PREDICTION OF FISSION GAS RELEASE AT HIGH BURN-UP

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ABSTRACT

Reliable design of LWR fuel rods requires the fission gas release to be predicted as accurately as possible. Indeed that physical phenomenon governs both the fuel temperatures and the inner gas pressure.

Fission gas release data have been reviewed by the NRC and it has been concluded that a fission gas release enhancement occurs at burn-up above 20 GWd/tM. To correct deficient fission gas release models which do not include burn-up dependence, the NRC developed an empirical correction method to describe burn-up enhancement effect.

BELGONUCLEAIRE has developed its own fission gas release model which is utilized in licensing calculation through the COMETHE code. Fission gas release predictions at high burn-up are confronted to the experimental data as well as to the predictions of the NRC correlation. The physics of the fission gas release phenomenon is discussed.

Conclusions are that fission gas release enhancement exists. However, it can start at burn-up as low as 5 GWd/tM. It is mainly a matter of temperature history.

INTRODUCTION

Fission gas release is an important phenomenon in the design of LWR fuel rods. Fission gas release controls both the fuel temperature, as it affects the heat transfer through the pellet clad gap, and the inner gas pressure. A reliable design requires the fission gas release to be predicted with a good accuracy. A number of gas release models have been developed and are utilized by LWR fuel vendors.

The assessment of LMFBR mixed oxide fuel data from EBR-II suggests that a fission gas release enhancement occurs at high burn-up, especially at burn-up above 20 GWd/tM. For the models lacking adequate burn-up dependence predictability, NRC proposes a correlation to correct that deficiency at burn-up above 20 GWd/tM [1].

BELGONUCLEAIRE has developed a proprietary model which considers the diffusion, the trapping and the re-solution in the matrix of a "Booth's Sphere";

the model has been incorporated in the integral fuel rod modelling code COMETHE which correlates the Booth's sphere to open porosities and grain size.

It is beyond the scope of this paper to describe the BN fission gas release model. It has been done elsewhere /2/. The model has been validated on the basis of BN own experimental data and experimental data from other sources (Figures 1 and 2).

The present paper will deal with the predictions of the BN fission gas release model at high burn-up and will compare them with some available experimental data as well as with the predictions of the NRC correlation.

BELGONUCLEAIRE FISSION GAS RELEASE DATA BASE

The data base accumulated and still being implemented by BELGONUCLEAIRE covers a wide range of heat ratings and burn-ups for UO2 fuel and UO2-PuO2 fuel. It extends to an average burn-up as high as 70 GWd/tM as shown in Figure 3. It can be noticed that the fission gas release does not exhibit a burn-up dependence, high fission gas release being obtained as well at low burn-up as at high burn-up (Figure 3a). The fission gas release is strongly dependent on linear rating as illustrated in Figure 3b and Figure 4 /3/.

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The study has been performed for LWR's fuel rods as well as for LMFBR's fuel pins. In what concerns LWR fuel rods, a wide range of linear ratings was covered (from 270 W/cm to 850 W/cm). The linear rating for LMFBR's is about 450 W/cm. As an example, COMETHE fission gas release predictions are confronted to the experimental data and the predictions of the NRC correlation in Figures 5 and 6 for LWR fuel rods (BR3/VN and BN1) and in Figures 7 and 8 for LMFBR fuel pins (RAPSODIE and MFBS-6).

COMETHE results, experimental data and NRC correlation are in good agreement in the case of fuel operating at high temperature (LMFBR's fuel pins or high rated LWR fuel rod). Concerning LWR fuel rods, the NRC correlation overestimate the fission gas release while COMETHE results compare well with the experimental data.

DISCUSSION

Independently of any fission gas release model, the thermal behaviour of LMFBR's and LWR's fuels versus burn-up is completely different.

The fission gas release enhancement in LMFBR's is systematic. It results from the operating conditions. The swelling of the stainless steel clad tends to open the gap and to increase fuel temperatures. These high fuel temperatures lead to an important gaseous bubble swelling (which compensates that increasing gap) and to columnar grain growth (still active at EOL in LMFBR's). These two phenomena produce very high fission gas release.

