International meeting on fast reactor safety
Knoxville, TN (USA) 21-24 Apr 1985
CEA-CONF--7839

FR8501776

RESULTS OF TESTS UNDER NORMAL AND ABNORMAL OPERATING CONDITIONS CONCERNING LMFBR FUEL ELEMENT BEHAVIOUR

A. LANGUILLE	CEA/IRDI/DMECN/DPFER	CEN CADARACHE	(FRANCE)
Ph. BERGEONNEAU	CEA/IRDI/DEDR/DRNR	CEN CADARACHE	(FRANCE)
C. ESSIG	INTERATOM detached at	CEN CADARACHE	(FRANCE)
Y. GUERIN	CEA/IRDI/DMECN/DECPU	CEN CADARACHE	(FRANCE)

ABSTRACT

During RAPSODIE and PHENIX reactors operation, a lot of tests have been performed in order to increase the knowledge of LMFBR fuel element behaviour under normal and abnormal conditions. Three main topics are emphasized in the paper :

- Fuel melting during steady-state operation including over power conditions (two experiments with melted fuel in RAPSODIE reactor).
- Influence of fuel element geometrical evolution on reactivity feedback effects and reactor dynamic behaviour (specific series of tests performed in PHENIX and RAPSODIE reactors).
- Clad damage evaluation during abnormal transients essentially very severe loss of flow (last tests performed in RAPSODIE reactor).

INTRODUCTION

The objective of this paper is to improve the knowledge on LMFBR fuel element behaviour during protected and unprotected transients in RAPSODIE and PHENIX reactors in order to evaluate its reliability. The range of the tests performed in these reactors is sufficiently large to cover normal and also extreme off normal conditions such as fuel melting. Results of such tests allow to better establish transient design limits for reactor structural components in particular for fuel pin cladding which play a lead role in controlling the accident sequence.

Three main topics are emphasized in this paper :

- Fuel melting during slow over-power excursions.
- Influence of the fuel element geometrical evolution on reactivity feedback effects and reactor dynamic behaviour.
- Clad damage evaluation during a transient (essentially very severe loss of flow).

1. FUEL MELTING BEHAVIOUR

Two experiments A and B were designed to be irradiated during the last runs in RAPSODIE reactor. They were performed to improve the knowledge on the fuel behaviour up to melting, informations on the thermal conductivity of the mixed oxide at high temperature and to test the validity of the codes use for the analysis of accidents in SPX1 reactor.

Experiments A and B were 19 pins subassemblies planned to give melting of various extents in order to get statistical informations on the behaviour of fissile pins similar in diameter to a SPX1 one and to demonstrate the harmlessness of high melted volume of fuel in a pin in the beginning of life.

1.1 Description of the different experiments

1.1.1 Fuel pins characteristics

All the pins were cladded with CW 316 stainless steel (o.d. 8,6 mm) and have a fissile stack of 320 millimeters high with highly enriched $(U,Pu)O_2$ fuel.

The characteristics of the fuels of the two experiments are given in table 1.

1.1.2 Irradiation conditions

Experiment A was loaded in the first row and B in the second row of the reactor. Figure 1 shows the power history for these both experiments.

The first phase of the irradiation was a two hours plateau (reactor power 16 THW) then, the power was increased in 45 minutes up to 30 THW. The irradiation ended by a reactor scram after 10 minutes at this power.

No clad failure has been detected during that time. During the last phase of the irradiation, experiment A pins reached linear powers from 1030 to 1060 W/cm and experiment B pins from 920 to 1005 W/cm.

Experiment A	Annular pellets o.d. 7,27 mm Fuel density ~ 95 % T.D. O/M ratio ~ 1,98 Filling gas: helium (19 pins) Tag gas capsules (radon) (5 pins)
Experiment B	Same geometrical characteristics for cladding and pellets as experiment A Fuel density : 94,9 % T.D. O/M ratio : 1,984 Filling gas : helium (15 pins) air (4 pins) Tag gas capsules (radon) (19 pins)

Table 1 - Pin characteristics for A and B experiments

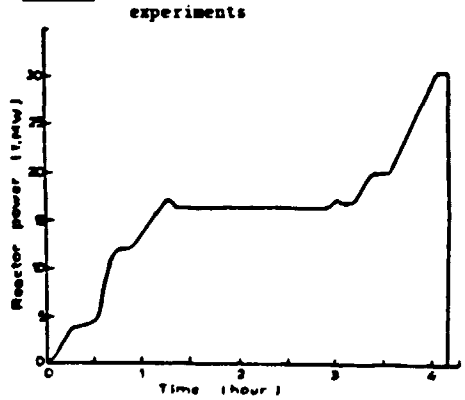

Fig. 1. Power history for irradiations A and B.

