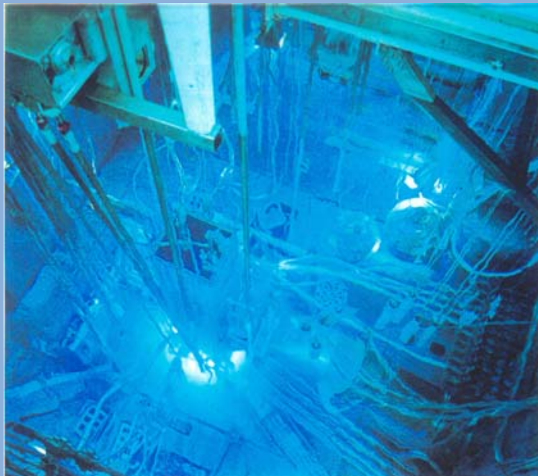
Safety assessment of IRIS experiments in the OSIRIS reactor

Research Reactor Fuel Management 2006, Sofia

N. FOURNIER, L. BERTRAND, J. COUTURIER

IRSN



SUMMARY

1. Introduction

Presentation of the OSIRIS reactor
Presentation of the IRIS device

2. Irradiation-related safety issues in the IRIS device

Authorization process
History

3. Safety assessment of IRIS experiments

Risks assessed
Compliance with thermal hydraulic safety criteria

- Qualification of thermal hydraulic calculation codes
- Verification of pressure drop in the IRIS device
- Verification of axial power distribution
- Risks related to the swelling of the fuel plates
- Calculation assumptions in transient conditions

4. Conclusion

Presentation of the OSIRIS reactor and the IRIS device

Presentation of the OSIRIS reactor

Research reactor operated by CEA

Site : Saclay, France

70 MW pool type water reactor with open core

Core :

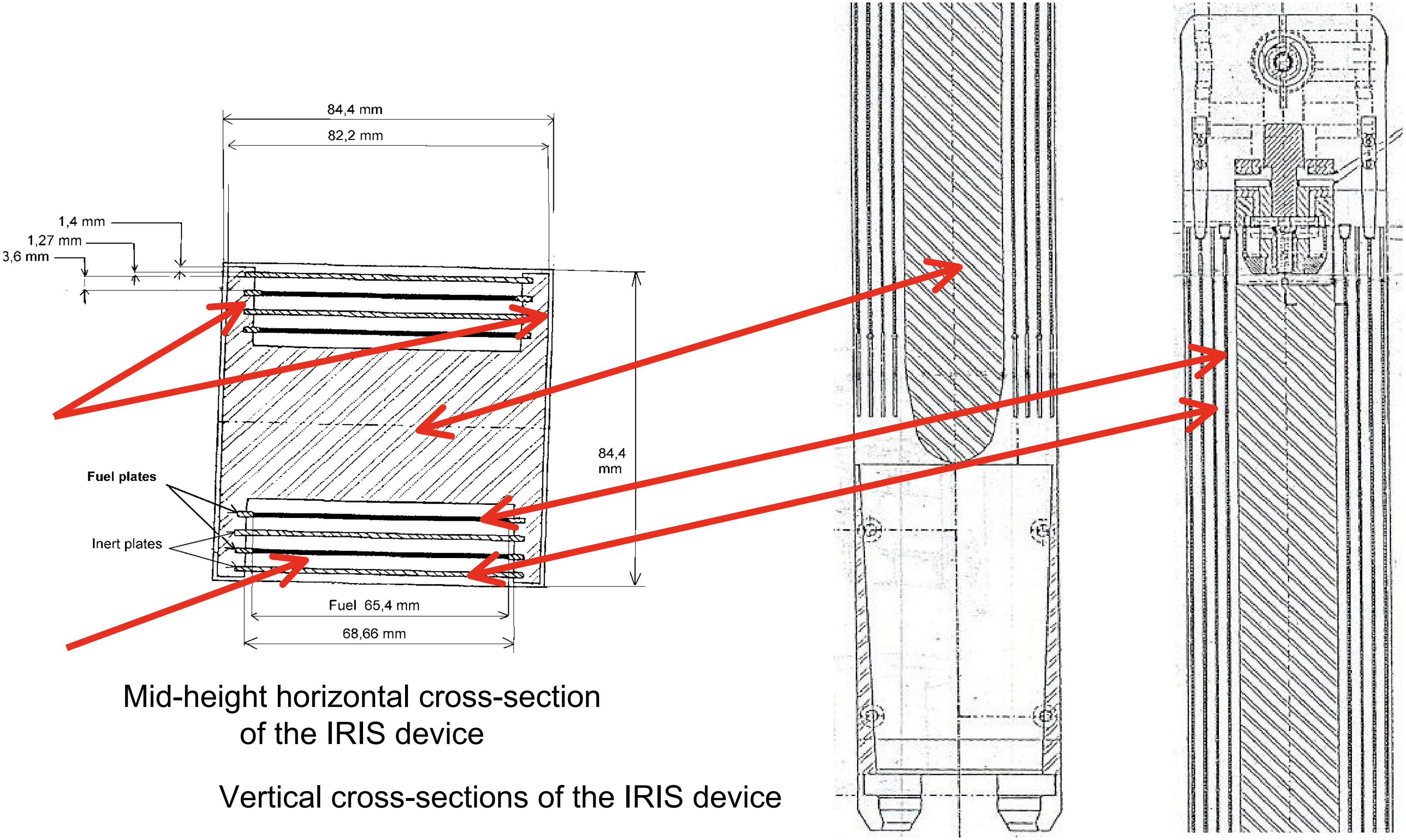
- Silicide (U_3Si_2) fuel plates enriched with 19,75% ^{235}U
- 38 standard fuel elements, 6 control elements
- Irradiation units inside and outside the core

