FR 8001282

INIS

International Conference on fast breeder reactor
fuel performance.
Monterey, USA, March 5 - 8, 1979
CEA - CONF 4601

PROBLEMS ENCOUNTERED IN THE DESIGN OF FUEL ELEMENTS FOR FAST BREEDER REACTORS SOLUTIONS TAKEN UP IN FRANCE

J. Leclère

CEA - CADARACHE - FRANCE

1. INTRODUCTION

From Rapsodie to Super Phénix 1, operating conditions aimed at became more and more severe /1/ as recalled in fig. 1 ; this trend, due to research of commercial development of this type of reactor will remain - although no firm definition is presently fixed we know that the objectives of Super Phénix 2 will be at last as high as those of Super Phénix 1.

If we consider for instance that evidence of swelling under irradiation was given only twelve years ago, at the time of the beginning of Rapsodie first core operation, which reached 6,25% for a damage of 35 dpa F /2/ we can judge of the work which has be done to design fuel elements for industrial reactors 150 times more powerful than Rapsodie and having to reach the 100-120 MWd/t and 120-150 dpa F range.

We try in this paper to review the main problems encountered and to comment briefly to what degree they are overcome.

2. OXIDE BEHAVIOUR

We can distinguish several types of problems /3/

- Thermal Conditions

A maximum of central temperature is reached at the beginning of life ; then, there is a decrease due to restructuration ; we know how to choose the characteristics of the pellets to maintain any possibility of fusion at a very low probability (including hot spot consideration) for the interesting range of linear power - say less than 500 W/cm.
One question remains : is there any increase of temperature at high burnup, mainly due to the formation of an oxide cladding reaction layer ?
Up to now we believe that such a phenomenon exists but does not lead to as high temperature as at start of irradiation fig. 2 and 4.

- Structural Evolution

Swelling is low enough to authorize high burnup ; work is continuing to study the way of its accomodation inside the pellet ; we give also interest to the kinetics of oxide-clad gap evolution (on the beginning of life, and in case of clad diameter increase), and to the formation of reaction layers, especially by Caesium composites, at the interface of cladding and oxide.

We regroup these phenomenons because they appear to be important when examining the possibility of mechanical interaction between cladding and fuel.

- Chemical Evolution

Migration of oxygen occurs at the beginning of irradiation and we have gained recent experimental results confirming the calculated shape of distribution.

Pu migration might be a cause of temperature increase at end of life ; however, we consider it is not a problem because it becomes noticeable for temperature levels higher than these encountered in commercial fuel element.

These phenomenons are mainly studied from theoretical point of view ; we just remain aware of possible consequences on oxide thermal field.

- Fission Gas Release

Although we have experimental results on its dependance from temperature and burnup, we consider 100% to have a reasonable margin on the size of the gas plenum.

It may be noticed that, even if the nature of probleme is the same, the practical needs for blanket element may be different due to its particular operating conditions, and lead sometimes to special studies : some experimental subassemblies are being irradiated - or prepared for irradiation - in Phénix.

3. CLADDING AND PIN BEHAVIOUR

- Nature of Material

It is obvious that the main efforts have been devoted to search for alloys having low swelling and irradiation creep characteristics. We do not present or discuss here the results of the theoretical approach /5/, considering only that no global explanation is still available. A lot of experimental irradiations, or samples or claddings, have been completed or are in progress, and gave the following main results.

Damage range explored reaches now usually 80-100 dpa F, and in some extreme cases 150 dpa F fig. 3 ; the data obtained at such doses can be considered as representative and reliable. But as the corresponding irradiation are time consuming, few materials are presently involved as clad. We have now definitely dropped 316 SS ; our best candidate is 316, 20% cold-worked, possibly with Ti stabilization, which we consider qualified for 120 dpa F. We have in test now 316 with various additions, nickel alloys which could be still better.

The problem is nearly the same for hexagonal wrapper alloys, ferritic steel being a supplementary candidate.

- Clad Behaviour

Our experience is now sufficient to say that the stresses induced by fission gas pressure, thermal and swelling gradients, are quite tolerable, because they remain far below the elastic limit of the materials ; problems might come from the loss of ductility under irradiation /6/ but up to now this fear proved not to correspond to reality. So we are not very anxious about that; nevertheless, it is a point to check in high burnup experiments.