1.2 Main results

Non destructive post irradiation examinations had been performed on whole pins of both subassemblies (profilometry, neutronography, γ scanning). Destructive examinations are in progress but not yet finished up to now.

First metallographic examinations on two pins have been already particularly studied (the first pin filled with air from experiment A and the second one filled with helium from experiment B). These early results confirmed that fuel melting has occured on the whole fissile column lenght ; the lower part of the column is completely filled with molten fuel, cavities and conical voids are also numerous (Figure 2).

Molten fuel volumes have been estimated on these basis to 54 % for pin A and 29 % for pin B of the total fuel volume.

Profilometry and first metallographic examinations showed no cladding deformation.

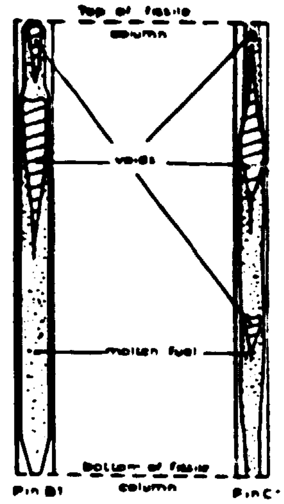

Fig. 2. Neutronographies of pins A and B after irradiation.

In one case only, molten fuel has been extruded on internal cladding face without any effect on it.

First comparison of experimental results with code calculations lead us to the following conclusions :

- Movement of molten oxide and relocation have to be more accuretaly modelised in order to get a correct estimation of the molten fuel volumes by thermal codes.
- From a mechanical point of view, calculations are in good agreement with results. In the beginning of life of a pin, an important amount of molten fuel (more than 50 %) due to an accidental reactivity insertion can occur without any damage on the cladding. Next experiments in PHENIX will allow us to test irradiated pins in such conditions in order to evaluate the margins and the performance limits in that case.

2. FUEL ELEMENT GEOMETRICAL BEHAVIOUR

The two specific series of tests conducted in PHENIX reactor during beginning and end of the 18th and 27th runs and the large dynamic transients performed in March 1983 during the last runs in RAPSODIE reactor provide important information on steady-state and transient fuel element geometrical behaviour.

The aim of tests in PHENIX reactor was to compare theoritical and measured feedback effects. As for our actual purpose, only the effects linked to fuel element behaviour are of interest, i.e. the doppler and the axial fuel expansion effects. These two particular effects, and only them, contribute to the so called "power coefficient h" which represents the reactivity induced by a variation of the core power equal to 1 MW while sodium temperatures remain constant (see ref. [1] for more details). Figure 3 and 4 show the predicted calculated values of this coefficient during beginning and end of run, at different steady-state core power levels, compared to the measured values. Two kinds of calculated values are presented corresponding to two different assumptions on fuel behaviour :

1) Fuel is axially linked to clad with a closed gap in all the 100 fissile core subassemblies.

2) Only the previous irradiated 80 subassemblies are supposed to follow the above assumption, the remaining fresh fuel being supposed to expand axially freely with an open gap between clads and pellets. Figures 3 and 4 show fairly well that at beginning of run a part of the fuel elements, i.e. the fresh part, is with an open gap, when at the end of run the whole fuel is sufficiently sticked to the clad to follow its axial expansion with closed gap.

