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STANDARD FUEL PERFORMANCES IMPROVEMENT IN FRENCH FAST BREEDER REACTOR PHENIX

AUTHORS

G. MARBACH

J. LECLERE

P. COURCON — SDEEC / CEN/CADARACHE

M. SAVINEAU — CENTRALE PHENIX

1 - PRESENTATION

The industrial operation of PHENIX, which started in july 1974, was conducted with a very good load factor (average availability 63,58 %, total production 786 500 Mw/h till the 1st of july 1981), and consequently several batches of fuel elements have been already used; so a full statistical knowledge of subassemblies behaviour was gained, and it was possible to propose and realize improvements in order to increase the burnup.

Some recalls : at nominal power, PHENIX produces 563 thermal MW, 250 electrical. The total number of fissile subassemblies extends from 103 to 116, depending on reactivity requirements; they are shared in two zones, the enrichments of which are 19 and 25 % Pu. Each subassembly includes 217 fissile pins and a separate cluster of 37 pins as upper blanket. The fuel is $UPuO_2$.

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The operating characteristics of fuel elements are :

maximal linear power : 450 w/cm

nominal mid-cladding temperature : 650 °C
maximal cladding temperature (hot spot conditions) : 700 °C.

Fuel loading and unloading take place between the operating cycles, which last about 75 EFPD*.

The behaviour of the subassemblies is followed mainly by non destructive and destructive post irradiation examinations; but, when in pile, the indications of the Na outlet thermocouples allow to be sure there is no abnormal evolution. The subassemblies to be examined are chosen in the frame of a coherent global plan, to supervise the whole core, especially each representive position.

Set initially to 50 000 Mwd/t (internal core), the burn up was rapidly increased to 60 000 for the first batch. Improvements allowed a 10 % increase in 1979 and a new plan to raise the performances is being completed, in order to retain 90 000 Mwd/t in 1983.

2 - SUBASSEMBLIES FOLLOWING

2.1. Examinations of irradiated subassemblies

After about 3 months of cooling period, the subassemblies the study of which is planned can be examined in the hot cell close to the reactor.

Determination of length, across flat distance and planimetry for hexagonal wrapper, and displacement of subassembly heads are made before dismantling. Then, (the extremities having been cut and the wrapper being opened) the selected pins can undergo two types of examination :

* Equivalent fuel power days

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- a profilometry, which gives the diametral increase and ovalizations
- a soudness measurement by eddy currents, which evaluates the damage of the cladding.

The most interesting pins are then sent to a specialized hot lab for destructive examinations, the main of which are :

- clad drilling, to evaluate the gas release fraction and analyse them;
- the clad swelling determination, made by immersion;
- the metallographical fuel examination, looking for a possible fuel-clad chemical interaction.

More detailed examinations can then be required for specific studies for instance electronic microscopy on cladding, or carbon analysis.

First destructive examination results are obtained about 9 to 12 months after the end of irradiation.

2.2. Limitating phenomena

2.2.1. Oxide behaviour

It appears that there is no limitation to the fuel element life due to the oxide itself.

For instance, fig 1 shows the cross section of PHENIX oxide after 6 irradiation cycles. The structure is characteristic of a fast reactor fuel, with a central hole and columnar grains in the hottest zone. The overheating due to a possible deterioration of thermal conductivity by fission products remains very limited.

The oxide swelling could induce a mechanical interaction with the cladding, but the characteristics of the pellet and cladding are such that it would happen at very high burn up, far above the nominal value for PHENIX fuel elements.

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2.2.2. The cladding corrosion

A layer, due to clad-oxide interaction, exits in the upper part of the fissile column. This reaction is the more important as the burn up and temperature are higher, although some examinations seem to indicate a saturation after a given burn up and about 600 °C.

The layer thickness does not exceed 50 µm, wich is low with regard to the thickness of the cladding (fig 2).

2.2.3. The cladding mechanical and the bundle behaviour

The cladding is submitted to various sollicitations.

The only primary stresses are these due to the fission gases pressure. The size of the plenum and the characteristics of the cladding material show that it remains an important margin before the moment when the induced thermal creep becomes no more negligible and leads to cladding damage.

The secondary stresses are mainly the thermal stresses, and the stresses bound to mechanical interaction inside the bundle.

The thermal stresses due to the thermal gradient in the clad can reach 90 MPa at beginning of life, but are progressively relaxed by irradiation creep.