Swelling and irradiation creep lead to cladding deformation the consequences of which are discussed later. They are studied in a lot of experiments, and special attention is paid to variable operating conditions, as explained in an other communication /7/

Chemical interaction proved not to be a limiting phenomenon because, due to a diffusion type evolution, the thickness concerned remains rather low : less than 100 µ et 100 000 MWd/t. For mechanical interaction, the situation is rather different : we cannot exclude its existence but we have no evidence of it on pins representative of industrial type. So we have on one hand set up a special experimental program, with pins designed to enhance interaction, to obtain the informations necessary to know the laws involved, to modelize the phenomenon ; on the other hand it has been decided that Rapsodie (in 1980 - 1981) and perhaps Phénix (in 1982-1983 ?) would realize some special irradiation cycles, simulating as well as possible the conditions met in the case of load following for an industrial reactor, to check the application of the laws referred to higher, and the behaviour of a whole core.

4. BUNDLE AND WRAPPER TUBE BEHAVIOUR

We do not discuss here the problems bound to wrapper tube behaviour : they are of the same nature as those of cladding, with of course different sollicitations ; we can just underline that wrapper distortions are more severely limited because of their consequences on subassembly manutentions.

Our observations on Fortissimo /8/ then Phénix highly irradiated subassemblies gave us during the last years a lot of indications on the way the pin bundle accomodates important deformations of pins and wrapper.

First we learnt that if they are made of different types of materials, a pin and its spacer wire are subject to mechanical interaction due to the difference of irradiation swelling, the consequence of which can be either the wire coming unstuck from the clad, either the clad taking a helical shape.

This individual pin behaviour is combined to the fact that, when the pin deformation becomes higher that the value which can be accomodated by resorption of mounting gaps, there is a tendancy of the bundle to use the gaps provided by the system itself (i.e. the distance of a wire diameter between a row of pins and a face of the wrapper at each compact plane). The result is a complex evolution of the bundle, we are now beginning to modelize.

What consequences do we draw ? For specifications of pins, we have new criteria on spacer-wire nature, dimensions and pitch. For subassembly performance, we progress in collecting and predicting data to use in thermohydraulical evaluations ; we know that the spacer-wire system is quite able to sustain important deformations inside the bundle without consequences on pin resistance at outlet temperature. A point we judge important is to appreciate the risk of apparition of contacts between pins, which could lead to excessive local hot spots. Up to now we never saw that in pile.

5. FAILED FUEL PROBLEMS

Even for the most irradiated pins we tested, we saw no evidence of an "end - of - life" phenomenon leading to failures. So we think at the moment that it will be possible to choose a burnup such that these failures do not exist and that the problems will come from fabrication ruptures. Anyway, this shows that an adequate simulation is difficult, the defects escaping fabrication controls are certainly very small and difficult to reproduce.
We work in this direction, studying in particular two problems :

- How did sodium and fission gases flow through a thin leak ?
Evaluation is supported by an experimental program in a sodium loop.

- What are the consequences of sodium entry in a pin, especially coming from Na-oxide-reaction ?
This will help us to build a model we should use to evaluate the time elapsing between the "birth" of the leak and the DND signal leading to the evacuation of the failed subassembly ; the knowledge of this time is important for the core gestion.

6. CONCLUSION

All the problems we mentioned have been seen and studied first in Fortissimo then found again in Phénix, with no difference of nature. So we are confident in extrapolation to Super Phénix or commercial reactor size.

For the oxide, the objectives are currently reached and overcome in Rapsodie (present record 160 000 MWd /t) ; so, as since several years, our main efforts concern cladding and wrapper material behaviour under irradiation. In this matter, we should have tendancy to say that a step has been made, considering that the range 100-120 dpa F is almost sure to be achieved ; nevertheless we need a statistical demonstration, and hope to make it in particular in Phénix, improving the core subassemblies constitution. Then we shall have to make another step to 150-180 dpa F, and we are just now in the selecting phase for candidate materials. We are encouraged to think that success is possible by some preliminary irradiations fig. 3.

The new family of problems we have identified for the bundle are interesting and necessary to study, as beeing liable to provide life limitation, but up to now they do not prevent to reach our objectives.

In conclusion we consider that we have confirmed the possibility to reach the first objective of Super Phénix, and that another step in performance appear reasonable in the present state of our knowledge of structural materials behaviour under irradiation.

