cracking. Sammarone performed experiments with several galvanic couples in boric acid solutions at 50 to 300°C.[45] Approximately 50 dissimilar metal couples were investigated. The only couples which showed evidence of galvanic corrosion were those involving aluminum, 4340 carbon steel, boronated stainless steel, boral, and nickel-plated 80 Ag-15 In-5 Cd.

Corrosion and boron absorption experiments were performed on several metals under irradiation in boric acid solutions (up to 50 ppm B) at ~50 to 60°C.[44] Pilot plant and laboratory tests also were conducted. The results indicated that carbon steel was not an acceptable material. Some pitting occurred on 6061 aluminum alloy specimens; behavior of 17-4 PH steel was acceptable. Aluminum corrosion was lower in the boric acid solutions than in pure water. No effects of oxygen at concentrations below 1.6 ppm were observed; tests at higher oxygen concentration were not conducted. The tests therefore differ from boric acid fuel pool chemistries, due to lower oxygen and boric acid concentrations.

Effects of Radiation on Corrosion

Effects of reactor radiation[a] on the corrosion of fuel bundle materials have been characterized.[46] At reactor primary system conditions, nuclear radiation has major effects on Zircaloy corrosion in oxygenated coolants, including BWR primary system chemistry. This results in 15 to 25 µm of uniform oxide on high-exposure Zircaloy BWR fuel rods, but with local thicknesses up to ~150 µm.[47] On PWR Zircaloy-clad rods, oxides on the coolant side are generally 15 to 20 µm at end-of-life,[18] and radiation has only a minor influence on corrosion in low-oxygen water reactor environments. This observation applies to both borated and nonborated reactor coolants.[18,46,48]

Reactor radiation also had minor effects on the corrosion of stainless steel and Inconel-600 in a low-oxygen reactor coolant.[46]

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[a] Principally neutron, gamma and beta radiation, with lesser fluxes of alpha, deuterons, etc. The available evidence points to fast neutrons as the principal source of accelerated in-reactor corrosion on the Zircaloys.

In water pool storage, neutron fluxes ($\sim 10^6$ n/cm^2 sec through nuclear waste canisters[49]) are almost certainly negligible from the standpoint of corrosion effects. Gamma fluxes on fuel rod surfaces are estimated to be $\sim 10^6$ R/hr at reactor shutdown, decaying by 3 to 4 orders of magnitude in four years.

Cowan and Tedman indicate that gamma fluxes change the chemical environments at corroding surfaces, in some cases having a pronounced effect on corrosion processes.[50] In oxygen-saturated fuel pool waters, formation of H_2O_2 will be favored. In some systems, stainless steel potentials are shifted to more passive values. Sensitized materials may shift to a potential regime where the matrix is more passive, but the chromium-depleted grain boundaries remain active, promoting intergranular attack. Cowan and Tedman warn that selection of cleaning solutions must be made carefully to avoid subsequent accelerated corrosion under irradiation. This consideration could be important if processes to remove crud from the fuel become desirable.

There is some evidence that pure gamma fluxes may accelerate Zircaloy aqueous corrosion in the thin film range at elevated temperatures, but the preponderance of evidence suggests that gamma fluxes do not significantly influence Zircaloy corrosion at reactor temperatures.[51] Visual observations suggest that gamma fluxes also do not have an accelerating influence on corrosion under pool storage conditions,[42] but we are not aware of systematic confirmatory data. The situation is similar for stainless steel, viz., lack of evidence that gamma fluxes either promote or inhibit corrosion, but with minimal detailed investigation of interactions between the gamma fluxes and other pool storage parameters such as water chemistry.

<u>Biological Corrosion</u>

Bacteria and other biological species are known to cause corrosion of numerous materials including iron-base alloys. There does not appear to be evidence that zirconium alloys are susceptible to biological corrosion. Some algae growth occurs in fuel pools, particularly on concrete walls when water chemistry is not carefully controlled. Algae growth has been a minor problem in pools with stainless steel liners which maintain high water quality, as indicated earlier.

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