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Nanostructural evolution in nuclear reactor pressure vessel steels studied by positron annihilation and three dimensional atom probe

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The nuclear reactor pressure vessel (RPV) is a hard-to-replace component serving as a high temperature and high pressure primary coolant boundary in nuclear reactors. Thus structural integrity and the clarification of microscopic mechanisms of irradiation-induced embrittlement of RPV steels are essential for safety reasons. The nanostructural evolution of irradiation-induced Cu-rich nano precipitates (CNPs) and vacancy clusters in the surveillance test specimens of reactor pressure vessels of a Calder Hall Reactor (CHR) and pressurized water reactors (Belgium PWRs, Doel-1 and Doel-2) has been studied. Firstly using positron annihilation spectroscopy, we here reveal that very low dose rate of the CHR can significantly enhance the Cu precipitation which causes the RPV embrittlement ata much earlier stage than that found from accelerated test in a material testing reactor. Secondly for the PWRs, combining the three dimensional local electrode atom probe (LEAP) and the positron annihilation techniques, we have found that in both medium (Doel-1, 0.13 wt.%) and high (Doel-2, 0.30 wt.%) Cu welds, the Cu rich nanoprecipitates (CNPs) are found to form readily at the very beginning of the reactor lifetime. Thereafter, during the subsequent 30 years of operation, the residual Cu concentration in the matrix shows slight decrease while the CNPs coarsen. On the other hand, small vacancy clusters of V3~V4 start appearing after the initial Cu precipitation and are accumulated steadily with neutron dose.