Cooling :

- Light water upward cooling flow
- Natural convection in the core
  when decreasing the flow rate
  in permanent low power conditions

Presentation of the IRIS device (1/3)

In-pile section : irradiation unit (aluminium alloy)



Mid-height horizontal cross-section
of the IRIS device

Vertical cross-sections of the IRIS device

Presentation of the IRIS device (2/3)

Exterior of the device identical to a standard element

→ Loaded into one of the experimental cells in the reactor core

Out-of-pile device used for measuring plates thickness

No instrumentation of the IRIS device

→ Device employed to measure the swelling of the plates after each cycle of the reactor

IRIS plates are monitored identically to the OSIRIS fuel elements (cladding rupture detection, tensile tests, vibration measurements)

Presentation of the IRIS device (3/3)

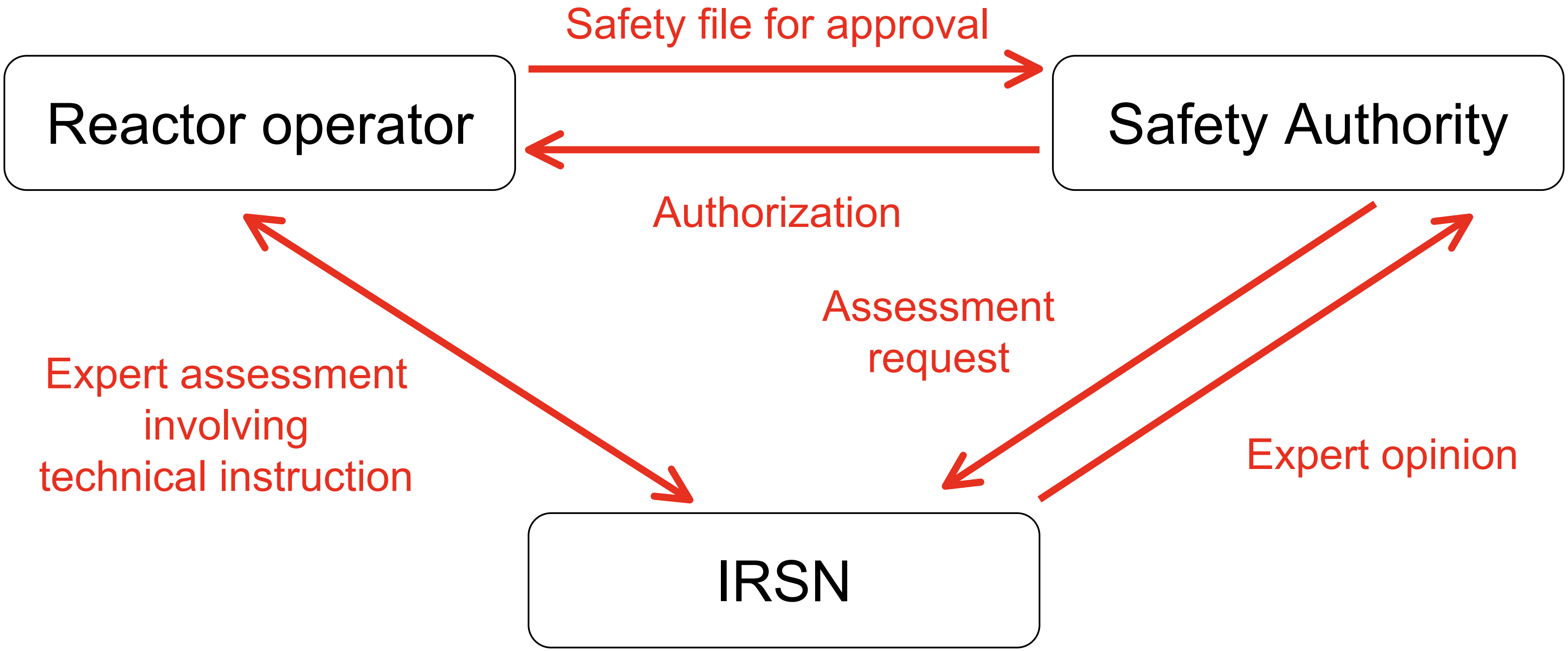
Purpose : new fuel type qualification

UMo fuel for the TUM FRM-II reactor (enriched to 50 % ^{235}U)

UMo and U_3Si_2 fuel for the future JHR reactor

Irradiation-related issues in the IRIS device

Authorization process



Safety file for approval

Reactor operator

Safety Authority

Authorization

Assessment
request

Expert assessment
involving
technical instruction

Expert opinion

IRSN

Authorization process for IRIS experiments (1/4)

Operator’s request

- Various fuel types
- Various heat fluxes
- Various core cells

→ Safety analysis based on an « operating range »

- Maximum heat flux at the hot point : 300 W/cm^2
- Maximum meat dimensions : 609,5 x 65,4 x 0,7 mm^3
- Maximum mass of U_{total} : 500 g per plate
- Maximum mass of ^{235}U : 100 g per plate
- Maximum burn-up : 80 %
- Maximum reactivity : 500 pcm
- …

Authorization process for IRIS experiments (2/4)

History

1999

- Request by the operator, at a maximum heat flux of 275 W/cm²

2002

- Request by the operator, at a maximum heat flux of 277 W/cm²

In both cases, based on the IRSN assessment, the Safety Authority ordered the operator to limit the maximal heat flux to 231 W/cm² (maximum value authorized for standard fuel elements)

