LETTERS TO THE EDITOR

ARGUMENTS CONCERNING THE EVALUATION OF CLADDING DILATATION DUE TO THERMODIFFUSION

In his evaluation, Norris[1] derives the diffusivity of vacancies and lattice atoms from the mobility of vacancies under thermal equilibrium conditions, multiplied by their irradiation-induced supersaturation. This is called "simple theory" under steady-state conditions in the literature.[2]

However, radiation can also accelerate diffusion by increasing the jump frequency of point defects.[3] Experiments have shown that enhancement of diffusion is considerably larger than the effect explained by the supersaturation of vacancies only.[4,5] In our calculations, we have used experimentally determined enhancement factors of copper and gold diffusion in aluminum,[4] transferred to homologous temperatures in stainless steel. Diffusion under thermal equilibrium has been multiplied by this factor in our calculations. This is the main reason for the different results obtained by Norris and by us.

Experimental work on irradiation-enhanced self-diffusion of nickel[5] yields an acceleration factor of 8×10^2 at 500°C and 3 to 32×10^{-9} dpa/s. Typical displacement rates in fast breeders are 10^{-6} dpa/s. Thus, an acceleration factor of $\sim 8 \times 10^4$ can be used. This is in accordance with the value used in our calculations, which had been estimated from the data published by Acker et al.[4] We have not considered the fact that enhancement is partly due to interstitial migration,[6] which can reduce somewhat the calculated effect.

As to the heats of transport, we agree with Norris in that different estimations are possible. We have taken a value of half the activation energy of diffusion, which seemed to be reasonable for an estimation.

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REPLY TO "ARGUMENTS CONCERNING THE EVALUATION OF CLADDING DILATATION DUE TO THERMODIFFUSION"

There is disagreement between alternative evaluations of the same effects by Venker et al.[1] and by Norris.[2] The consequent diameter increase of typical fast reactor fuel pin cladding is predicted to be a maximum of 4 or 0.01 μm/yr, according to which alternative is believed. The comments above[3] help identify the origin of the discrepancy.

The evaluation in Ref. 1 is based on experimental results for irradiation-enhanced diffusion of copper and gold in aluminum[4] and claims support from data for irradiation-enhanced self-diffusion in nickel.[5] Both sets of work were carried out on annealed single crystals in which dislocation densities would have been low, in the former case being quoted as 10^{10} m^{-2}. In both sets of work, it was shown that the mutual vacancy interstitial recombination rate exceeded the rate of loss of defects to sinks. By contrast, the stainless-steel cladding of a fast reactor fuel pin rapidly develops voids and dislocations in the neutron flux that it experiences. A total sink density of 10^{14} m^{-2} is a low estimate. Generally, diffusion to sinks replaces mutual recombination as the dominant defect loss mechanism, so that the steady-state vacancy and interstitial concentrations become inversely proportional to sink density. Transfer of an "acceleration factor" to this situation from annealed single-crystal data is only valid if both the different sink density and the different dominant defect loss mechanism are taken into account; it cannot be done without some theory. I suggest that neglect of these considerations makes the acceleration factor applied in Ref. 1 to stainless steel a factor of ~400 too high.

The evaluation by Norris[2] employs a simple theory of vacancy and interstitial concentrations under irradiation, without considering the irradiation enhancement of interstitial mobility (an effect of most importance at very low temperatures) or the role of multiple defects such as divacancies. Venker et al.[3] are critical of these omissions, but they are incorrect in suggesting that the simple theory, which includes interstitials, does not account for the experimental data that they employ. In fact, Acker et al.[4] and Schüle et al.[5] use the simple theory for the interpretation of their results.

The evaluation of cladding dilatation is limited by uncertainties in the heats of transport rather than by use of the simple theory of irradiation-enhanced diffusion. The conclusion remains that the contribution of these thermomigration effects to cladding dilatation is negligible.

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