Fission gas release enhancement can occur in LWR's but not necessarily at burn-up above 20 GWd/tM. For instance, in the case of unstable fuels, the pellet clad gap opening resulting from fuel irradiation induced densification increases the fuel temperature. If the temperatures are high enough, significant gaseous swelling can take place and lead to tunnelling mechanism (Figure 5 and Figure 10). After one cycle of irradiation, some fuel rods are shuffled in higher rated core zone. The resulting increase of linear power lead to higher fuel temperatures and fission gas release enhancement can occur (Figure 9). Moreover, the creep down of the Zircaloy clad tends to close the pellet clad gap and to decrease the fuel temperatures. That effect is well illustrated in Figures 9 and 10 which compare for the same power histories, the effect of clad material nature on the fission gas release predictions (stainless steel clad does not creep in LWR environment). An important remark is that the NRC calculation does not systematically overestimate the fission gas release (Figure 9). The fission gas release enhancement predicted by COMETHE (Figure 9) is a pure temperature effect in the case of the Zircaloy clad while in the case of the stainless steel clad, it is a temperature effect coupled with tunnelling mechanism. That explains the sudden increase in the fission gas release. The modern 17 x 17 LWR fuels are stable and the operating linear rating are relatively low. Fission gas release less than 1 % can be expected in 17 x 17 fuel rods at burn-up as high as 50 GWd/tM [4].

CONCLUSIONS

Fission gas release enhancement exists but considering a burn-up threshold limit is a wrong approach. The enhancement requires some burn-up but can start as early as 5000 MWd/tM (BR3/VN for instance). It is mainly a matter of temperature history. Accurate predictions of fission gas release requires first to predict correctly the fuel rod behaviour (gap closure, fuel restructuration, ...) by means of an integral fuel rod modelling code.

Such a requirement seems to be fulfilled by COMETHE which has been successfully applied to LMFBR's fuel as well as to UO2 or UO2-PuO2 fuels in LWR's.

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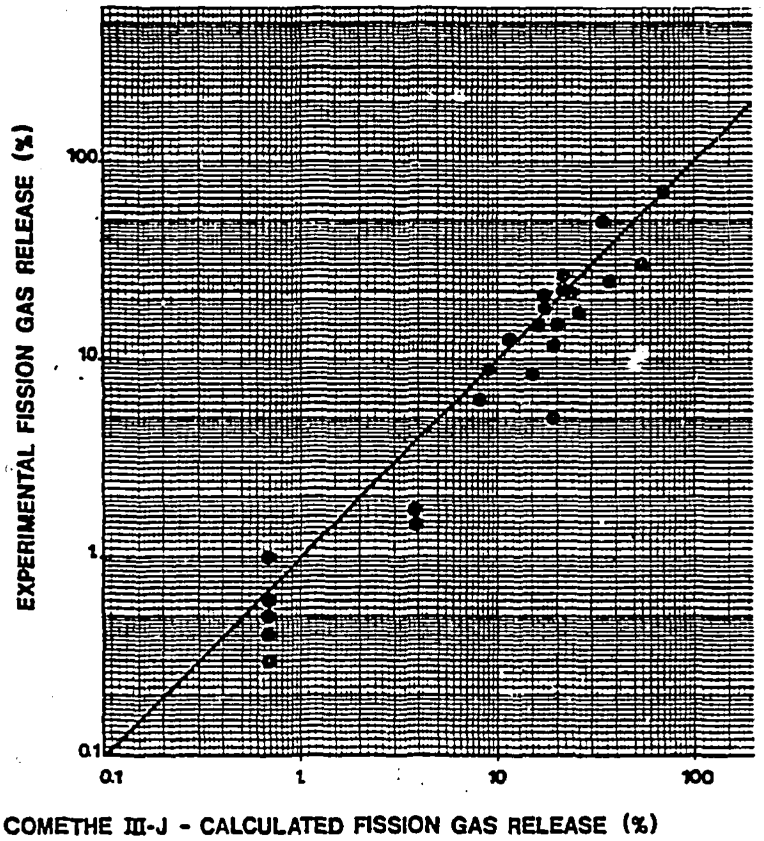