Authorization process for IRIS experiments (3/4)

Causes of this restriction

- The thermal hydraulic computer codes used had not been sufficiently validated to demonstrate the lack of harmful thermal hydraulic phenomena, particularly during incident and accident transients

- Reservations about the changes in the axial shape factor of the neutron flux during irradiation (influence of control assembly movements)

- Uncertainties over the calculation of the neutron flux radial distribution

Directive from the Safety Authority
to irradiate instrumented fuel plates in the IRIS device

Authorization process for IRIS experiments (4/4)

History (continued)

2005

- Request by the operator, at a maximum heat flux of 300 W/cm^2
- Based particularly on the results of the irradiation of instrumented fuel plates in the IRIS device
- Response to IRSN's reservations

IRIS experiments safety assessment

Risks included in the safety file presented by the operator

- X Thermal hydraulic risks relating to a loss of cooling in the experimental fuel channels

  → Determination of the maximum heat flux at the hot point

- Control of the reactivity, prevention of plate or device lift-off

- Plates and device mechanical resistance

- Storage conditions of new and irradiated fuel plates (sub-criticallity control)

- Radiological risks

- Plates behaviour under irradiation

In 1999 and 2002, IRSN considered this analysis as acceptable, except in the case of the thermal hydraulic risks

Compliance with thermal hydraulic safety criteria (1/3)

The criteria's aim is to prevent all deterioration in the cladding of the experimental fuel plates

by boiling

by local or general drying out of the cooling channel

The same criteria are used for the OSIRIS reactor

No nucleate boiling under normal operating conditions

- with all thermal hydraulic parameters (power, flow rate, temperatures, pressures) taken at <u>alarm</u> thresholds
- in permanent conditions of forced and natural convection

Compliance with thermal hydraulic safety criteria (2/3)

No redistribution of flow rate or departure from nucleate boiling in the channels

