FISSION PRODUCT RELEASE DURING REACTOR OPERATION

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ABSTRACT

Chemically assisted mechanical process as stress corrosion cracking is recognized as the principal mode of fracture of Zircaloy in L WR. Clad failure generally occurs during unsteady reactor operation as power ramps. Fission products as iodine, bromine and cesium and their compounds have been recognized as the most aggressive agents in Zircaloy stress corrosion cracking.

The present paper is dealing with some proposed mechanisms of the release of these fission products in L WR modern fuel rods, of the 17 x 17 type. The results of a parametric study performed with the COMETHE III-J code to investigate the effect of power ramping on fission product release are displayed. The goal of that parametric study was to investigate the possibility of a fission product release enhancement during a power ramp. Three mechanisms leading to such an enhancement were proposed and discussed. We concluded that a vapour transport mechanism along the fuel cracks would be the most likely one.

INTRODUCTION

Unsteady reactor operation is recognized as an important factor in L WR fuel rod failure, due to fuel - clad mechanical interaction (PCMI). Many investigations have shown recently that the PCMI effects could be enhanced by fission product deposit on the clad inner surface, leading to Zircaloy Stress Corrosion Cracking (S C C).

The present paper will deal with some proposed mechanisms by which the fission products are made available at the clad inner surface. The nature of the fission products involved in the Zircaloy stress corrosion cracking is not definitively established. However, the halogens iodine and bromine, cesium and their compounds have been identified to participate in Zircaloy S C C as they are the most volatile species and the most aggressive agents in Zircaloy inner clad corrosion.

CALCULATION

A parametric study was carried out by means of the COMETHE III-J code to investigate the effect of a power change on fission product release. The study has been performed for a 17 x 17 type rod, the characteristics of which are listed in the Table I hereafter.

TABLE I

Fuel rod characteristics

Array : 17 x 17

Clad outer diameter : 9.5 mm

Clad inner diameter : 8.36 mm

Diametral gap : 165 μm

Fuel bulk density : 93.5 % TD

The considered case consisted of a long holding period at 75 % nominal power followed by a ramp to 100 % nominal power. The irradiation conditions before and after ramp are summarized in Table II below.

TABLE II

Irradiation conditions

Linear power before ramp : peak : 258 W/cm
average : 207 W/cm

Burn-up before ramp : peak : 34,650 MWd/tM
average : 27,300 MWd/tM

Ramped linear power : peak : 340 W/cm
average : 272 W/cm

Amount of fission gases produced before ramp : 503 cc STP

Amount of fission gases released before ramp : 1.3 cc STP

Fission gas release before ramp : 0.27 %

Four ramp rates were investigated as shown in Table III below.

TABLE III

Characteristics of the considered ramps

Ramp rate (%/h)	Ramp Duration (hours)
3	8
2	12
1	24
0.5	48

The fission product release was investigated assuming that it was proportional to the fission gas release. The fission gas release calculation of COMETHE is quite sophisticated : the long range fission gas diffusion is estimated by means of an equivalent diffusion sphere which can be affected by irradiation ; the diffusion kinetics takes resolution and trapping into account.

The equivalent diffusion sphere radius is correlated to the fuel specific surface or the fraction of open porosity.

DISCUSSION

It is not yet clearly established if fission gas bursts actually occur during power variations in typical L W R conditions.

The goal of this study was to investigate the possibility of a fission products enhanced release during a power ramp.

Three proposed mechanisms leading to such an enhancement are :

1. Additional cracking of the fuel pellet can increase its specific surface and therefore, let more fission products diffuse out of the cracked pellet sectors. In this mechanism, a significant amount of fission product can be released during the ramp if the fuel specific surface is considerably increassed by about a factor 20, i.e. if the equivalent diffusion sphere radius is decreased from its steady state value (100 μm)to its lowest limit, i.e. the grain size (5 μm). The fraction $\Delta N/N_0$* of fission gas released during the ramp is plotted in Fig. 1 as a function of the diffusion sphere radius (a) and the ramp rate. One can noticed that the fission gas release is very sensitive to that latter parameter. Such an important variation of the fission product release cannot be attributed to additional cracking. A simple calculation involving the macroscopic and microscopic specific surface for cracked fuel pellet demonstrates that if the number of radial cracks increases from 4 to 6, the equivalent diffusion sphere radius is only affected by 20 %.
2. The presence of fission products on grain boundaries can lead to transient fuel swelling by temperature induced vaporization and pressure build-up in the pores leading to tunnelling effect.
3. The fuel temperature increase during the ramp induces a much faster gaseous phase transport, due to the large sensitivity of vapour pressure with temperature ; this transport should take place along the most likely path, i.e. the fuel radial and axial cracks.