COMPARISON BETWEEN CALCULATED
AND EXPERIMENTAL FISSION
GAS RELEASE

FIG.1

BR3/VN RODS -
FRACTIONAL FISSION GAS RELEASE
VERSUS RELATIVE POWER LEVEL

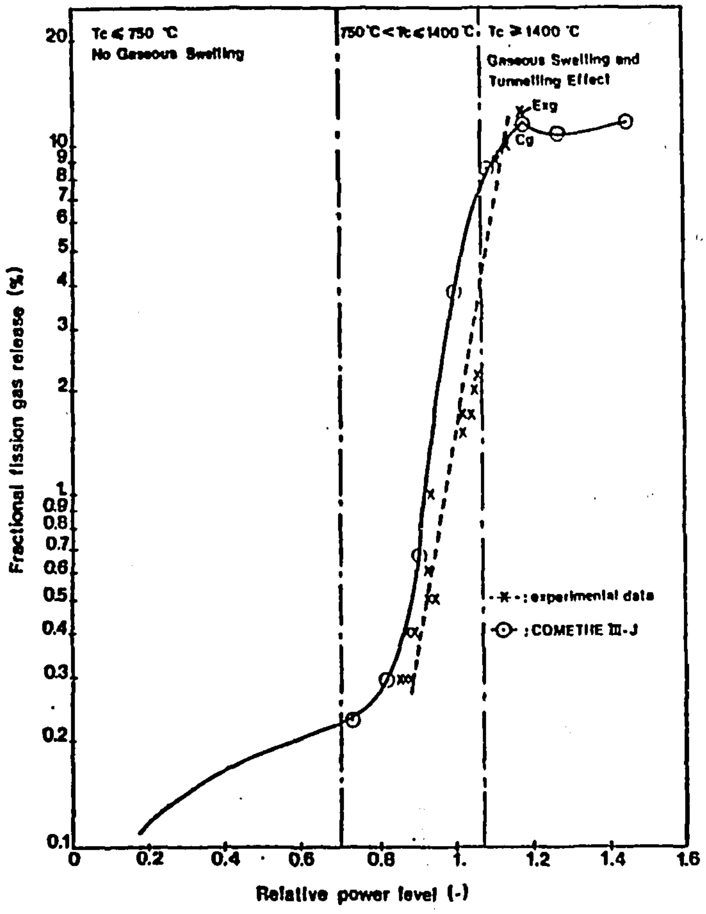

FIG.2

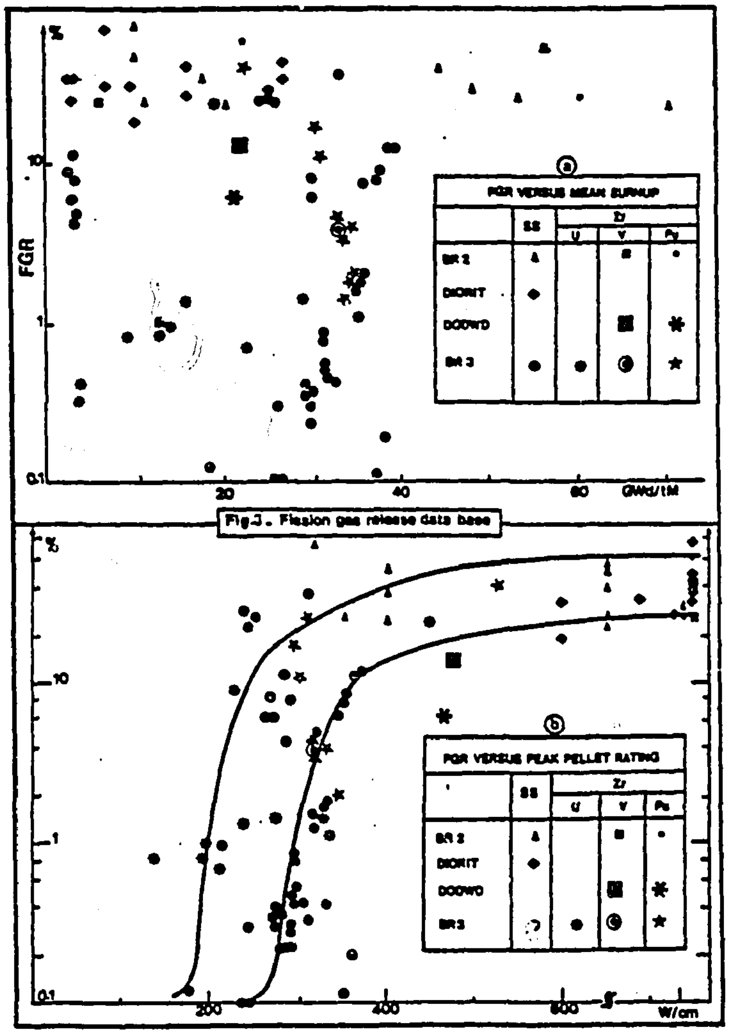

Fig.3. Fission gas release data base

FIG.3

VARIATION OF FISSION GAS RELEASE WITH ROD RATING
from KRB Gundremmingen (3)