- with all thermal hydraulic parameters (power, flow rate, temperatures, pressures) taken at <u>protection</u> thresholds
- assuming also that the reactor would be operated in these conditions

No redistribution of flow rate or departure from nucleate boiling in the channels during flow rate transients

- reactor coolant pumps shut down with allowance for the inertia of their flywheel
- loss of three reactor coolant pumps with wheel blocked on one pump and taking into account the flywheel inertia of the other two
- guillotine break in the reactor coolant system piping

Compliance with thermal hydraulic safety criteria (3/3)

Approach adopted by the operator

Determination of the limit values of the heat fluxes corresponding to reaching the thermal hydraulic phenomena in permanent conditions

Determination of the values of the heat fluxes corresponding to reaching the thermal hydraulic phenomena during flow rate transients

The lowest of the heat fluxes thus determined is adopted as being the maximum heat flux permitted

Uncertainties are deducted from this power value

A neutron flux calculation is performed to check that the actual heat flux at the hot point is lower than the maximum value

Assessment performed by IRSN (1/13)

Qualification of thermal hydraulic calculation codes

The codes have been validated for the OSIRIS reactor core

- FLICA and SIRENE for the thermal hydraulic calculations
- APOLLO 1 and DAIXY for the neutron flux calculations

But the coolant channels of the IRIS device are :

- wider than for the standard and control elements of the OSIRIS core (3.6 vs. 2.46 and 2.79 mm)
- heated unilaterally

In 1997, measures had been carried out in an instrumented OSIRIS standard fuel element which concluded to discrepancies in the results, perhaps due to a bad modelling

IRSN expressed reservations about the calculations performed by the operator

Assessment performed by IRSN (2/13)

Instrumented fuel element

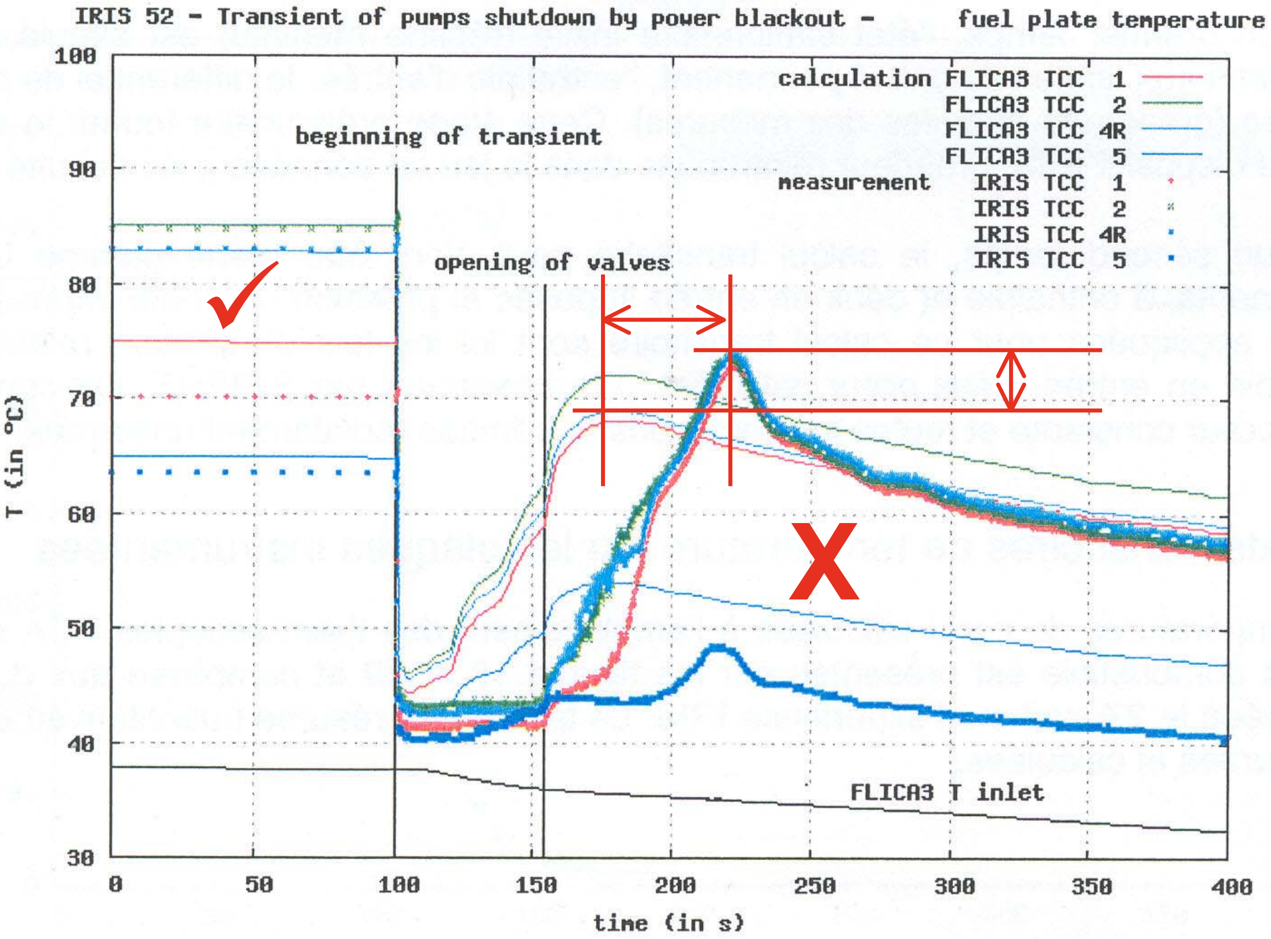
Measures of the temperature of the cladding of the instrumented fuel plates