The Fig. 2 presents the most important parameters involved in the second and third mechanisms.

In fact, mechanism 2 is only to be considered if the vapor and fission gas pressure existing in the pores is high enough to override the existing hydrostatic pressure. As shown in Fig. 2, only I_2 and Br_2 are susceptible to create such an overpressure. But, as iodine and bromine are almost totally bonded to cesium - at least in the case of stoichiometric or hypostoichiometric fuel - to form CsI and CsBr with much lower vapour pressure, such an overpressure seems unlikely in a 17 x 17 rod.

Therefore, the third mechanism seems to be by far the most significant ; as this mechanism is governed by the vapour pressure properties of the transporting compound, it is quite sensitive to the temperature distribution existing along the fuel cracks and on the clad inner side. Fig. 2 shows some transporting compounds which could play a significant role.

CONCLUSION

Three mechanisms of fission product release were proposed and discussed in the case of a 17 x 17 fuel rod. We may conclude that the most likely mechanism is a vapour transport along the fuel cracks.

* $\Delta N = N_1 - N_o$, where N_o is the amount of fission gases released before the ramp ; N_1 is the amount of fission gases released after the ramp.

REFERENCE

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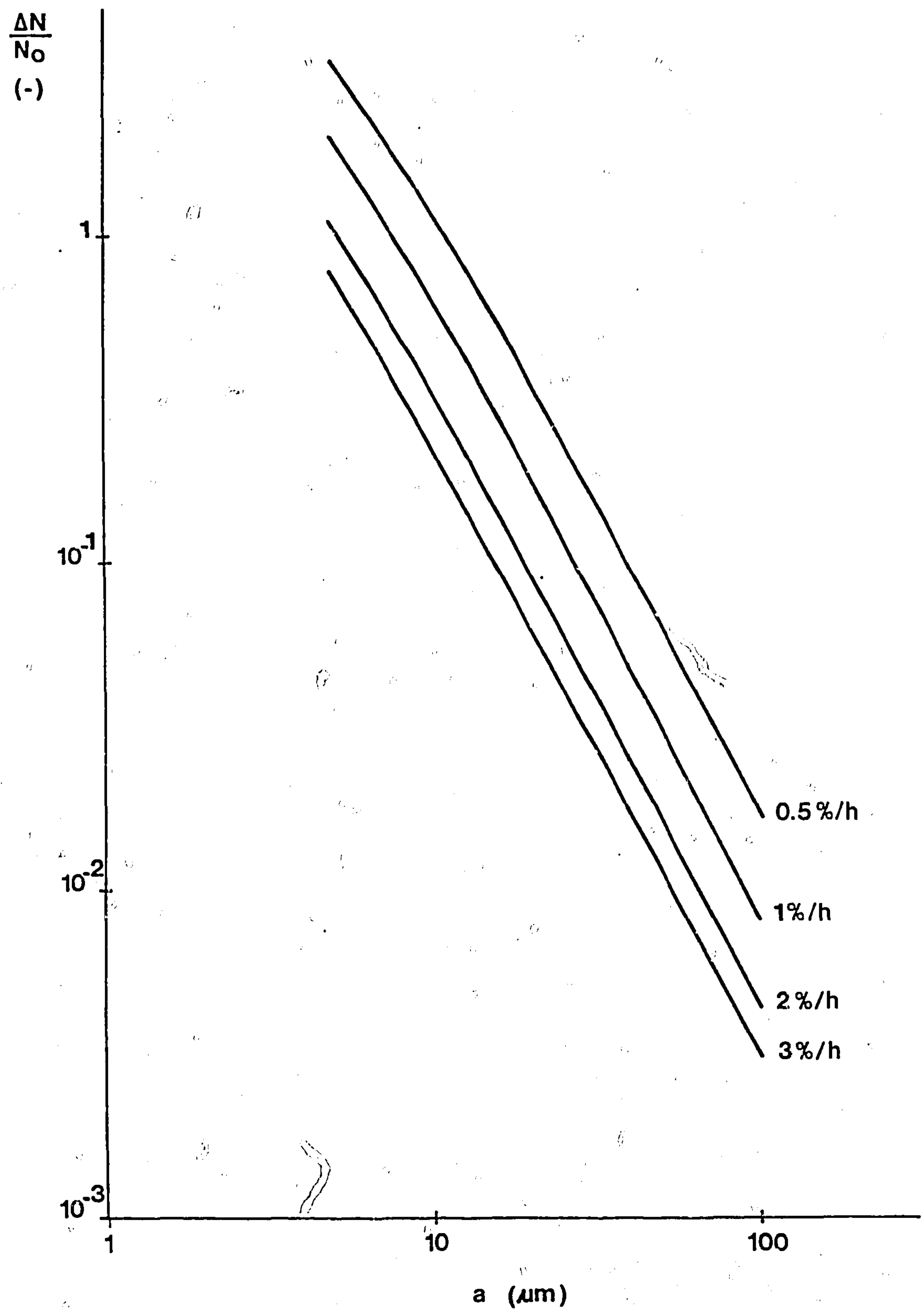