REFERENCES

/1/ P. DELPEYROUX and Al.
Super Phénix 1 fuel element optimization - first check of overall behaviour.
BNES conference - London Nov. 77

/2/ F. ANSELIN and Al.
Irradiation behaviour of the mixed oxide driver fuel elements of Rapsodie 24 MW.
ENS conference - Paris April 75

/3/ H. MIKAILOFF and Al.
The main problems raised by the in-pile behaviour of mixed oxide
ENS conference - Paris April 75

/4/ P. BLANCHARD and Al.
The comportment at high burnup of standard fuel Rapsodie-Fortissimo

/5/ J.M. DUPOUY and Al.
Swelling and irradiation creep of 316 stainless steel
CEA Conf 4342 (1978) - Alushta conference May 78

/6/ J.M. DUPOUY and Al.
Post irradiation mechanical properties of annealed and cold worked 316 stainless steel after irradiation to high Fast neutron Fluences
Scottsdale conference - June 77

/7/ J. ROUSSEAU and Al.
Problems bound to grid following
Monterey - conference March 79

/8/ P. BLANCHARD and Al.
Observations on the geometry of an irradiated Rapsodie subassembly
ANS 23-1 (1976) 151

Fig. 1. EVOLUTION OF FAST REACTOR STANDARD FUEL PERFORMANCES

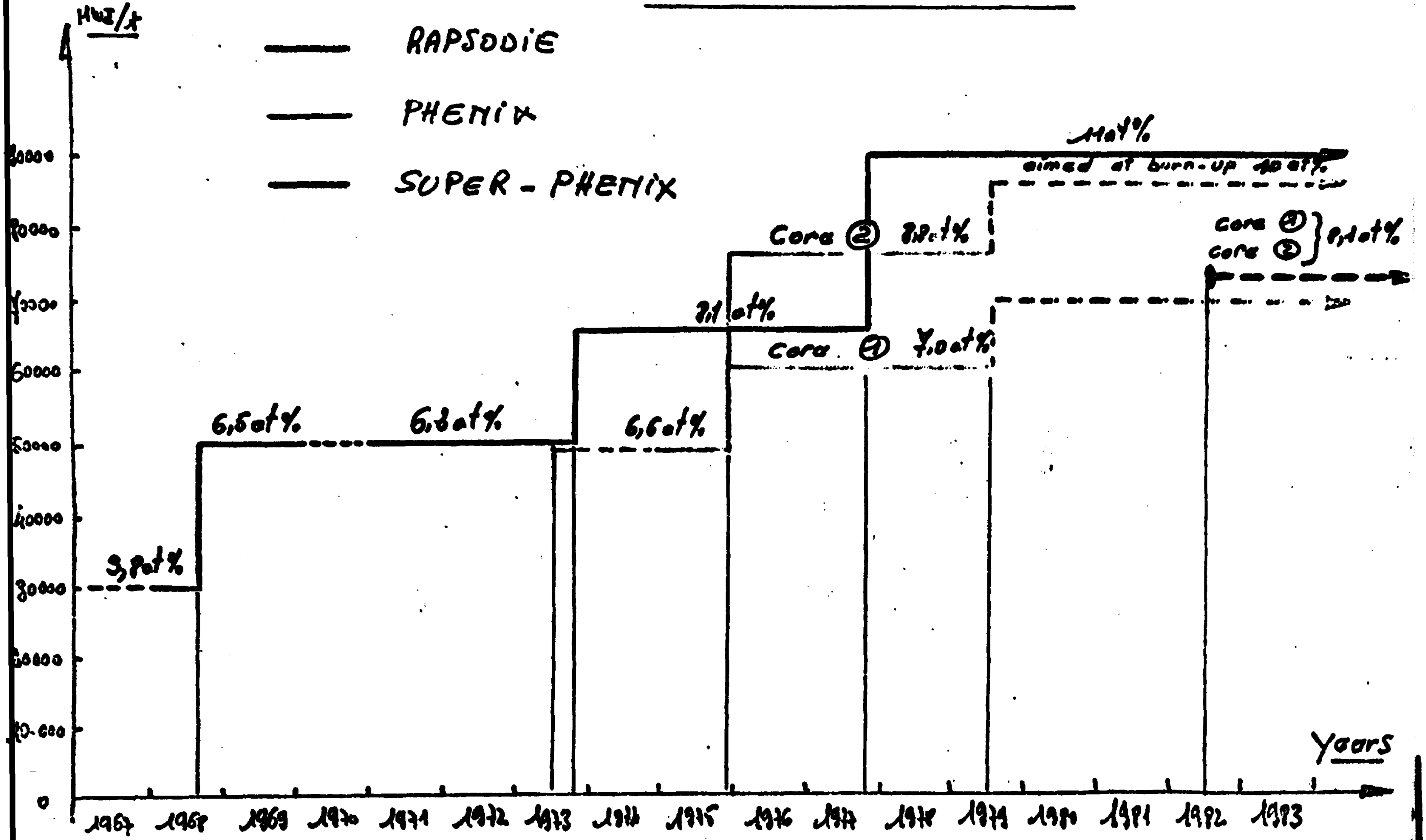

Fig.2 - EVOLUTION OF RAPSODIE FUEL CORE TEMPERATURE RAPSODIE

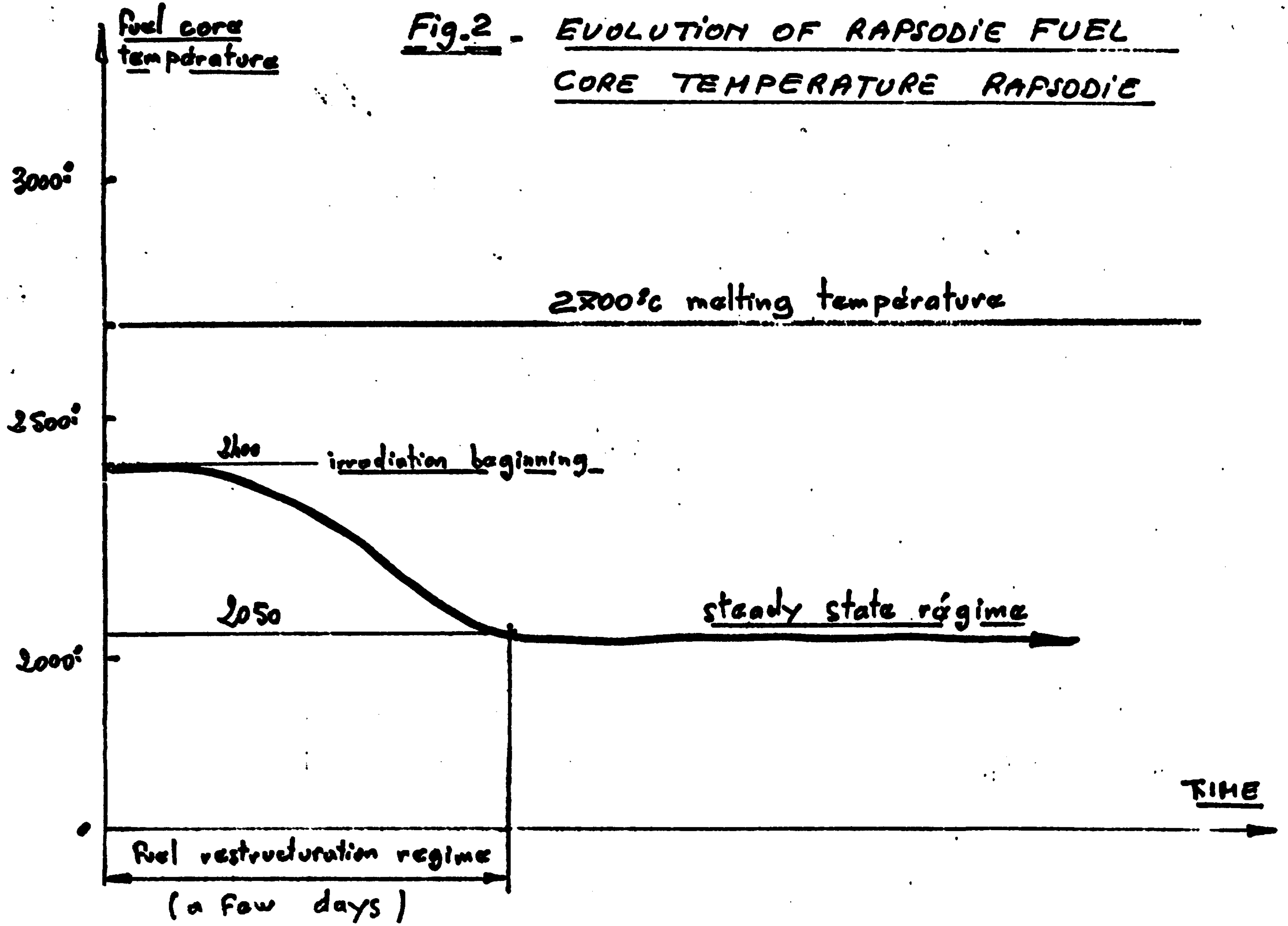

Fig. 3. IRRADIATION RESULT ON STRUCTURAL MATERIAL (explored range)