- in two different core cells
- in permanent conditions and during a shutdown of the primary pumps with allowance for the inertia of their flywheel

Results

- in permanent conditions : good compatibility between calculations and measurement
- during the transient : lag between calculations and measurements and under-estimation of the calculated maximum temperature

Assessment performed by IRSN (3/13)



Temperature calculation on the instrumented fuel plate before « realignment »

Assessment performed by IRSN (4/13)

Interpretation

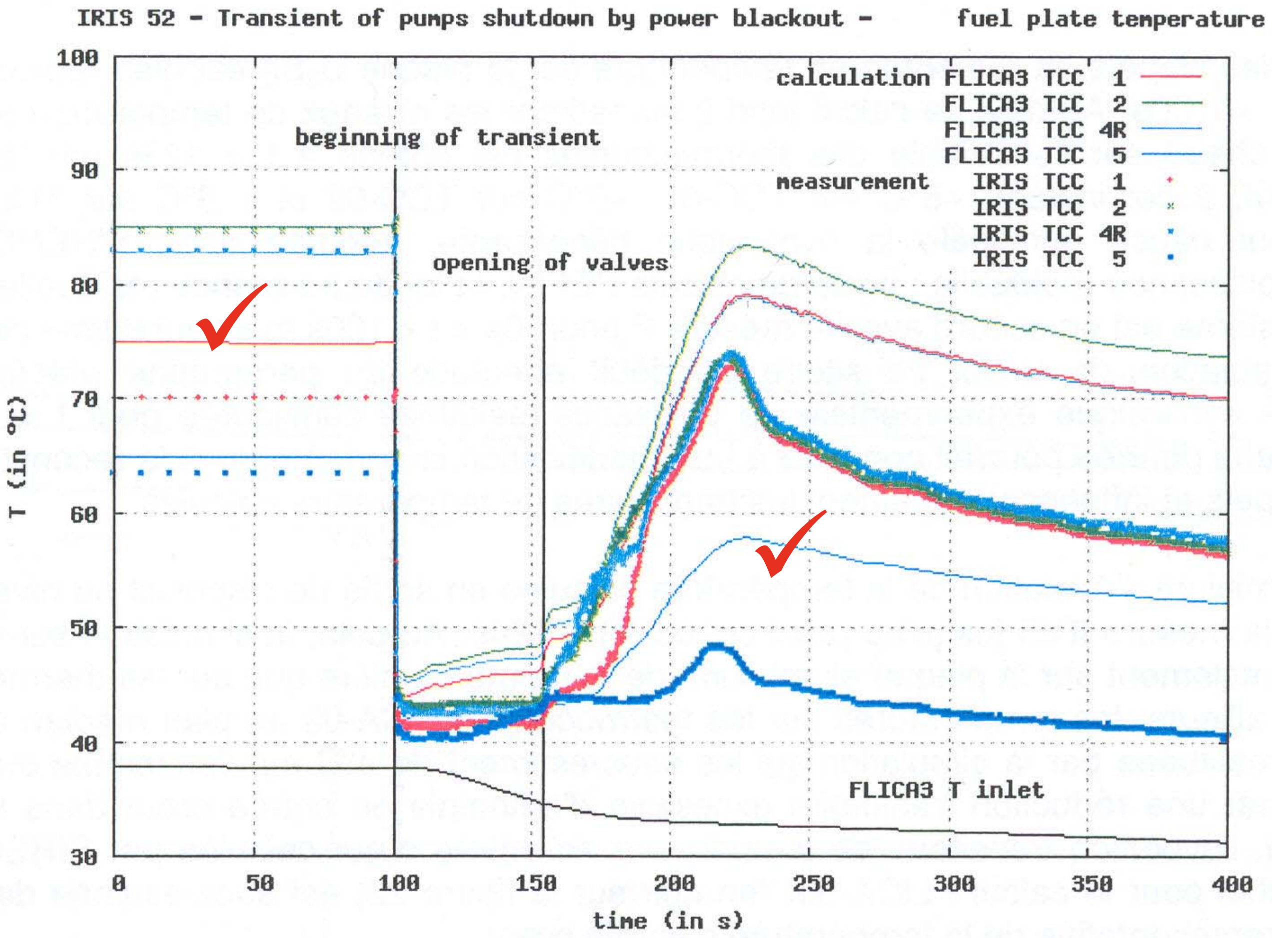
- According to the operator, discrepancies due to the model on the law of decrease of the flow rate of the coolant pumps during the transient (underestimated by the calculation)

