Atom Probe Field Ion Microscopy and Atom Probe Tomography Characterization of Neutron-irradiated Pressure Vessel Steels.

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The related techniques of atom probe field ion microscopy (APFIM) and atom probe tomography (APT) provide powerful microanalytical tools to investigate and characterize the solute distribution in the steels used in nuclear power reactors. The atom probe is a combination of a field ion microscope in which the microstructure of the needle-shaped specimen may be imaged with atomic resolution and a single-atom-sensitive mass spectrometer in which the solute distribution may be elementally analyzed at the atomic level. Since a time-of-flight mass spectrometer is used, the instrument is capable of detecting all elements with equal sensitivity. In the three-dimensional atom probe (3DAP), the x, y, and z coordinates and the mass-to-charge ratio, and hence the elemental identity, of the atoms in a small volume are determined in a mass spectrometer equipped with a position-sensitive single atom detector. In this 3DAP instrument, the volume analyzed is typically ~10 to ~20 nm square by ~100 to ~250 nm long and contains between 10^5 to 10^6 atoms. The atoms within the analyzed volume may be reconstructed in a computer after the experiment to determine the spatial distribution of all the solutes present in the specimen. These microanalytical techniques enable the solute distribution in the matrix and at interfaces, such as lath or grain boundaries, and the presence of small clusters and precipitates to be characterized at the highest spatial resolution available in any real space microanalytical technique.

These atom probe techniques have been applied to several neutron irradiated and thermally aged Western and Russian pressure vessel steels. The results have revealed the presence of many different microstructural features including copper-enriched clusters and precipitates, phosphorus clusters, a variety of carbide, nitride and oxide precipitates, solute segregation to dislocations, and a complex pattern of solute segregation and precipitation at lath and grain boundaries. The presence of these features is dependent on the composition of the steel and its thermal and exposure history. In addition, the atom probe technique has been used to measure the composition of the matrix after various stages of processing of the steel, subsequent exposure to neutron irradiation and post irradiation annealing treatments. A variety of examples of the features present in the steels used in nuclear reactors will be presented to demonstrate the types of information that may be obtained with the atom probe.

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