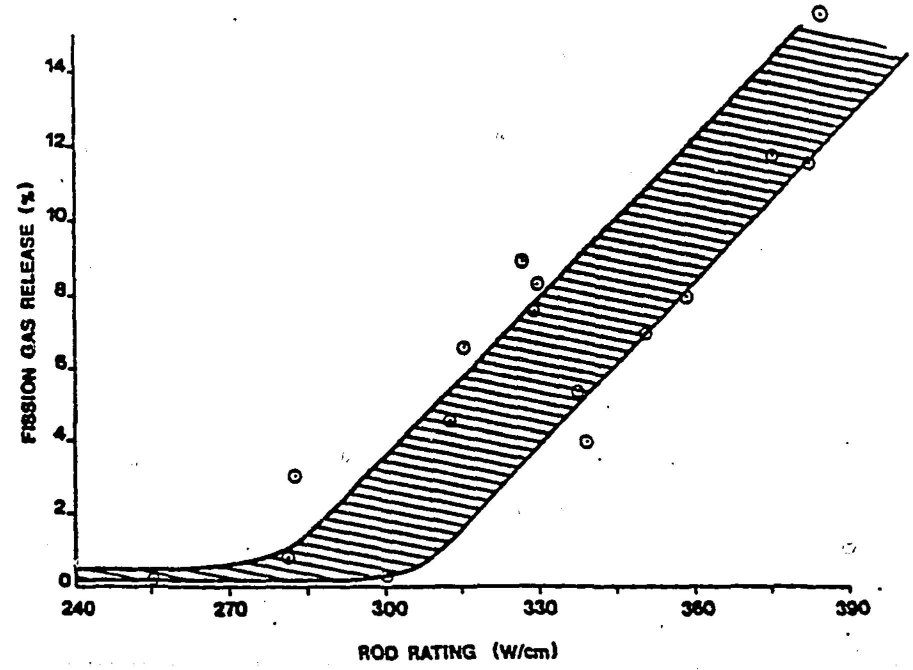

FIG.4

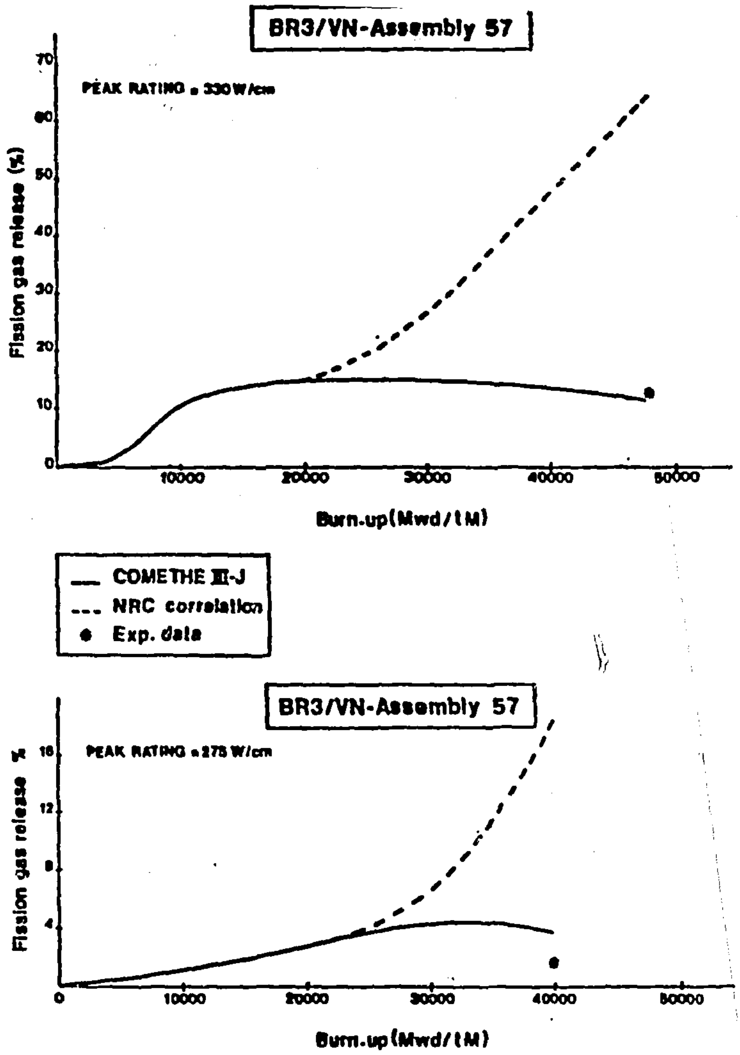

FIG.5

Fuel rod BN1 irradiated in EL3

Peak rating: 850W/cm .

