Application of Statistical Test for Characterization Survey in Nuclear Decommissioning: Regulatory Perspectives

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1. Introduction

The Characterization Survey plays a fundamental role in the decommissioning of nuclear power plants (NPPs) by identifying contamination levels and determining the spatial distribution of radionuclides before remediation or final status surveys. Regulatory bodies, including the U.S. Nuclear Regulatory Commission (NRC) and Korea's Nuclear Safety and Security Commission (NSSC), require statistical validation to ensure that survey results comply with regulatory safety standards [1]. The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) outlines best practices for conducting characterization surveys, emphasizing the necessity of statistical methods tailored to environmental variability [1]. This paper focuses on applying statistical test methodologies in Characterization Surveys and examines their regulatory implications in ensuring compliance and public safety.

2. Characterization Survey in Nuclear Decommissioning

2.1. Role and Objectives of the Characterization Survey

The Characterization Survey serves as an essential phase in site assessment by verifying contamination levels, supporting risk assessment, and guiding remediation strategies [1]. This survey establishes the baseline radiological condition of a site before decontamination efforts begin, ensuring that subsequent remediation efforts are targeted effectively. It also provides scientifically validated contamination mapping for regulatory approvals, which is necessary to ensure that site conditions meet safety guidelines. Furthermore, the Characterization Survey assists in planning future Final Status Surveys (FSS) by ensuring that the site meets the necessary Derived Concentration Guideline Levels (DCGLs), allowing for a structured transition to the final stages of decommissioning [2].

Regulatory frameworks emphasize that Characterization Surveys should incorporate statistically reliable sampling and measurement techniques to prevent misclassification of contaminated and uncontaminated areas. Applying nonparametric statistical tests enhances the scientific robustness and defensibility of site evaluations. This approach reduces the risk of false negatives that could lead to overlooked contamination, as well as false positives that could result in unnecessary remediation costs [1, 3].

2.2. Statistical Methods for Characterization Survey Validation

Statistical methodologies play a critical role in validating the results of Characterization Surveys. The Wilcoxon Rank Sum (WRS) test is commonly used to compare contamination levels between survey units and background reference areas, making it particularly effective when contamination is present in the reference site [1]. The Sign test is applied to evaluate whether contamination levels within a survey unit are statistically lower than the DCGLs, which allows for a reliable determination of site safety without requiring background measurements [2]. Additionally, the Kolmogorov-Smirnov test assesses differences in contamination distributions across survey units, improving contamination delineation and enhancing survey accuracy [3].

By integrating these statistical tests into the Characterization Survey, site evaluators can generate scientifically defensible results that support regulatory compliance. The use of rigorous statistical analysis ensures that decommissioning decisions are made based on reliable data, minimizing uncertainty in site characterization [4].

3. Regulatory Compliance in Measurement Planning

3.1. Case Study: U.S. Approaches to Characterization Surveys

International decommissioning projects employ structured methodologies for conducting Characterization Surveys to ensure accuracy and compliance. Maine Yankee NPP implemented MARSSIM-based surveys that classified areas according to contamination levels, allowing for the

selection of appropriate measurement instruments for each area [2]. Zion NPP utilized Historical Site Assessment (HSA) data to guide Characterization Survey efforts, ensuring that measurement points were placed effectively in suspected contaminated regions [3]. Rancho Seco NPP developed a multi-stage Characterization Survey Plan to refine contamination zones, helping to optimize remediation activities and reduce unnecessary costs [4]. These international case studies illustrate the importance of structured methodologies in improving survey precision and regulatory adherence.

3.2. Application to Korea's Regulatory Framework

In Korea, the Characterization Survey is an essential component of the Final Decommissioning Plan (FDP), which must be submitted to regulatory authorities before site remediation begins [5]. The Korean Nuclear Safety Act mandates that all survey plans clearly outline the methodologies for contamination assessment. Measurement instrument selection must be tailored to site-specific radionuclides and contamination conditions to ensure that the most effective detection tools are used. Survey points must be strategically placed using statistically validated approaches to guarantee representative sampling and minimize uncertainty in contamination mapping. Statistical test procedures must align with MARSSIM guidelines and international best practices to ensure that site assessments meet regulatory requirements.

By incorporating internationally recognized methodologies into Korea's regulatory framework, Characterization Surveys can achieve greater consistency and scientific reliability. The standardization of survey protocols ensures that decommissioning projects are conducted in a transparent and scientifically rigorous manner, benefiting both regulatory bodies and the public [5].

4. Future Perspectives on Statistical Validation in Characterization Surveys

4.1. Advancements in Data Analysis Techniques

Emerging data analysis techniques such as Bayesian statistical models and machine learning algorithms offer significant improvements in Characterization Surveys by enhancing contamination prediction accuracy and reducing measurement uncertainty [2]. These advanced methods provide dynamic updates to contamination models as new survey data become available, allowing for more precise decision-making in real-time site assessments.

4.2. Expanding Regulatory Guidelines for Statistical Approaches

Given the increasing complexity of site characterization, regulatory frameworks must evolve to incorporate advanced analytical techniques. Hybrid models that combine parametric and nonparametric statistical approaches can offer more comprehensive contamination assessments, improving the ability of regulators to evaluate site conditions accurately. Future regulatory guidelines should accommodate these advancements, providing clear frameworks for integrating new statistical methods into standard decommissioning procedures [3].

5. Conclusion

The Characterization Survey is an essential phase of nuclear decommissioning, forming the foundation for remediation efforts and regulatory compliance. The application of nonparametric statistical tests ensures that site evaluations remain scientifically robust and defensible. By aligning survey methodologies with MARSSIM guidelines and integrating international best practices, regulatory bodies can enhance the reliability and accuracy of decommissioning assessments. As statistical methodologies and technologies continue to advance, regulatory frameworks must adapt to incorporate these improvements, ensuring that nuclear site decommissioning remains efficient, transparent, and safe.

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