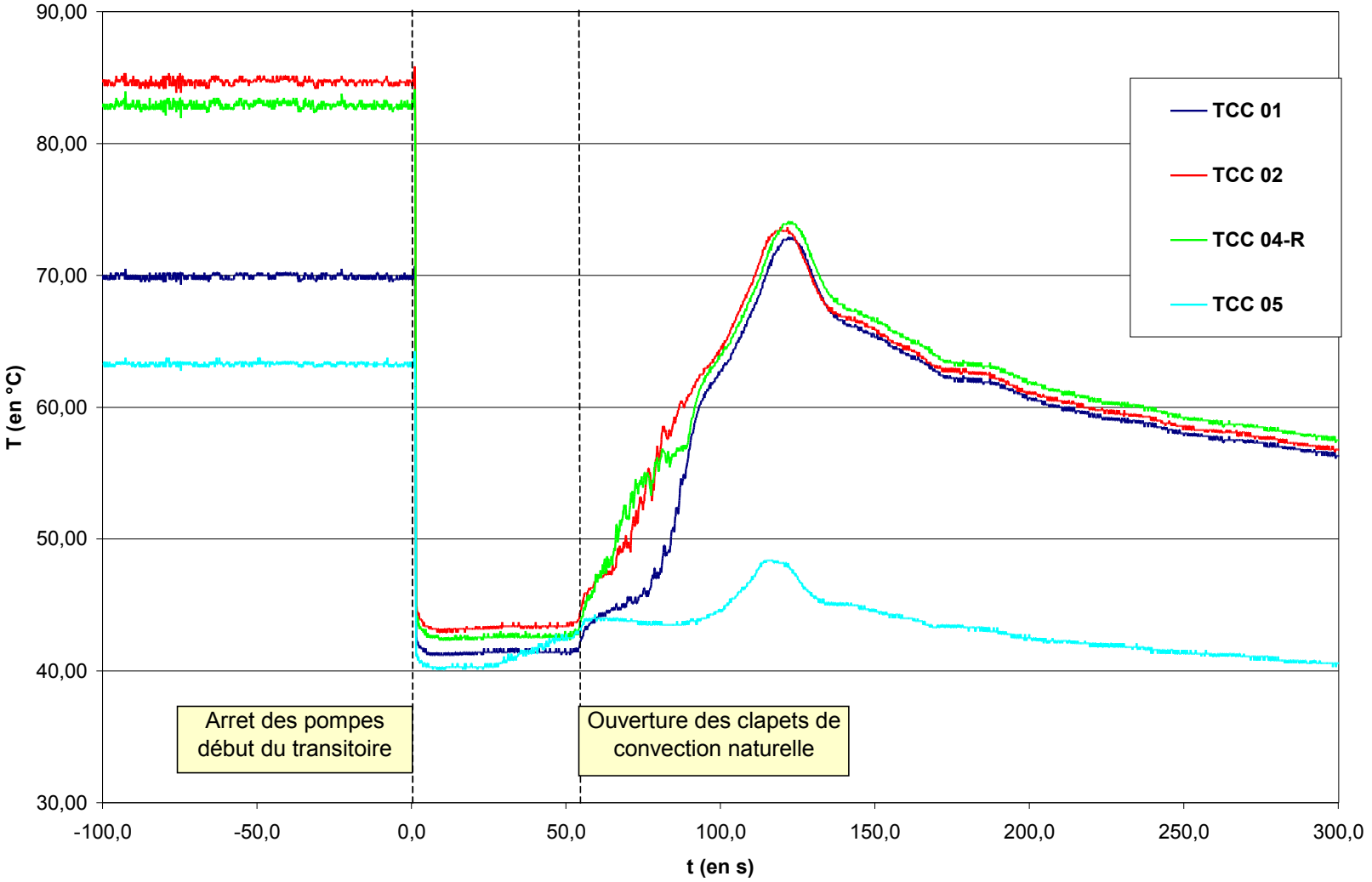
TC2, 40 MW	
46,4	47,7
45,2	45,4

TC2, 63 MW	
60,4	62,6
59,2	59

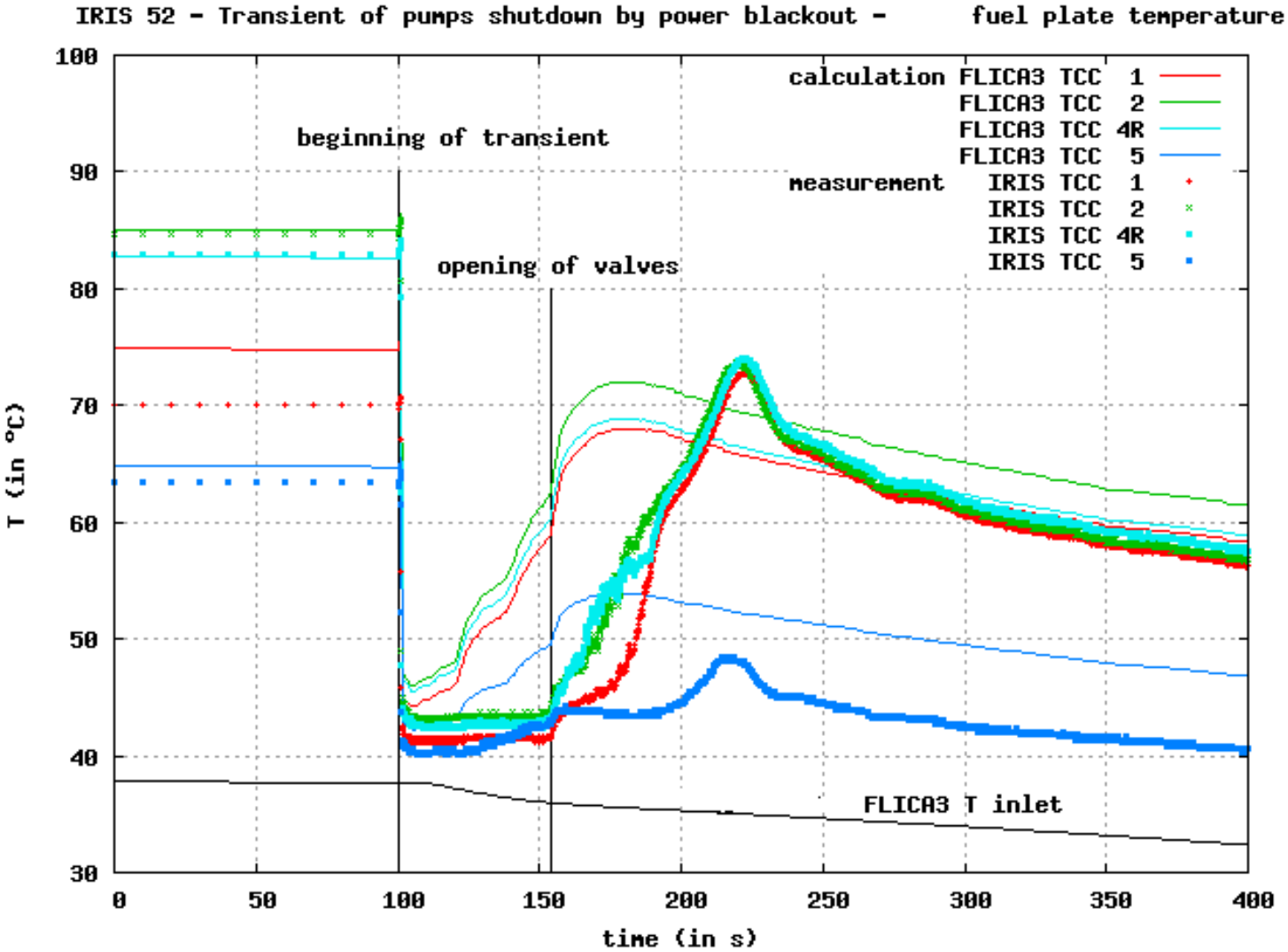
TC1, 40 MW	
42	43,6
40,8	41,8

TC1, 63 MW	
53,8	56,3
52,6	53,6

Measurement results in location 52



First calculation results with SIRENE-FLICA code



Law of flow decrease

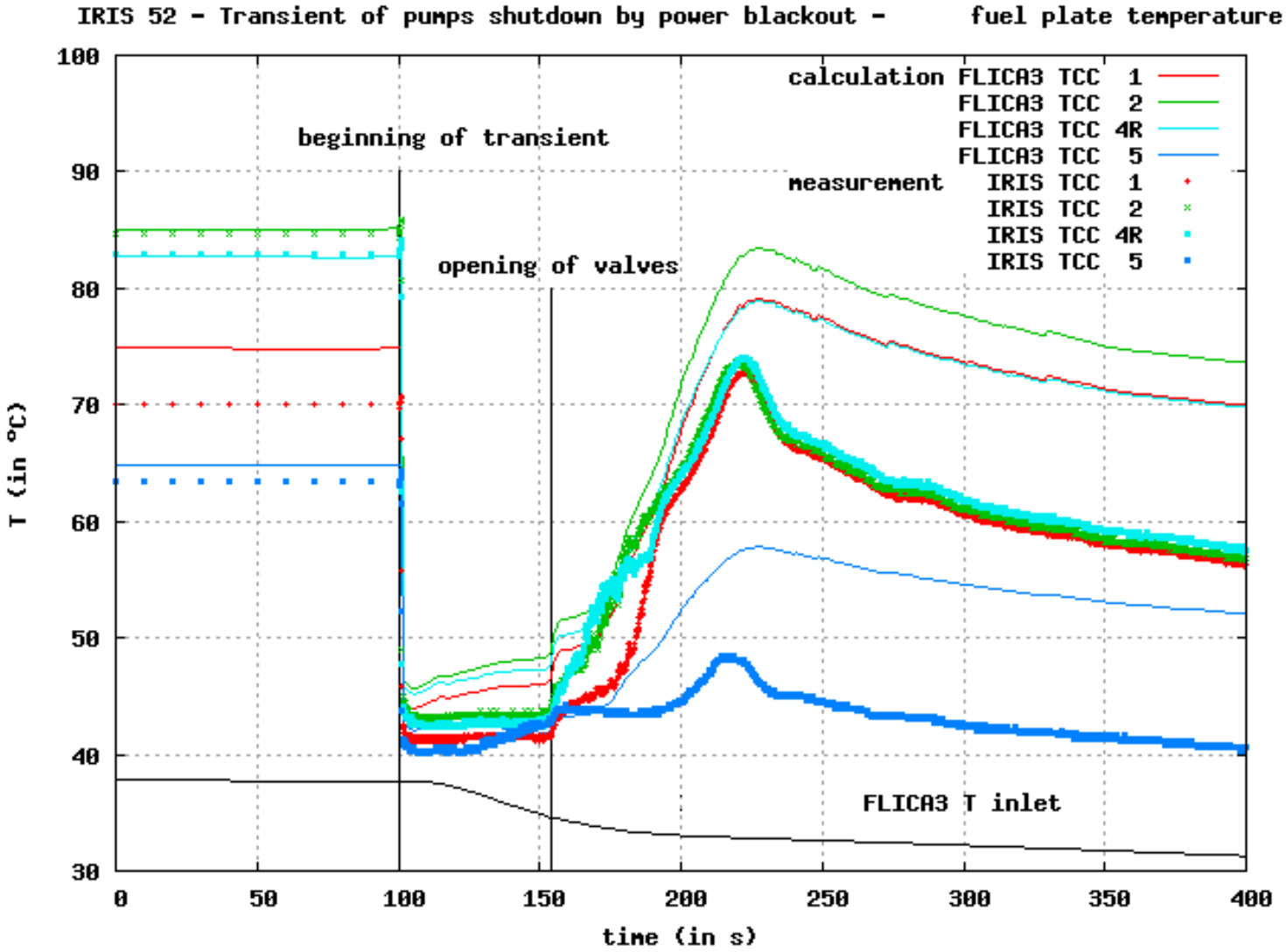
- for t < 54 s :

The law of flow decrease has been deduced from the difference of pressure measured during the transient phase in the reactor core

- for t > 54 s :

The flow law has been evaluated such as the calculated temperatures in the instrumented plate fit exactly to the measured ones.

Results after flow adaptation

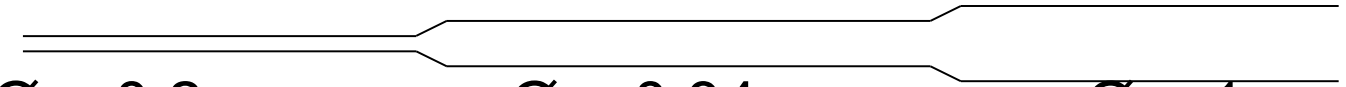


Conclusions

- First calculation :
  - ➢ very good agreement during steady states
  - ➢ transient : increase of temperature occurred too early but maximum value very close to reality (≠ 3°C)
- After adaptation of the flow law, good agreement during all phases and conservative temperatures
- This experiment contributes to the qualification of thermal hydraulic computer codes but also validates neutronic calculations which are made in amount
  - ➢ Whatever the location of the IRIS device in the core, good knowledge of the irradiation conditions (P, T, B-up)
- Specific authorization for an experiment a little greater than 300 W/cm^2 obtained