In RAPSODIE reactor, the results for the end-of-life tests bring more experimental information on the irradiated fuel elements behaviour. During the large dynamic transients described in ref. [2], core power and temperatures were measured and compared to the predicted calculated values, with the use of theoritical feedback effects models. Because of the lack of Doppler effect in RAPSODIE reactor, only the model used for axial fuel expansion effect can be tested. Figure 5 shows the evolution of measured central S/A outlet temperature during the LOF-transient compared to two predicted curves corresponding to the respective assumption : whole fuel axially linked to the clad and whole fuel expanding freely. Obviously only the first assumption is in good agreement with experimental results.

This well confirms that for irradiated fuel elements, as observed in PHENIX reactor, the pellets are sticked to the clads and follow these last in their transient expansion where as fuel is cooling down during LOF transients and a fortiori during all kinds of transients.

3. CLAD DAMAGE EVALUATION DURING THE LAST LARGE TRANSIENT IN RAPSODIE REACTOR

The last dynamic transient in Rapsodie reactor performed in April 83 simulated a loss of primary and secondary pumps. the initial state of reactor operation was :

- Reactor power : 21,2 THW
- Inlet core sodium temperature : 402°C
- Mean axial heating : 105°C

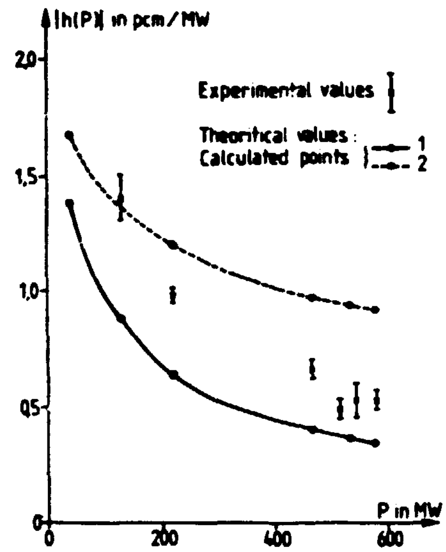

Fig. 3. "h" coefficient versus thermal power at the beginning of PHENIX 18th run

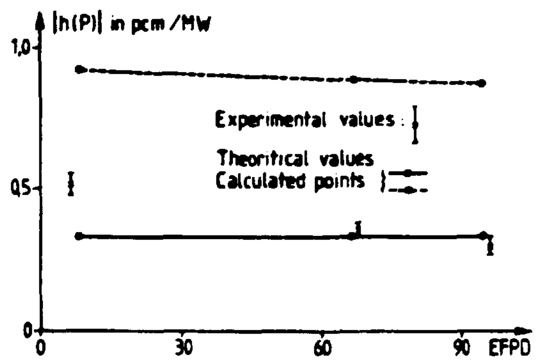

Fig. 4. "h" coefficient versus burn up during the PHENIX 18th run

3.1 Description of test conditions

This transient was initiated from this state by a loss of all electric power without scram.

By feed back effects, reactor power has decreased quickly while outlet sodium temperature was increasing (Fig. 6).

The subassembly in the central position of the reactor was an instrumented one which permitted sodium temperature measurements inside the bundle. The hot sodium channel temperature has increased in 150 s from 580°C