The difference of swelling between the claddings and the hexagonal wrapper leads to the disparition of the mounting gaps, then mechanical interaction begins. First the accommodation is made both by flexion of the cladding and ovalization under the spacing wire. In a second period, when contacts exists - in the compact rows - between hexagonal tube and wire and cladding, the only possible accommodation consists in ovalization of the cladding.

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Fig 3 give examples of stresses and strains calculated for a cladding of a bundle in phase of interaction.

The damage level of the cladding depends on the extent of irradiation creep and mainly on the swelling of the steel. All improvement in fuel pin performance is bound to decrease of cladding material swelling.

The same remark can be made for the behaviour of hexagonal wrapper material, for which the swelling leads to across flat augmentation and bowing.

The effort of selection and research on materials allowed substantial progress as indicated fig 4, and a reduction of deformation by at least five, for doses of about 100 dpaF.

3 - THE DEFINITION OF MAXIMAL BURN UP

It is given by the analysis of the difference limiting phenomena, and the supervising of their evolution by adequate examinations.

The previous paragraphs clearly shew that the main limitation came from the swelling of clad and wrapper material. An improvement in clad material elaboration allowed a gain of 10 % for maximal burn up in 1979. This level is fixed by the good results obtained on monitoring subassemblies, keeping a reasonable margin to take account of the dispersion on a great number of pins. This allowed up to now to have no rupture on standard subassemblies.

This evolution is depicted by the histograms of doses for core subassemblies in 1978 and 1981 (fig 5).

A recent progress in the composition of clad, wire, and wrapper material will lead to a new augmentation of the burn up in the next future. A plan was elaborated, it consists in defining several levels of dose, an examination being necessary before progression to the upper level.

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The increase life time of the subassemblies has favourable consequences on reactor operation :

- the expenses bound to the number of fabricated (and later reprocessed) subassemblies are lowered;
- the length of operating cycle can be increased : from 56 JEPP initially, it was set to 60 then 75 EFPD at the end of 1979;
- last, the manutention and dismantling systems are less used, important consequence on the fiability of fuel evacuation chain.

4 - CONSEQUENCES ON INDUSTRIAL FAST REACTORS

The increase of PHENIX performances allow to gain knowledges on the different aspects of subassembly behaviour at high dose, and on the operation of the whole fuel cycle.

The burn up progression constitutes a confirmation of the objective set for the first core of SUPER PHENIX 1, in dose and burn up, and gives the best hope for fuel operation.

The constant improvement of burn up of french fast reactors RAPSODIE and PHENIX makes us confident on good performances for future commercial reactors, for which burn up of about 150 000 Mwd/t do not appear irrealistic.