Thermocouples setting

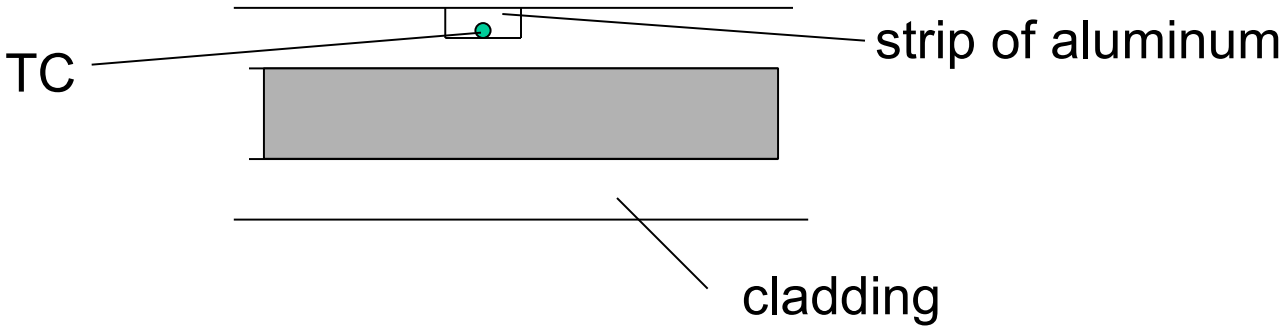
- each TC has different diameters according to its location in the plate



Ø = 0.2 mm (13 or 38 mm)

Ø = 0.34 mm (82 to 592 mm)

Ø = 1 mm (15 m)



Law of flow decrease

- for t < 54 s :

$$\Delta P_{frottement} = C_f \cdot \frac{Q^2}{2\rho . D_h . S^2} \quad \text{with} \quad C_f = 0.2\left(\frac{Q.D_h}{S.\mu}\right)^{-0.2}$$

in planed channel for Re > 5000

$$\frac{Q(t)}{Q_0} = \left(\frac{DP^{coeur}(t)}{DP_0^{coeur}}\right)^{0.56}$$

- for t > 54 s :

t(s)	% $Q_{nom.init}$
54	10
70	7
90	3
120	1
>170	1.2

Instrumented IRIS plate in 52

Data	Initial value stabilised at the beginning of the transient t = 0s		Evolution before opening of the clapets 3s < t < 54s		Maximal value after opening of the clapets t > 54s	
	Mes.	Calcul.	Mes.	Calcul.	Mes.	Calcul.
TCC-01 TCC-02 TCC-04 rec TCC-05	70 °C 85 °C 83 °C 63 °C	74 °C 84 °C 82 °C 64 °C	41 → 41 °C 43 → 43 °C 43 → 43 °C 40 → 42 °C	43 → 46 °C 45 → 48 °C 45 → 47 °C 41 → 41 °C	73 °C à t = 122 s 74 °C à t = 120 s 74 °C à t = 122 s 48 °C à t = 117 s	83 °C à t = 123 s 79 °C à t = 123 s
TCA-01 TCA-03 TCA-05	40 °C 38 °C 38 °C	43 °C 39 °C 37 °C	38 → 37 °C 38 → 37 °C 37 → 36 °C	38 → 36 °C 37 → 35 °C 37 → 34 °C	49 °C à t = 125 s 44 °C à t = 121 s 38 °C à t = 120 s	57 °C à t = 128 s 39 °C à t = 124 s absent

Instrumented IRIS plate in 17

Data	Initial value stabilised at the beginning of the transient t = 0s		Evolution before opening of the clapets 3s < t < 54s		Maximal value after opening of the clapets t > 54s	
	Mes.	Calcul.	Mes.	Calcul.	Mes.	Calcul.
TCC-01 TCC-02 TCC-04 rec TCC-05	54 °C 61 °C 60 °C 50 °C	56 °C 62 °C 63 °C 51 °C	39 → 38 °C 41 → 40 °C 41 → 40 °C 38 → 39 °C	41 → 42 °C 42 → 43 °C 42 → 43 °C 40 → 39 °C	s 58 °C à t = 124 s 59 °C à t = 127 s 43 °C à t = 120 s	57 °C à t = 121 s 60 °C à t = 121 s 59 °C à t = 121 s 47 °C à t = 121 s
TCA-01 TCA-03 TCA-05	39 °C 38 °C 37 °C	40 °C 39 °C 38 °C	37 → 36 °C 37 → 36 °C 37 → 36 °C	38 → 37 °C 38 → 37 °C 37 → 36 °C	44 °C à t = 130 s 40 °C à t = 124 s 36 °C à t = 120 s	43 °C à t = 121 s 39 °C à t = 121 s 37 °C à t = 121 s

Gamma spectrometry

- 3 goals :
  - to obtain spatial distribution of counting rate of the main fission products :
    - ^{140}Ba-La, ^{103}Ru, ^{95}Zr (representative of the power)
    - ^{137}Cs (representative of the burn-up)
  - to quantify the average fission product activities, in the maximum power area → calculated activities of the main fission products are compared to measured ones (M/C ratio)
  - to evaluate the burn up of the fuel
- Results (IRIS 1 and 2) :
  - 0.9 < M/C < 1.1