In-situ characteristics, atomic diagnosis, and mechanistic modeling of corrosion in the primary circuit of pressurized water reactors

ZY Bai[1], YH Li[1], SM Ding[1], Jie Qiu[1], Digby D. Macdonald[2]

[1]Key Laboratory of Thermo-Fluid Science & Engineering, Ministry of Education, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi Province 710049, China

[2]Department of Nuclear Engineering, University of California at Berkeley, Berkeley, CA 94720, America.

Presenter's e-mail address: b15735171052@stu.xjtu.edu.cn

Abstract: With the global expansion of pressurized water reactors (PWRs), addressing corrosion damage, particularly stress corrosion cracking (SCC), of critical materials has become paramount. This study investigates corrosion phenomena in PWRs through three key areas: in-situ analysis, diagnostic theory, and mechanistic modeling. A multifunctional research platform capable of operating under extreme super/subcritical water conditions at temperatures up to 500°C was developed. This platform was used in-situ electrochemical tests to simulate the corrosion behavior of primary circuit materials in PWRs. Results show that with increasing temperature, the open-circuit potential of nickel-based alloys decreased, current density significantly increased, and impedance modulus declined. All tested alloys exhibited n-type semiconductor properties in their passive films. Additionally, the impedance initially increased and then decreased as dissolved hydrogen levels rose, suggesting that trace hydrogen improves corrosion resistance. The Point Defect Model III (PDM III) was employed to analyze these behaviors further, providing insights into the kinetics of corrosion at the microstructural level. Notably, PDM III was refined by incorporating cathodic reaction descriptions and optimizing methods for evaluating passive film capacitance and electronic impedance. This enhanced diagnostic framework was applied to corrosion processes in supercritical water environments. Finally, the coupled environmental fracturing model was utilized to assess operational conditions, demonstrating that optimizing dissolved hydrogen concentration and pH levels can effectively slow crack growth, thereby extending equipment service life. This work enhances our understanding of the corrosion mechanisms affecting nuclear materials and offers tools and models to improve material selection, design, and corrosion mitigation in nuclear power plants.

Keywords: PWR's Corrosion, Point Defect Model, Atomic diagnosis theory, Mechanistic modeling

Reference

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