Helium and Damage Rate Dependence of Swelling in Simulated Ferritic Alloys Using a Hybrid Cluster Dynamics Model

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The safer, more efficient reactor designs of the future have much higher temperature and radiation dose requirements which necessitate more tolerant materials such as ferritic-martensitic alloys. Ion irradiation is frequently used to study the radiation damage incurred during reactor operation using an accelerated damage rate, allowing well-controlled experiments which reach damage levels of interest one thousand times faster and minimize sample activation. This technique comes with one crucial caveat: damage rate itself has a large impact on the kinetic evolution of defects that controls radiation effects and raises questions of how well accelerated experiments can reproduce neutron irradiation. A cluster dynamics model was developed to investigate the impact of damage rate on swelling phenomena in simulated ferritic alloys at high irradiation damage levels. The model uses a novel hybrid approach to treat the large problem dimensions in cluster size, significantly coarsening the model to a mean size approximation in the growth regime. Implementation of a heterogeneous nucleation mechanism fundamentally altered how peak swelling temperature is affected by damage rate by providing a preferred nucleation pathway independent of the thermal stability of vacancy clusters. Finally, the bias toward interstitial absorption at small cavities was included in the cluster dynamics model, which reproduces three key experimental observations in ferritic alloys that have been problematic for traditional rate theory models of radiation effects, namely: low swelling rate, a long incubation period before the onset of void swelling, and a strong effect of helium on cavity nucleation.