Improvements

- « Realignment » of the cooling pumps flow rates to the measures

With this new law, new calculations were performed, showing an improved compatibility between calculations and measurements

Assessment performed by IRSN (5/13)



Temperature calculation on the instrumented fuel plate after « realignment »

Assessment performed by IRSN (6/13)

Verification of pressure drop in the IRIS device

1999

- Tests performed on a hydraulic mock-up of the OSIRIS primary cooling system
- Measurement of flow rate vs. pressure drop
- Comparison to the analytical law

→ The measurements did not include low flow rate values

2003

- Such measurements were performed

The analytical law was replaced by the measurements in the thermal hydraulic calculation codes

Assessment performed by IRSN (7/13)

Verification of axial neutron flux distribution

Calculation scheme

- Calculation of the average core power
- Calculation of radial neutron flux distribution

→ 2D calculation scheme

- The axial neutron flux distribution is not calculated
- A cosine distribution with an axial neutron flux shape factor of 1.3 is taken into account in the thermal hydraulic calculations

→ The actual axial neutron flux shape factor is measured in the ISIS reactor (mock-up of the OSIRIS reactor) to check that the actual factor is lower than 1.3

Assessment performed by IRSN (8/13)

Assessment

- The operator was asked by the Safety Authority to perform a calculation with a « realistic » (measured) axial neutron flux distribution to check that the cosine model is conservative

