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辐照-高温耦合作用下核电堆坑混凝土劣化机制与结构长期性能评价方法

摘要

核电延寿是国际核电发展的重要战略，超设计期后核电结构服役性能评价与提升是确保安全延寿的重要保障。核电堆坑结构长期处于高温辐照环境，其辐照作用下的劣化检测及评价是决定能否延寿的关键因素。针对辐照作用下堆坑结构长期性能精准评价难题，开展了大量高剂量辐照试验并创建国内首个辐照混凝土性能数据库，基于试验数据开展理论分析，系统揭示了高剂量辐照作用下混凝土宏观性能退化机理，建立了基于微观力学的辐照混凝土多尺度性能演化模型，构建了辐照-热-力耦合机制作用下堆坑结构性能评价与寿命预测方法，实现了辐照混凝土结构性能的精准预测。研究成果成功应用于秦山二期和田湾核电延寿中期评估项目中，精准挖掘了机组的安全裕度。

关键词

辐照，混凝土，核电，堆坑，性能评价

Abstract

Nuclear power plant (NPP) life extension is a critical strategy for the global development of nuclear energy. The evaluation and enhancement of the in-service performance of nuclear power structures beyond their design service life serve as an essential safeguard for safe life extension. Nuclear reactor pit structures are chronically exposed to high-temperature and irradiation environments, and the detection and evaluation of their irradiation-induced deterioration constitute a decisive factor for life extension feasibility.To address the challenge of accurately evaluating the long-term performance of reactor pit structures under irradiation, extensive high-dose irradiation tests were conducted and the first domestic performance database for irradiated concrete was established. Based on experimental data, theoretical analyses were performed to systematically reveal the macroscopic performance degradation mechanism of concrete under high-dose irradiation. A micromechanics-based multi-scale performance evolution model for irradiated concrete was developed, and a performance evaluation and life prediction method for reactor pit structures under the irradiation-thermal-mechanical coupling mechanism was constructed, enabling precise prediction of the performance of irradiated concrete structures.The research findings have been successfully applied to the mid-term life extension evaluation projects of Qinshan Phase II and Tianwan Nuclear Power Plants, accurately identifying the safety margins of the units.

Keywords

Concrete; Nuclear Power; Reactor Pit; Performance Evaluation

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