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水体放射性核素在线监测系统研发及现场应用

摘要

为提高环境水体放射性监测能力并实现核事故的快速预警，研发了一套可适配多种工况的在线水体放射性测量系统。该系统基于大体积低本底铅室屏蔽结构设计，可根据监测需求配置高纯锗（HPGe）或溴化铈（$CeBr_3$）探测器。通过数值模拟方法，确定了系统对不同能量伽马射线的探测效率及典型核素的最小可探测活度浓度。结果表明，对于常见人工放射性核素 131I、60Co 及 137Cs，系统在正常工况下最小可探测活度浓度均低于 0.02 Bq/L。利用核素衰变纲图与天然衰变链关系，计算了水中天然放射性核素贡献的总 α 与总 β 活度。采用低本底气式正比计数器对在线测量结果进行验证，两者在总 α 与总 β 测量中的平均相对误差分别为 12.6% 与 4.5%，结果一致性良好。该监测系统提供站房与车载两种安装方案，已实际应用于饮用水源、长江流域及核设施排放口等关键点位，并纳入四川省核应急体系，解决了复杂环境下快速测量与稳定运行的工程问题。

关键词

水体 γ 核素在线监测，溴化铈探测器，总 α 与总 β

Abstract

To enhance the monitoring capability of environmental water radioactivity and enable rapid warning of nuclear accidents, an online water radioactivity measurement system adaptable to various working conditions has been developed. The system is designed based on a large-volume, low-background lead-shielded structure and can be configured with either a high-purity germanium (HPGe) or cerium bromide (CeBr3) detector flexibly according to monitoring requirements. Through numerical simulation, the detection efficiency for gamma rays of different energies and the minimum detectable activity concentration for typical radionuclides were determined. The results show that for common artificial radionuclides such as 131I, 60Co, and 137Cs, the minimum detectable activity concentration of the system is below 0.02 Bq/L under normal operating conditions. Using the decay schemes of radionuclides and the natural decay chains, the total α and total β activities contributed by natural radionuclides in water were further calculated. The online measurement results were validated using a low-background gas-flow proportional counter, and the average relative errors were 12.6% and 4.5% for total α and total β measurements respectively, indicating good consistency. The monitoring system offers two installation options: station-based and vehicle-mounted. It has been practically deployed at key locations such as drinking water sources, the Yangtze River basin, and nuclear facility discharge outlets, and has been incorporated into the nuclear emergency system of Sichuan Province, addressing engineering challenges related to rapid measurement and stable operation in complex environments.

Keywords

online monitoring γ nuclides in water, cerium bromide detector， total α and tota β

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