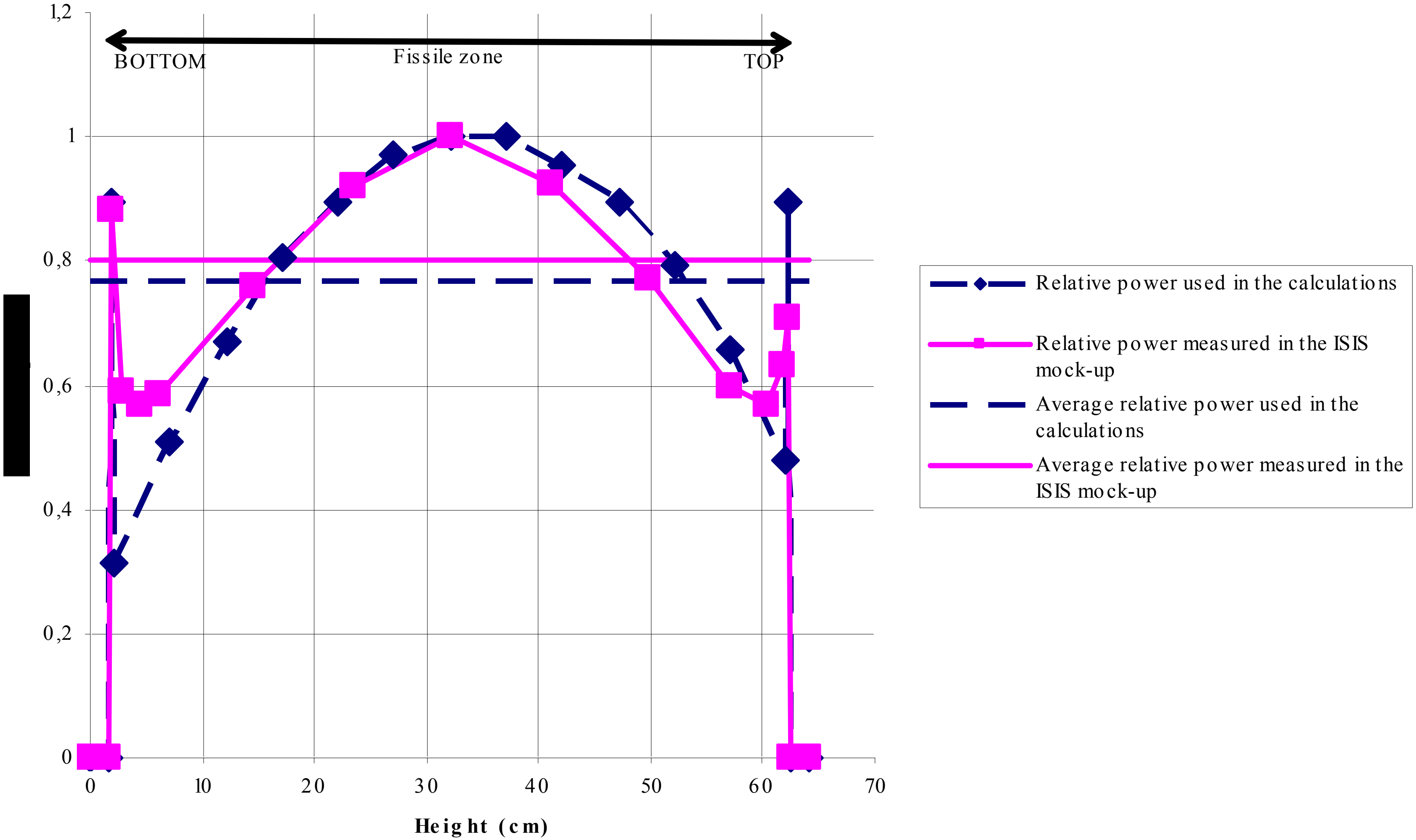
COMPARISON

- The operator was also asked to prove that the influence of the movements of the control assemblies does not trigger an increase in the neutron flux axial shape factor beyond 1.3

→Irradiations of the « MEREVER » device (switchook fitted with 5 neutron detectors distributed axially) inserted in the water cooling channels of the OSIRIS reactor

RESULTS

Assessment performed by IRSN (9/13)



Comparison between relative powers used in the calculations and measured in the ISIS mock-up

Assessment performed by IRSN (10/13)

Axial neutron flux shape factor	Maximum neutron flux position (mm) 0 = mid-height
1,20	-5
1,20	10
1,21	-5
1,21	-5
1,21	0
1,21	10
1,21	10
1,21	25
1,20	15
1,19	0
1,19	10
1,19	5

Axial neutron flux shape factor	Maximum neutron flux position (mm) 0 = mid-height
1,22	-55
1,23	-50
1,23	-35
1,23	-30
1,23	-25
1,22	-15
1,20	5
1,19	-10
1,18	-20
1,19	-30
1,19	-35
1,18	-25

