

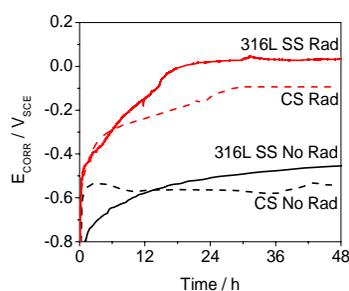
## Gamma-Radiation Induced Corrosion of Carbon Steel and Stainless Steel

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Stainless steel and carbon steel are used in systems that pass water (or heavy water) through the reactor core in nuclear power plants. Stainless steel is more resistant to general corrosion over a range of water conditions, but it is relatively more expensive and difficult to use. Also, under oxidizing conditions, it is susceptible to stress corrosion cracking. Carbon steel is cheaper and less susceptible to cracking, but it has acceptable corrosion resistance only under a narrow range, high pH range of water conditions.

Steel corrosion kinetics strongly depend on the water redox conditions, temperature, pH and ionic strength. The high radiation fields present in a reactor core will cause water to decompose into a range of redox-active species (both highly oxidizing (e.g.,  $\cdot\text{OH}$ ,  $\text{H}_2\text{O}_2$ ) and highly reducing (e.g.,  $\cdot\text{e}_{\text{aq}}^-$ ,  $\cdot\text{Q}^-$ ). These transient species can significantly influence corrosion kinetics. The effect of  $\gamma$ -radiation on the corrosion of carbon steel and Type 316L stainless steel has been investigated using a range of electrochemical and surface analyses techniques. Since corrosion depends strongly on the oxide formed on the surface, the main focus of the studies has been to establish the mechanism by which radiolysis affects the nature of the oxide that is formed on steel surfaces.

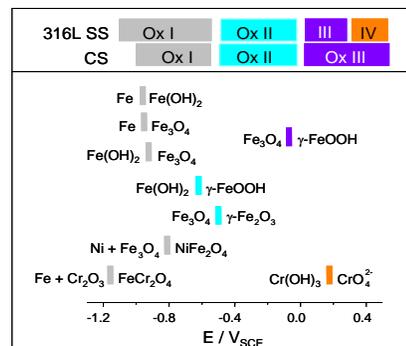
The driving force for aqueous corrosion is the difference in the electrochemical potentials of the two interacting phases, the steel (and/or metal oxide, if present) and water. This potential difference is related to the corrosion potential,  $E_{\text{CORR}}$ , at the steel/water interface. Our studies have shown that  $\gamma$ -irradiation changes the chemical potential of the water phase as a result of the radiolytic production of the redox active species, but it has negligible impact on the potential of the metal phase [1,2]. Consequently,  $E_{\text{CORR}}$  increases significantly when the corroding system is exposed to  $\gamma$ -radiation, Figure 1.



**Figure 1:**  $E_{\text{CORR}}$  recorded on 316L stainless steel and carbon steel in a deaerated 0.01 M borate solution at pH 10.6 and 25 °C, with and without  $\gamma$ -irradiation.

Comparison of the  $E_{\text{CORR}}$  values with the equilibrium potentials of various possible redox reactions of the constituent elements in steel, Figure 2, show that  $\gamma$ -irradiation increases  $E_{\text{CORR}}$  from a point in oxidation region Ox I, where the metal oxidation is limited to the formation of  $\text{Fe}^{\text{II}}$  oxides (as  $\text{Fe}(\text{OH})_2$  or  $\text{FeCr}_2\text{O}_4$ ) or a mixed  $\text{Fe}^{\text{II}}/\text{Fe}^{\text{III}}$  oxide ( $\text{Fe}_3\text{O}_4$ ), to a point on the border

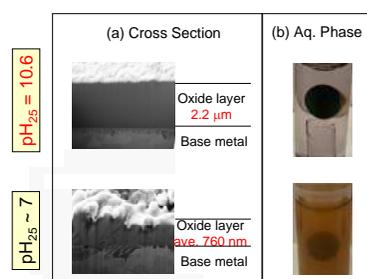
between Ox II and Ox III, where these oxides can oxidize further to form  $\text{Fe}^{\text{III}}$  oxides or hydroxides. Raman and XPS analyses of steel coupons corroded with and without irradiation have confirmed the formation of these oxides. Electrochemical and surface analyses of oxides formed on the steels under various potentiodynamic and potentiostatic conditions have also confirmed the identity of the oxides that are formed as a function of the potential on the metals.



**Figure 2:** Equilibrium potentials (vertical bars) for the redox reactions on steel constituent elements at pH 10.6 and 25 °C and associated redox pairs.

The oxide composition is not significantly influenced by solution pH, temperature or ionic strength. However, these parameters do significantly affect the morphology and thickness of the oxide (Figure 3a), and the amount of metal dissolution (Figure 3b). These effects arise from the solution parameter control of non-faradaic processes such as dissolution, condensation, surface hydration, etc. The non-faradaic processes influence the competition between the different reaction paths to form oxides, giving rise to the formation of unique films in each region.

The effect of the presence of ionizing radiation varies depending on the solution conditions and the presence of a pre-existing oxide on steel surface. For example,  $\gamma$ -radiation increases the metal dissolution rate from carbon steel at pH 6.0 while it decreases the corrosion rate at pH 10.6 (Figure 3). Our work also indicates that at higher pHs, the increase in  $E_{\text{CORR}}$  due to irradiation leads to the formation of a more protective oxide film on carbon steel, while it does not appear to offer a similar advantage to 316L stainless steel.



**Figure 3:** Effects of  $\gamma$ -radiation at two different pHs on carbon steel corrosion at 150 °C.

## References

- [1] K. Daub, X. Zhang, J.J. Noël, J.C. Wren, *Corros. Sci.* 53 (2011) 11-16.
- [2] Q. Knapp, J.C. Wren. *Electrochim. Acta*, 80 (2012) 90-99.