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Eutectic Penetration Times in Irradiated EBR-II Driver Fuel Elements*

by

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The experimental test procedure employed the use of a high-temperature furnace which heated pre-irradiated elements to temperature and maintained the environment until element-cladding breach occurred. Pre-irradiated elements of the Mark-II design were first encapsulated in a close-fitting sealed tube that was instrumented with a pressure transducer at the top of the tube and a thermocouple at the element's top-of-fuel axial location. The volume of the capsule was evacuated in order to better identify the pressure pulse which would occur on breach and to minimize contaminants. Next, a three-zone fast-recovery furnace was heated and an axial temperature profile, similar to that experienced in the EBR-II core, was established. The encapsulated element was then quickly inserted into the furnace and remained there until clad breach occurred. The element was then removed from the furnace immediately. Visual and metallurgical examination of the rupture site was done later. A total of seven elements were tested in the above manner. Details of the Mark-II design are given in Reference 7 with the nominal dimensions quoted here: clad O.D., 0.442 cm, clad I.D., 0.381 cm, and fuel O.D., 0.330. These data were correlated by the following equation with a correlation coefficient of 0.958,

$$r = 0.011987 \left(\frac{T}{715}\right)^{28.501} (1 + b)^{0.54573} \qquad (1)$$

over the range of $750°C \leq T \leq 850°C$, and $0 \leq b \leq 7.8$ at%,

where r is the eutectic penetration rate in mm/hr, T is the temperature in °C, and b is the burnup in at%.

Six of the seven data points and the curve fit of equation (1) are illustrated in Figure 1. Also shown in Figure 1 are eutectic penetration data obtained from out-of-pile dip-tests with 304 stainless steel clad in contact with molten uranium.[5] the eutectic alloy which forms at about 715°C is assumed identical to that formed in the Mark-II elements and has a composition of U-34 at% Fe. A comparison of the data obtained from the rupture tests with the out-of-pile eutectic penetration tests indicates that the clad breach eutectic penetration rates are much higher than that obtained from the dip-tests. The reason for this is the fact that the actual irradiated fuel elements were employed and thus indirectly included other variables which may have affected the eutectic penetration rate. That is, parameters such as fission gas pressure, fission products, sodium bond, fuel porosity, clad properties after irradiation, and other in-pile environmental effects which may not necessarily affect the eutectic formation rate, could affect the time to element rupture via an indirect mechanism. For example, the time to element breach may not necessarily depend upon how long the eutectic takes to penetrate through the entire clad thickness, but upon the time needed for the eutectic to penetrate sufficiently into the clad until the cladding stress is sufficiently increased to breach the cladding. Because both high and low burnup elements were included in this study, these in-pile effects can be generally included by incorporating a fuel burnup parameter into the results. Thus, although the eutectic formation phenomena is the reason for element breach once the eutectic temperature is exceeded, there does appear to be other factors which enhance the effective penetration rate, i.e. time-to-rupture. The contribution of these other factors is difficult to quantify at this time.

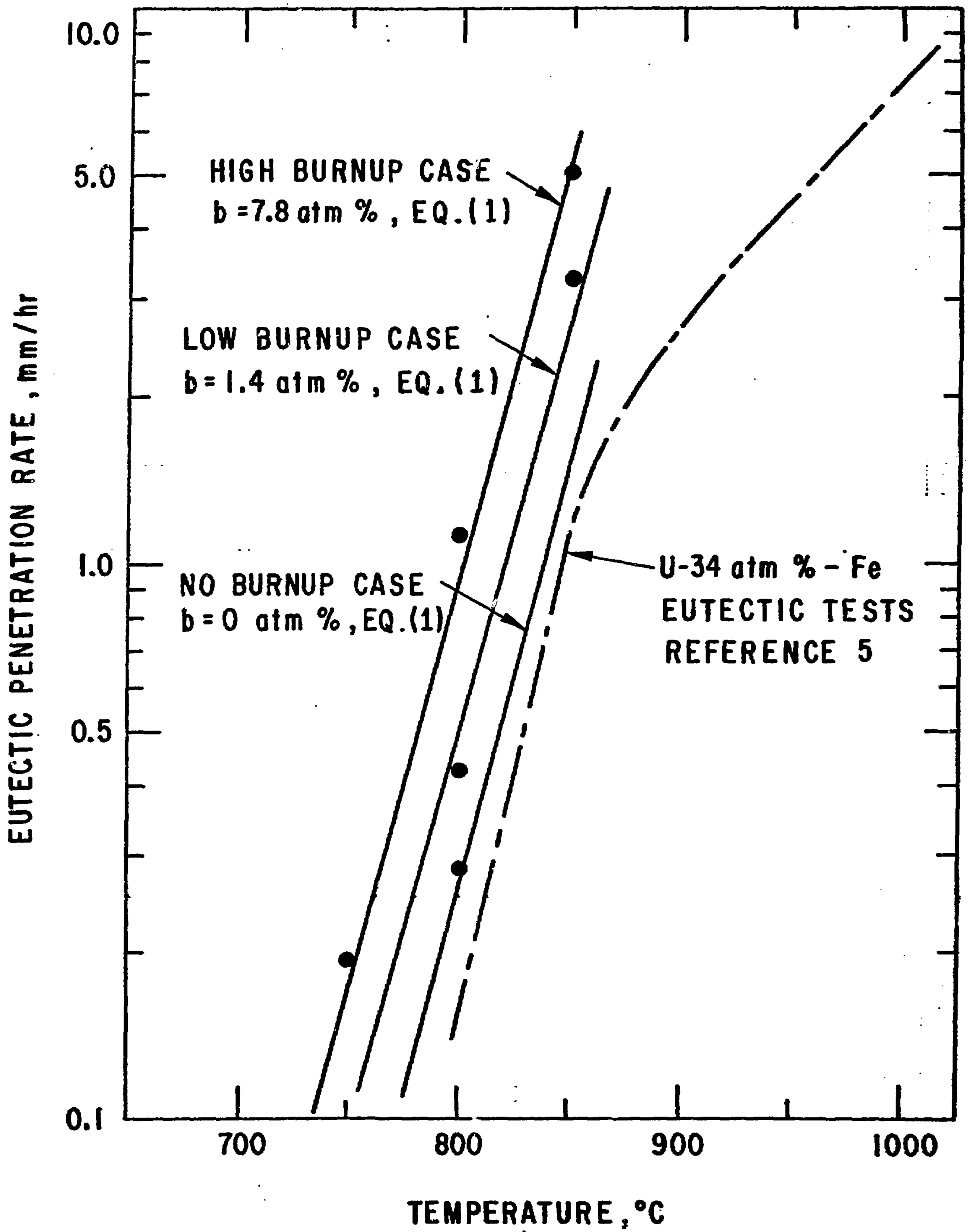

Figure 1. A Comparison of Eutectic Penetration Rates Between Fuel-Cladding Rupture Tests and Molten-Dip Tests

References:

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6) C. M. Walters and C. E. Dickerman, "TREAT Study of the Penetration of Molten Uranium and U/5 w% Fs Alloy Through Type 304 Stainless Steel," Nuclear Science and Engineering, Vol. 18, 1964, p. 518-524.

7) G. L. Hofman, et al., "Irradiation Behavior of Unencapsulated EBR-II Mark-II Driver Fuel to a Maximum Burnup of 6 at.%," Argonne National Laboratory Report ANL-8119, February 1976.