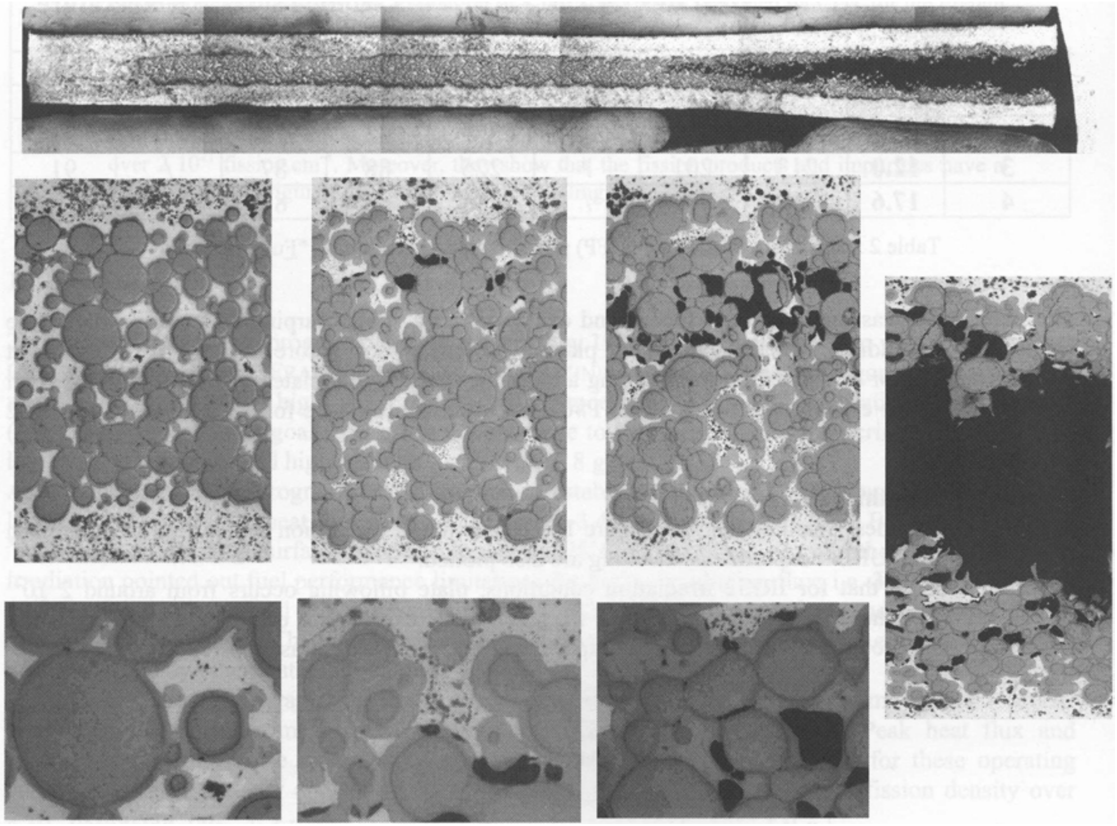
Axial neutron flux shape factor	Maximum neutron flux position (mm) 0 = mid-height
1,19	0
1,20	-40
1,20	-25
1,20	-35
1,20	-25
1,20	-15
1,18	-35
1,20	-25
1,19	5
1,18	-20
1,18	-45
1,17	-35

Evolution of axial neutron flux shape factor and maximum neutron flux position measured during the OSIRIS reactor cycle (in 3 different core cells)

Assessment performed by IRSN (11/13)

Swelling of the experimental fuel plates

IRIS 2 : Significant swelling in the UMo fuel plates



Assessment performed by IRSN (12/13)

Risk of excessive shrinking of the water channels

→ Effective cooling of the plates ?

Facts :

- Shrinking due to the swelling spread between two adjacent channels & fuel plates opposite to inert plates
- Swelling localised over a small surface area (not a generalised shrinking but additional specific head loss)
- Tearing in the middle of the fuel meat but no decohesion of the meat and the cladding)

The risk run by this swelling would be a risk of cladding rupture, detected by the reactor protection system

During IRIS experiments cladding rupture detection thresholds are lowered

Assessment performed by IRSN (13/13)

Calculations assumptions in transient conditions

Transients : pumps shutdown or break in the reactor coolant systems

Operator approach

&

- Before transients, all thermal hydraulic parameters equal to the reactor protection threshold values
- Permanent reactor operation prohibited beyond the alarm thresholds

→ Accumulation of an abnormal reactor operation and an accident (widely conservative)

IRSN considered it acceptable to take the thermal hydraulic parameters as equal to the reactor alarm threshold values (permitted by the reference safety standards for nominal operation)

Conclusion

Conclusion (1/2)

Taking into account all these elements, IRSN considered it acceptable for the operator to irradiate experimental fuel plates at a maximal heat flux of 300 W/cm^2

For the specific irradiation of plates based on UMo fuel, enriched with 50% ^{235}U (for the FRM-II reactor)

By lowering of the alarm and protection thresholds by 5%

Maximal heat flux at the hot point = 314 W/cm^2

Conclusion (2/2)

This demonstration

- **validated the calculations performed**
- **justified a higher maximal irradiation power**

  (particularly by using a « realistic » flow rate / pressure drop law of the device)