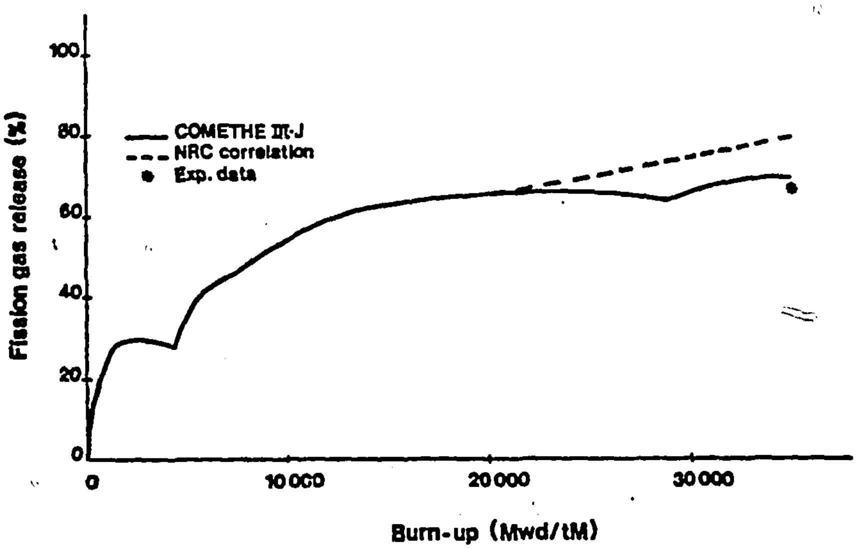

FIG.6

RAPSODIE I experiment

Fuel pin AUO1 - peak rating : 430 W/cm

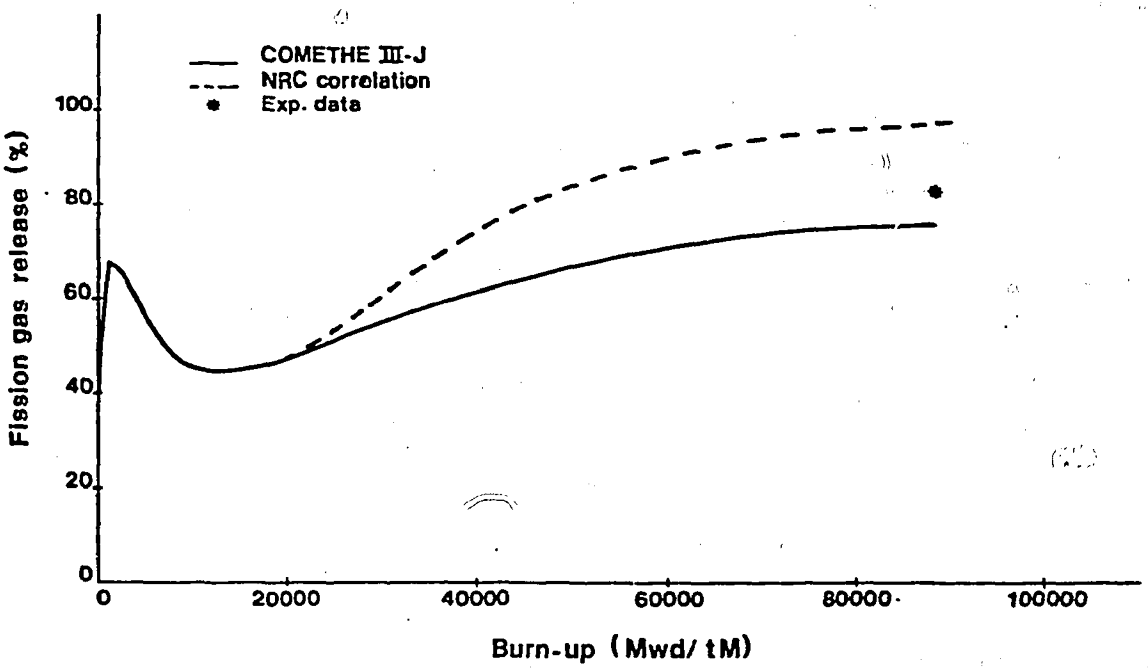

