6 Summary

Crack growth rates have been determined in tests conducted in a PWR environment at 316°C on Alloy 600 removed from the Davis–Besse CRDM Nozzle #3, and Alloy 182 from Nozzle #11 J–groove weld, as well as at 320°C on Alloys 82 and 182 from the “A” hot–leg nozzle–to–pipe weld from the V.C. Summer reactor coolant system. The purpose of these tests was to determine whether the crack growth in these materials from the Davis–Besse and V.C. Summer plants are consistent with our understanding of CGRs in Ni–alloy and welds. The results are compared with the existing CGR data to determine the relative susceptibility of these alloys to PWSCC. The tensile properties, microstructure, and fracture morphology of the nozzle material have also been characterized. The significant results are summarized as follows:

(a) For the Davis–Besse CRDM nozzle Alloy 600, the microstructure along the longitudinal plane is similar to that along the circumferential plane; the grain size varies from 30–200 µm with an average value of ≈75 µm. The material appears to have good GBC of Cr–rich carbides and a few carbides randomly distributed in the matrix. The tensile strength of the material is comparable to the typical (average) value observed for thick-section Alloy 600 products.

(b) The SCC CGRs of the Alloy 600 nozzle are a factor of 4–8 higher than those of the median curve for Alloy 600. The growth rates correspond to the ≈95th percentile of the various data sets used in developing the median curve, i.e., the nozzle material exhibits very high susceptibility to SCC. The material exhibits predominantly IG fracture, even during predominantly mechanical fatigue. A TG fracture is observed at the very beginning of the test (i.e., near the machine notch), but, in most cases, it changes to IG fracture when the first grain boundary is encountered.

(c) The reasons for the high growth rates for the nozzle Alloy 600 are not clear. Materials with good GBC of carbides and relatively low or average tensile yield stress are generally considered to have low susceptibility to SCC in PWR water. Differences in the microstructure in terms of extent and nature of carbide precipitation (e.g., absence of Cr–rich M_7C_3 carbides with a dendritic morphology) may be important for susceptibility of Alloy 600 to PWSCC.

(d) The cyclic CGRs of the Alloy 600 nozzle in PWR water at 316°C show significant environmental enhancement of growth rates. The specimen orientation does not seem to have any effect on CGRs. Although a matter of coincidence, the cyclic CGRs in PWR water at 316°C can be represented by the curve obtained for Alloy 600 in a NWC BWR environment at 289°C.

(e) The weld alloys from both the Davis–Besse and V.C. Summer plants show a typical dendritic microstructure. Tensile yield strength is higher and ductility is lower for the Davis-Besse Alloy 182 J–groove weld compared with the Alloy 600 nozzle material. The yield and ultimate strengths of Alloy 182 specimens from the butter region of the V.C. Summer weld are higher than those of Alloy 82 specimens from the weld region. This difference in tensile strength is essentially because of differences in the orientation of the dendritic structure and not differences in alloy composition; dendrites are parallel to the stress axis in the weld specimens and transverse to the stress axis for the butter specimens.

(f) For the Davis–Besse Alloy 182 weld and the V.C. Summer Alloy 82 weld and Alloy 182 butter materials, the SCC CGRs under constant load are a factor of 5 to 10 lower than the disposition curve proposed for Alloy 182 weld metals. The growth rates correspond to the ≈10th to 25th percentile of the various heats used in developing the disposition curve, i.e., the field weld alloys exhibit low susceptibility to SCC.

(g) Correlations have been developed to determine the CGRs of Ni–alloy welds in air as a function of loading conditions and temperature. In air, the growth rates of weld alloys are a factor of ≈2.5 greater than those of Alloy 600 under similar loading conditions.

(h) The cyclic CGRs for Alloy 182 and Alloy 82 weld specimens from either the Davis–Besse CRDM nozzle J–groove weld or V.C. Summer reactor vessel nozzle–to–pipe weld showed very little environmental enhancement. Under predominantly mechanical fatigue loading conditions (i.e., low load ratios and high frequency), the CGRs for the V.C. Summer weld alloys are a factor of ≈5 lower than those typically observed for laboratory–prepared Alloy 182 or 82 welds.