DISCUSSION

David Franklin[1] –Questions:

1. One of the equations you use to predict the design performance of irradiated stainless contains the ratio of the reduction in area of irradiated and unirradiated material. What is the physical significance of this parameter? Isn't this parameter relatively insensitive to irradiation when compared to other parameters such as uniform elongation?

2. EBR-II in-reactor creep experiments have shown that, except at high temperatures, creep in pile has a very different effect on material properties than creep after irradiation. How then do you predict the effect on material properties than creep after irradiation. How then do you predict the effect of creep hold times by using postirradiation tests?

3. Recent experiments in fatigue testing indicate that damage due to the hold times may occur only in an atmosphere that is not present in a sodium-cooled reactor. Does this influence your prediction of in-pile materials performance?

C. R. Brinkman (author's closure)

1. The original Coffin-Mason relation and numerous investigations have shown that a simple power-law relationship exists between plastic strain range and number of cycles to failure as obtained from strain-controlled fatigue tests. Furthermore, one of the constants in this equation is related to the true ductility D or true strain at failure as determined by tensile tests at the particular temperature of interest. This dependence on true ductility or reduction in area is reflected in Eqs 1 and 2. Multiplying the constant B in Eq 3 by the ratio of true ductilities results in a modified Universal Slopes Equation. While the Universal Slopes Equation does not account for strain rate and hold-time effects at elevated temperatures, it has been shown to be very useful in estimating fatigue behavior for many materials over a wide temperature range.[2]

Unfortunately, reduction of area measurements determined from irradiated tensile tests are not reported as frequently as uniform elongation measurements; and there may be some question as to how sensitive true fracture strain or true

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[2] Manson, S. S. and Halford, G. R., "A Method of Estimating High Temperature Low Cycle Fatigue Behavior of Materials," *Thermal and High Strain Fatigue*, Monograph and Report Series No. 32, The Metals and Metallurgy Trust of the Institute of Metals and the Institution of Metallurgists, London, 1967, p. 154.

ductility is to irradiation[3] in comparison with uniform elongation, particularly when taken over a broad irradiation and deformation temperature range. Recent test data, however, have shown that some of this lack of understanding has been due to the fact that several embrittling mechanisms occur that are dependent upon irradiation and test temperature, fluence, and strain rate. The tensile data of Holmes et al as reported in this volume for irradiated Type 316 stainless steel, and that of Bloom et al,[4] however, show that reduction of area is sensitive to irradiation-induced ductility changes. The point to be made is that low-cycle strain-controlled fatigue behavior of irradiated materials is sensitive to irradiation-induced changes in ductility as measured by reduction of area determinations. Also, reduction in area has the advantage that it is not gage length dependent as is uniform elongation.

2. The prediction of the behavior of stainless steel LMFBR components subject to complex stress-strain-time wave forms that induce inelastic strain is complex. Methods of estimating behavior under combinations of static and cyclic loading are presently nonexistent. However, from the results of hold-time tests conducted thus far we are hopeful that, with more postirradiation test data, methods will be possible allowing calculation of lifetimes to within factors of two to five. We further feel that such techniques can best be developed from postirradiation tests where a number of tests can be conducted accounting somewhat for the statistical nature of creep and fatigue. Such tests also offer an advantage over in-reactor tests in that the loads and strain can be measured or applied accurately at a fairly low cost. In-reactor effects may be added from a few tests after development of a method involving postirradiation tests at less cost.

3. The important influence of environment, particularly oxygen at elevated temperatures, on fatigue processes has been known for sometime. It is expected, therefore, that fatigue and creep-fatigue behavior of components exposed to sodium will be somewhat different from that if they had been subjected to the same service in air. It is expected that the environmental effect will be strongly dependent upon the oxygen and possibly carbon content of the sodium; however, excluding other effects such as cesium attack on cladding, results from tests conducted in air are thought to be reliable for present design considerations. Data obtained from tests conducted in air, however, may not be conservative for all loading conditions and environments envisioned for LMFBR service,[5] and this problem is presently receiving attention at several laboratories.

[3] Stiegler, J. O. and Weir, J. R., "Effects of Irradiation on Ductility," *Ductility*, American Society for Metals, 1968, p. 311.

[4] Bloom, E. E. and Weir, J. R., "Effect of Neutron Irradiation on the Ductility of Austenitic Stainless Steel," *Nuclear Technology*, Vol. 16, No. 1, Oct. 1972, p. 45.

[5] Andrews, R. C. et al, "Effect of High Temperature Sodium on Austenitic and Ferritic Steels," Mine Safety Appliance Research Corporation Report MSAR 67-103, July 1967.