Dual Ion Irradiation of Commercial and Advanced Structural Materials: High Dose Resistance for Extended LWR Operation

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The lifetime extension of current reactors and the design of next generation systems rely on the radiation resistance of structural materials for core internals. The accumulation of transmuted helium in such components becomes critical at higher doses, as the co-evolution of irradiation-induced defects and interstitial helium significantly alters microstructural stability, swelling, and hardening. To anticipate such microstructural behavior in light water reactors (LWRs), ten austenitic and ferritic alloys were irradiated simultaneously using ~5 MeV self-ions and helium. Helium energies were systematically degraded from 2 MeV by passing ions through a rotating aluminum foil, thus achieving a fixed ratio of ~13 appm He/dpa.

Characterization after irradiation to 150 dpa at 400 °C revealed marked similarities and variations in microstructural evolution among alloys. Nanoscale cavities were observed in all irradiated samples, although these amounted to modest swelling (<0.3%). Similarly, the alloys showed a distinct lack of secondary phases beyond oxides in the ODS steel 14YWT. Pre-existing γ' and γ'' precipitates in the Ni-base alloys were disordered or dissolved during irradiation, and common irradiation-induced Ni_2Cr or G-phase particles did not form. Microstructures of the ferritic alloys (14YWT and optimized T92) generally showed the least change, and those of the austenitic stainless steels (316L and 310) showed the most. While pre-existing features (e.g., dispersed oxides) were unaltered during irradiation of either class, a third more swelling and twice the dislocation loop formation were observed for the austenitic steels versus the ferritic. Microstructural stability for the Ni-base alloys generally fell between the steel classes and was observed to vary more as a class than the others. Precipitate strengthened Ni-base alloys (X750, 718A, and 725) showed worse swelling and dislocation loop formation than the solid solution alloys (690, 625, and C22), with a notable dependence on iron content. Perhaps the most significant finding, however, was that most of these materials showed comparable or better radiation resistance (defined in terms of swelling and dislocation loop formation with irradiation) than commonly used 316L stainless steel or alloy X750, suggesting suitability for similar applications.