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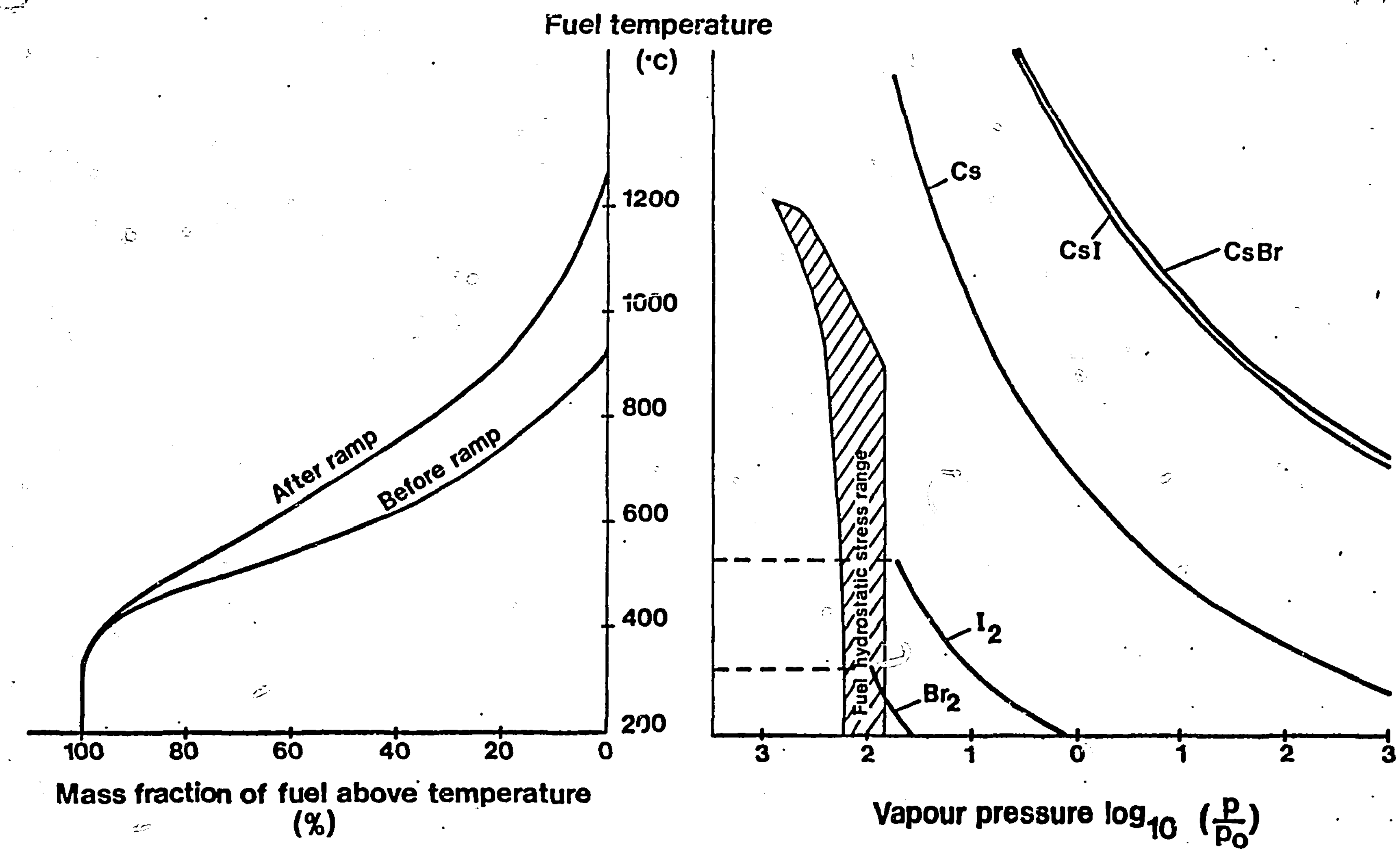
Fission gas release during power ramp as a function of diffusion sphere radius and ramp rate

Fig.1



belgonucleaire Parameters involved in fission product release mechanism FIG. 2