Contribution ID: **60** Type: 口头报告

铀污染土在线 **EDXRF** 探测系统研制与现场验证

摘要

铀污染土壤的现场快速筛查与分类，是核设施退役、放射性污染治理以及铀矿冶环境修复中的重要环节。在这些应用场景中，大量土壤通常需要在处置、回填或复用前完成分类。传统实验室分析方法准确性较高，但分析周期较长，难以满足连续化现场筛查和分选的需求。本研究研制了一套用于铀污染土快速筛查的在线能量色散 X 射线荧光（EDXRF）探测系统。该系统可在动态输送条件下开展测量，集成了样品预处理、土层高度控制、高压 X 射线激发、基于硅漂移探测器的荧光测量、X 射线透射成像、密度测量以及软件控制分选等功能，形成了一套适用于现场应用的集成化平台。

系统主要利用铀元素的 L 系特征 X 射线进行识别和定量。现场测量时，X 射线管管压为 130 kV，管流为 300 μA。虽然铀的识别主要依据 L 系特征线，但采用 130 kV 管压可以提高初级 X 射线对动态输送土层的穿透能力和有效激发通量。测试过程中，传送速度设置为 20–30 cm/min；每个测量周期内，EDXRF 能谱累计时间为 1 min，以提高计数统计性，并获得通过探测区域土壤的代表性铀信号。系统还可进行土层高度控制和密度测量，从而计算物料吞吐量。前期选取了三个现场制备样品作为初始标定样，其名义活度分别为 1.00、3.14 和 9.00 Bq/g。后续 ICP-MS 分析表明，这三个样品的实际活度与名义值存在差异，因此在与实验室结果对比前，对现场装置测量结果进行了标定误差修正。

将修正后的现场装置测量结果与 ICP-MS 结果进行对比，共获得 16 组配对数据，决定系数为 $R^2 = 0.928$，平均绝对相对偏差为 32.1%。系统探测下限估计为 0.7 Bq/g，低于 1.0 Bq/g 的筛查阈值。对于活度低于 0.7 Bq/g 或高于 1.0 Bq/g 的样品，装置未出现误判，说明其在 0.7–1.0 Bq/g 临界区间之外具有较稳定的判别能力。在测试工况下，系统计算吞吐量大于 1 t/h。此外，对相同土壤样品进行压样处理后，采用实验室大荧光设备进行 XRF 测量。压样 XRF 结果与现场装置测量结果之间具有较好的线性关系，决定系数为 $R^2 = 0.9454$，表明在线 EDXRF 系统获得的铀响应趋势与实验室 XRF 测量结果基本一致。上述结果表明，该在线 EDXRF 系统可用于铀污染土现场快速筛查。后续工作将进一步围绕标准标定样品、基体效应校正，以及土壤水分、粒径和土层厚度变化补偿等方面进行优化。

关键词

铀污染土；在线 EDXRF；现场探测；快速分选；核设施退役

Abstract

Rapid on-site screening and classification of uranium-contaminated soil are important in nuclear facility decommissioning, radioactive contamination remediation, and uranium mining-related environmental restoration, where large volumes of soil may need to be classified before disposal, backfilling, or reuse. Conventional laboratory analysis provides accurate uranium concentrations but is time-consuming and difficult to apply to continuous field sorting. In this study, an in-line energy-dispersive X-ray fluorescence (EDXRF) detection system was developed for rapid uranium-contaminated soil screening under dynamic conveying conditions. The system integrates sample pretreatment, soil-layer height control, high-voltage X-ray excitation, silicon drift detector-based fluorescence measurement, transmission imaging, density measurement, and software-controlled sorting in a field-deployable platform.

Uranium was identified and quantified mainly using its L-series characteristic X-ray lines. Field measurements were performed at a tube voltage of 130 kV and a tube current of 300 μA. The tube voltage of 130 kV was selected to provide sufficient primary-beam penetration and excitation flux for moving soil layers. The conveying speed was set to 20–30 cm/min. For each measurement interval, the EDXRF spectrum was accumulated for 1 min to improve counting statistics and obtain a representative uranium signal from the soil passing through the detection zone. The system also allowed soil-layer height control and density measurement, enabling the material throughput to be calculated. Three field-prepared samples with nominal activities of 1.00, 3.14, and 9.00 Bq/g were initially used for calibration. Subsequent ICP-MS analysis showed that their actual activities differed from the nominal values; therefore, calibration-error correction was applied before comparison with laboratory results.

The calibration-corrected field-device results were compared with ICP-MS measurements. A total of 16 paired results were obtained after correction, giving a coefficient of determination of $R^2 = 0.928$ and a mean absolute relative deviation of 32.1%. The detection limit of the developed system was estimated to be 0.7 Bq/g, which is below the 1.0 Bq/g screening threshold. The developed system showed no misclassification for samples below 0.7 Bq/g or above 1.0 Bq/g, supporting reliable discrimination outside the borderline range of 0.7–1.0 Bq/g. The system achieved a calculated throughput of more than 1 t/h under the tested operating conditions. In addition, pressed-pellet XRF measurements of the corresponding soil samples were conducted using a laboratory XRF spectrometer. The pressed-pellet XRF results showed a strong linear relationship with the field-device results, with $R^2 = 0.9454$, indicating that the in-line EDXRF system captured a uranium response trend consistent with laboratory XRF measurements. These preliminary results demonstrate the feasibility of the developed in-line EDXRF system for rapid field screening of uranium-contaminated soil. Further improvement will focus on certified calibration samples, matrix-effect correction, and compensation for soil moisture, particle size, and layer-thickness variations.

Keywords

uranium-contaminated soil; in-line EDXRF; field detection; rapid sorting; nuclear decommissioning

Authors: Mr 子场, 王 (成都理工大学); Prof. 庆贤, 张 (成都理工大学); Prof. 明, 王 (成都理工大学); Mr 镖, 蒋 (成都理工大学); Mr 国昱, 谢 (成都理工大学); Mr 鸿飞, 肖 (成都理工大学); 茂淋, 熊 (成都理工大学)

Presenter: Mr 子场, 王 (成都理工大学)

Session Classification: 核技术及应用、医学物理与工程

Track Classification: 口头报告: 核技术及应用、医学物理与工程