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FIG.7

MFBS-6 (BR2) - Pin T 13

Peak rating: 480 W/cm

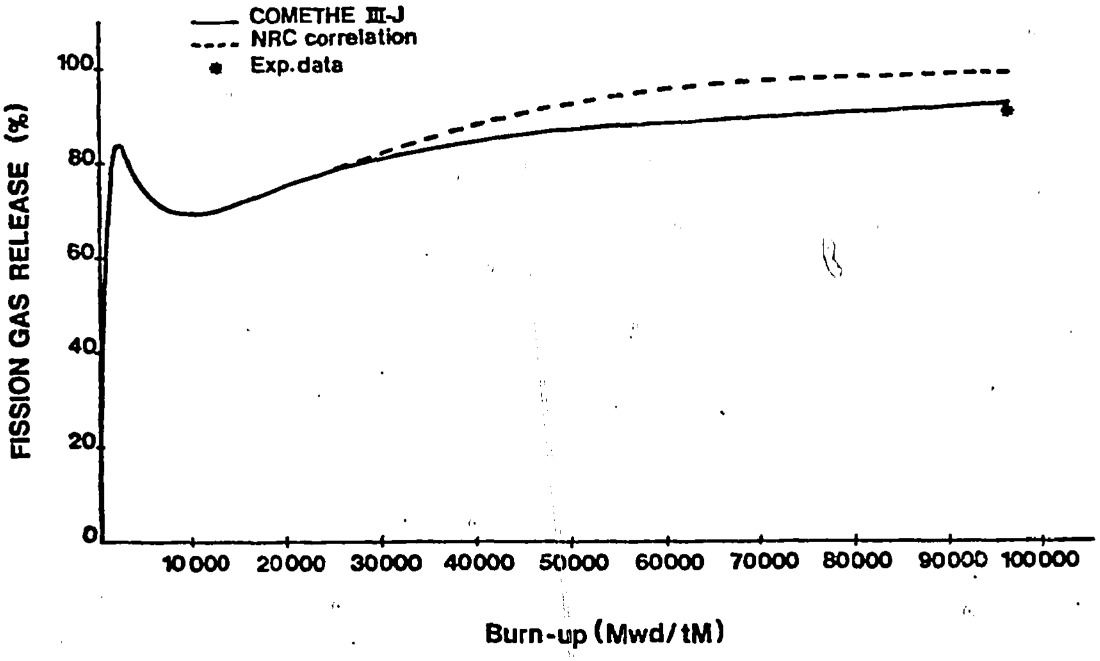

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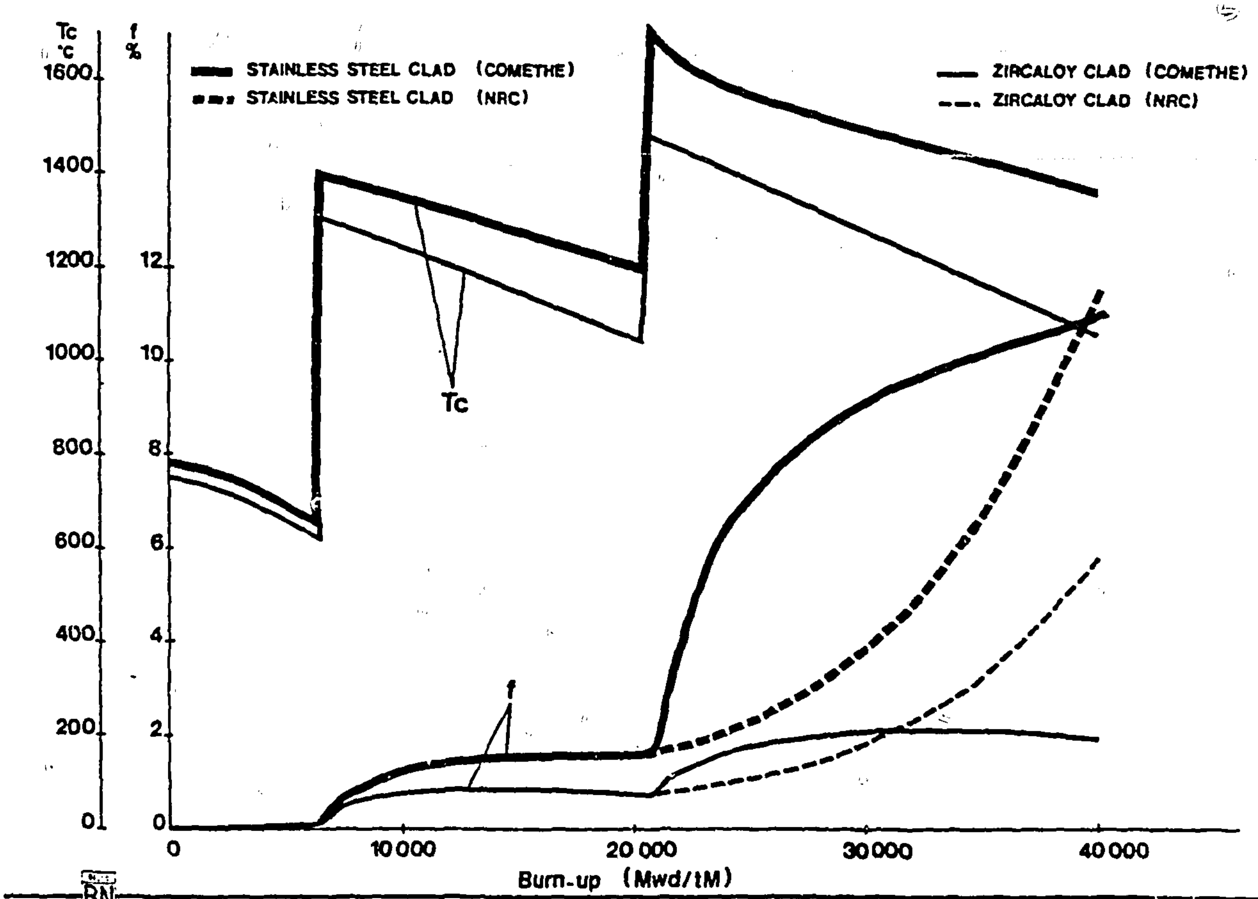
FIG.8