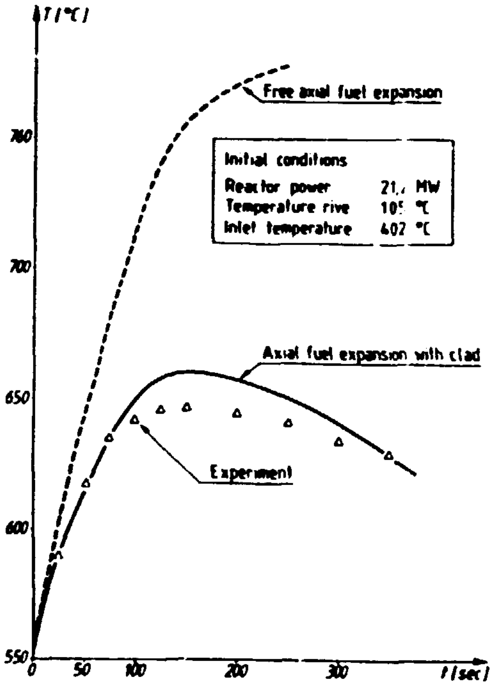

Fig. 5. Central S/A outlet temperature during RAPSODIE end of life test

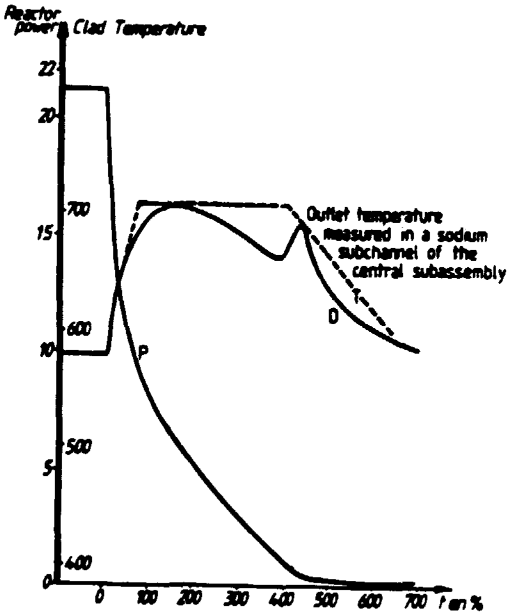

Fig. 6. Thermal transient during last large dynamic test in RAPDOSIE reactor

to 750°C in this subassembly until the natural convection was established after which sodium temperature receded. Nuclear power was decreasing until a very low value (few kilowatts).

3.2 Experimental results

The thermal evolution has concerned the whole core. The reactor was loaded with driver subassemblies (TMG ~ 720°C) but also many experiments. We have selected the more interesting experiments on this point of view (Table 2) whether the irradiation conditions were high (dose, cladding temperature) or whether internal gas pressures were high. Maximal cladding temperature reached, on few experiences was about 800°C.

No clad failure has been detected during this transient in particular no gas failure.

3.3 Thermomechanical calculations

The thermal transient has been taken in account in a simplified form (Fig. 6) : a linear increase in temperature for 90 s, upholding maintenance at constant temperature for 360 s and then a linear decrease.

Considering exact experimental conditions (preirradiation and thermal transient), the clad damage function D has been calculated with a thermomechanical code (Table 2). Thermal creep strain is the main cause of damage. Damage function is largely less than 1 (D ≤ 0,3), this result is coherent with the fact that no clad failure had been detected.

EXPERIMENT	IRRADIATION B U.	MAXIMAL CLADDING TEMPERATURE	MAXIMAL CLAD. TEMPERATURE DURING TRANSIENT	CLAD DAMAGE FUNCTION	
				WITHOUT INC.	WITH UNCERTAINTIES
SUBASSEMBLY X (61 pins)	19 at %	630°C	720°C	0,050	0,100
BIG Y (7 pins)	17 at %	625°C	720°C	0,060	0,142
SUBASSEMBLY Z (61 pins)	12,5 at %	670°C	800°C	0,11	0,27

Table 2 - Damage function during last test in RAPSODIE

CONCLUSION

These tests are very conforting concerning the good behaviour of the fuel element under abnormal conditions. In reactivity transients (control rod withdrawal for instance), the calculations and experimental results indicate there is a margin-to-failure even if the primary Plant Protection System fails to perform. During transient undercooling events, cladding temperature is a major factor in cladding integrity and we have seen damage function (including cladding strain limits) can be successfully applied even during severe transients. Today, great effort is done in the R and D on fuel element behaviour under abnormal conditions in order to better appreciate performance limits in the design and particularly we are increasing our experimental support in this field.

REFERENCES

1. P. COULON, Ph. BERGEONNEAU, J.C. GAUTHIER, M. VARRIER. Thermal feed-back effects in a pool-type LMFBR : theoretical and experimental results on PHENIX reactor. Proceed of the LMFBR Safety Topical Meeting - July 19-23, 1982 - LYON - IV - 473

2. C. ESSIG, B. BERTHET, E. MANCUSO, E. GESI, A. GOURIOU, P. BERGEONNEAU, V. ENTEL, A. VASILE, A. REETZ, A. DONATI. Dynamic behaviour of RAPSODIE in exceptional transient experiments. International Tomical Meeting on Fast Reactor Safety - April 21-24, 1985 - KNOXVILLE