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页岩气田环境辐射监测与风险评估

摘要

天然放射性物质（NORM）广泛存在于页岩气钻井作业产生的废弃物中，会对生态环境构成潜在风险，因此受到公众与学者们的日益关注。本研究针对中国西南地区处在不同作业阶段的页岩气田，采集其周围环境土壤土壤、开采废水和污水处理厂处理前后水样。通过结合空气 γ 吸收剂量率、土壤氡浓度、放射性核素活度浓度及常规危害指数，综合评估区域环境放射性水平与从业人员潜在职业暴露风险。研究结果表明，该区域空气 γ 吸收剂量率与土壤放射性水平和国内外其他油气田监测结果基本相当，且放射性水平与铀系核素含量高度相关。土壤中铀-238 与镭-226 呈显著线性相关，说明两种核素在土壤体系中接近放射性平衡；铅-210 与镭-226 比值持续大于 1，且随开采平台运营时长增加而升高，反映出氡子体存在累积效应。现场实测剂量率与理论计算剂量率存在明显偏差，说明辐射剂量评估工作应优先采用实地直接监测手段。从业人员剂量评估结果显示，页岩气田工作人员年有效剂量低于 1 mSv/a。此外，未经处理的原水中检测出镭-226、镭-228 等核素浓度超标，而现有水处理工艺可有效削减上述放射性核素含量。本研究成果可为页岩气田放射性风险评估提供本底数据支撑，同时凸显了开展长期常态化监测、强化放射性废水管控的必要性。

关键词

天然放射性物质（NORM）；页岩气开采；环境辐射暴露；放射性核素迁移；放射性废水处理

Abstract

Naturally occurring radioactive materials (NORM) are present in waste generated during shale gas drilling activities and pose potential risks to the environment, drawing increasing public and scientific attention. In this study, soil, wastewater and effluent samples were collected across multiple operational stages of shale gas development in Southwest China. A combination of in-situ gamma absorbed dose rate in air, soil radon concentration, radionuclide activity concentrations, and conventional hazard indices was used to evaluate environmental radioactivity and potential occupational exposure. The results showed that both the gamma absorbed dose rates and soil radioactivity were comparable to those observed in other oil and gas fields, that were strongly correlated with uranium-series nuclides. A strong linear relationship between 238U and 226Ra, indicating the two radionuclides were in near radioactive equilibrium within the soil. The 210Pb/226Ra ratio was consistently greater than 1 and increased with platform operation time, suggesting an accumulation of radon progeny. Discrepancies between measured and calculated dose rates highlighted the need to prioritize direct measurements in dose assessments. Worker dose assessments revealed annual effective doses below 1 $mSvy^{-1}$. Furthermore, elevated concentrations of 226Ra, 228Ra, and 40K were detected in untreated-water, which could be effectively reduced by existing treatment technologies. These findings provide a baseline for radiological risk evaluation in shale gas fields and highlight the necessity for continuous monitoring and wastewater management.

Keywords

Naturally Occurring Radioactive Materials (NORM); Shale Gas Extraction; Environmental Radiation Exposure; Radionuclide Migration; Radioactive Wastewater Treatment

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