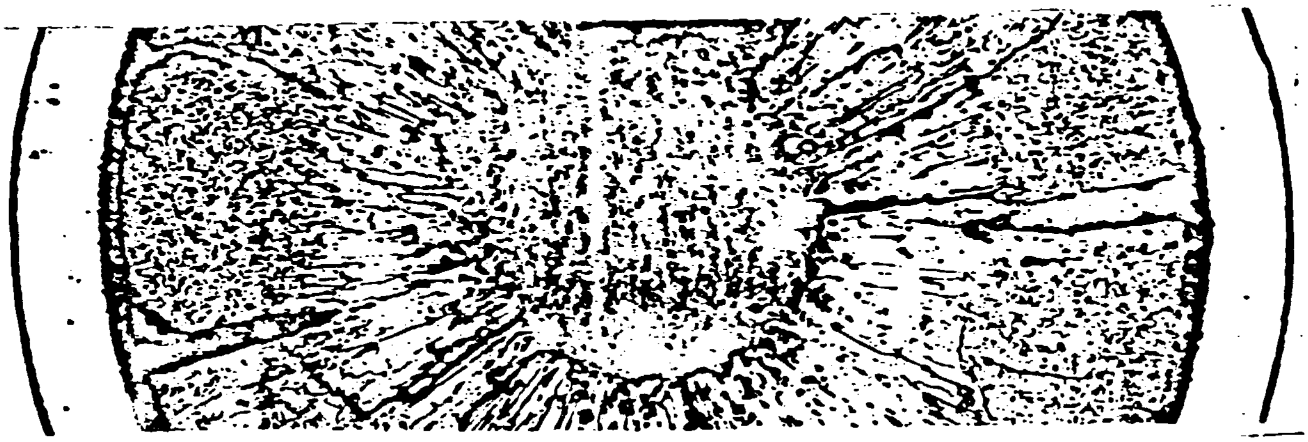


FIG. 1. PHENIX OXIDE FUEL - CROSS SECTION
61 000 MWD/t.ox. - 7.2 at. %

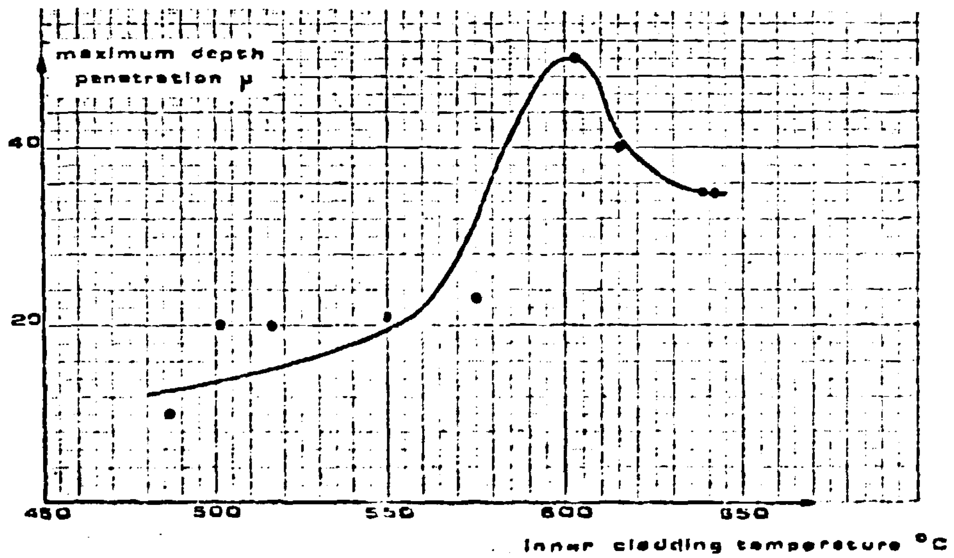


FIG. 2. EVOLUTION OF MAXIMUM DEPTH PENETRATION IN FUEL CLADDING WITH INNER CLADDING TEMPERATURE

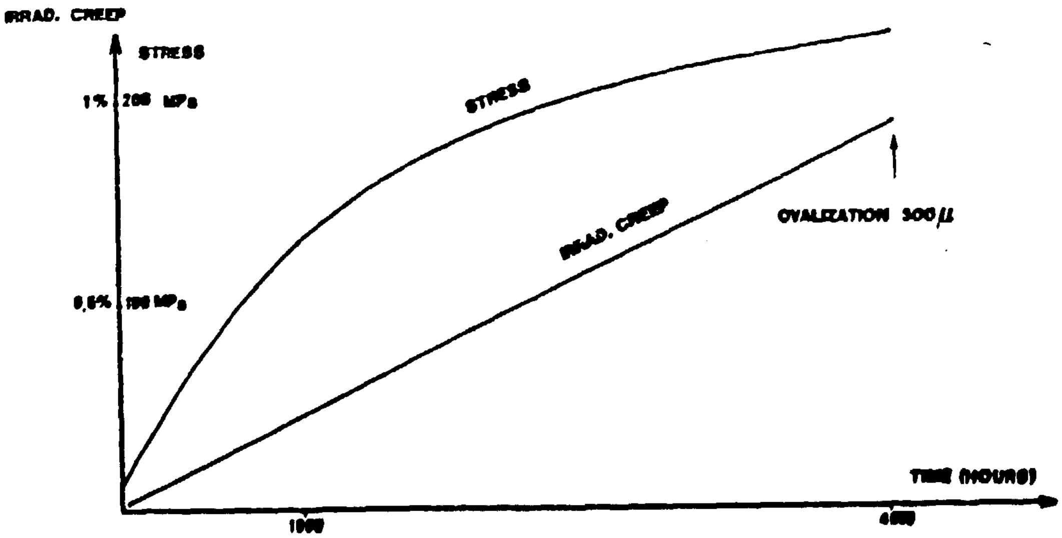