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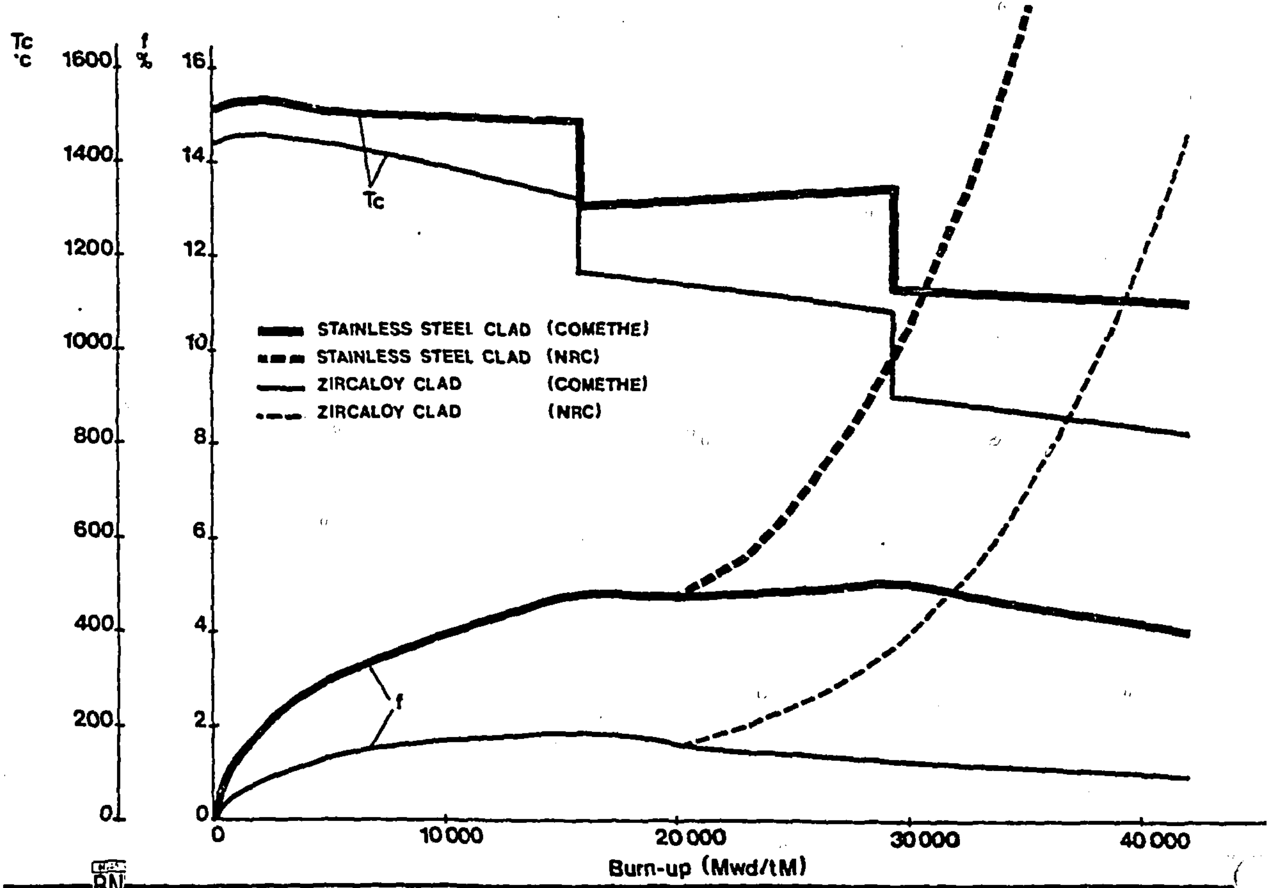
15x15 FUEL ROD
Maximum rating at 3rd cycle (360 W/cm)

FIG.9



BN belgonucleaire

15x15 FUEL ROD
Maximum rating at cycle1(320 W/cm)

FIG. 10