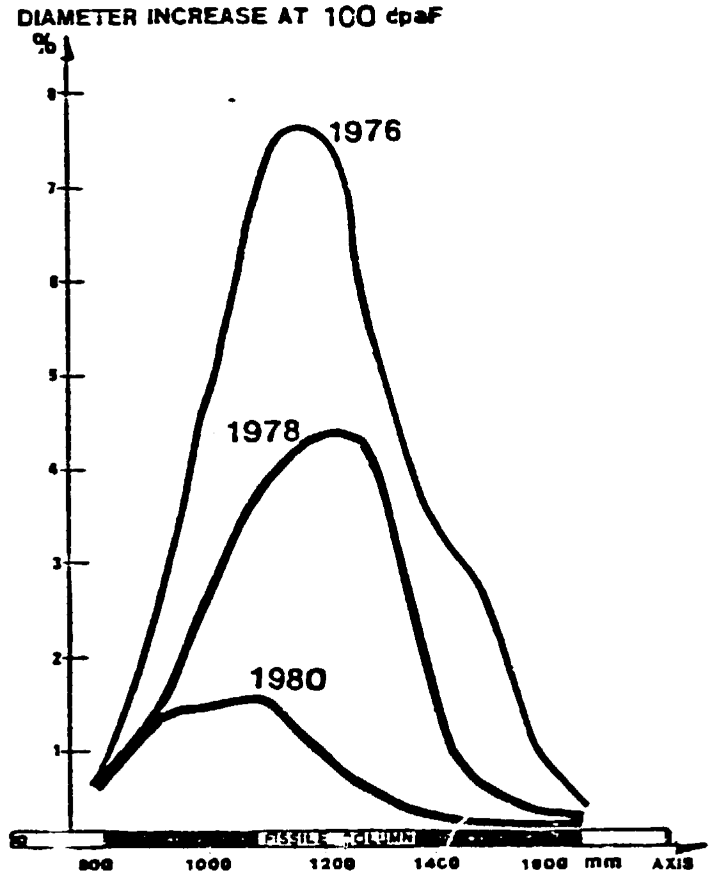
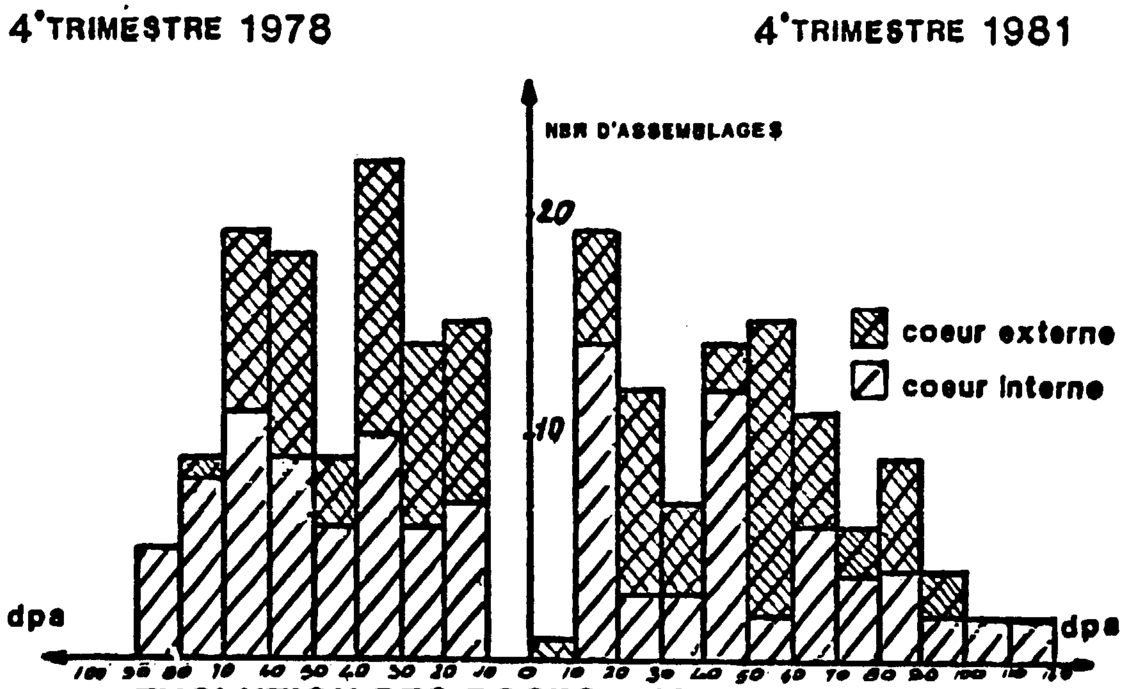


FIG. 3. EQUIVALENT STRESSES AND IRRADIATION CREEP STRAIN UNDER THE SPACER WIRE VERSUS THE IRRADIATION TIME



IMPROVEMENT OF CLAD DEFORMATION WITH YEARS

FIG. 4.



EVOLUTION DES DOSES DES ASSEMBLAGES
PHENIX EN REACTEUR

FIG. 5.