

Final Status Survey Design for Application of MARSSIM in Nuclear Power Plant Decommissioning

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1. Introduction

After the decommissioning of a nuclear facility is completed, a Final Status Survey (FSS) must be conducted to demonstrate that the residual radioactivity in the site and meets the regulatory release criteria. In the United States, the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) is provided as the methodology for demonstrating compliance with the release criteria upon site release, offering a systematic, statistically based procedure for surveying residual radioactivity in post-decommissioning structures and soil [1]. MARSSIM has been widely applied at commercial nuclear power plants such as the Zion and Rancho Seco sites in the United States to demonstrate regulatory compliance for site release [2,3]. As the decommissioning of Kori Unit 1 proceeds, a site-specific FSS design and a review for its field application are required. Accordingly, this study finalizes an FSS plan that incorporates MARSSIM, NUREG-1757 which provides guidance on the characterization required for the decommissioning and license termination of nuclear facilities and relevant overseas application cases, and establishes the corresponding implementation and decision-making plan for field application [4].

2. Materials & Methods

2.1 Overview of the MARSSIM Procedure

The MARSSIM procedure comprises site identification, historical site assessment, scoping survey, characterization survey, remedial action support survey, and final status survey; the main procedure is presented in Fig. 1. The FSS determines whether each survey unit's residual radioactivity meets the site-release criteria; statistical tests (Sign test, Wilcoxon Rank Sum (WRS) test) are applied, generally to reject the Scenario A null hypothesis that the residual radioactivity exceeds the criteria. FSS implementation requires designing the radionuclides of concern, DCGL determination, classification, survey unit setup, background reference area, measurement instruments and protocols, MDC determination, and statistical test selection [1].

Selection of Radionuclides of Concern (ROC)

Based on the overall analysis results, the cumulative dose contribution of each radionuclide is evaluated, and

radionuclides whose expected exposure dose is less than 10% of the site release criterion are screened out as insignificant radionuclides, following the recommendations of NUREG-1757 [4]. Easy-to-detect (ETD) radionuclides and those usable as surrogates are preferentially selected as radionuclides of concern.

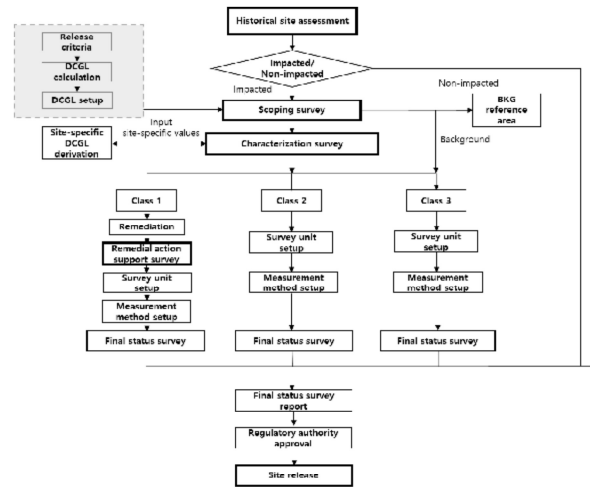


Fig 1. MARSSIM Process

Determination of DCGLs

The site-specific $DCGL_W$ derived in advance from the site characteristics is applied. For surrogate radionuclides that must also represent the estimated radionuclides, a modified DCGL is derived as;

$$(1) \quad DCGL_{surr,mod} = \frac{1}{DCGL_{surr}} + \sum \frac{R_i}{DCGL_i}$$

$DCGL_{surr,mod}$: modified DCGL of the surrogate radionuclide

$DCGL_{surr}$: DCGL of the surrogate radionuclide

R_i : abundance ratio of estimated radionuclide i to the surrogate (C_i/C_{surr})

$DCGL_i$: DCGL of hard-to-detect (HTD) radionuclide i

The operational DCGL is obtained from Eq. (2) for surrogate-based radionuclides and Eq. (3) for the others, where R_{soil} (soil dose contribution, which may be taken as 1 by referring to overseas cases) and F_{Aggr} (cumulative dose contribution for excluding insignificant radionuclides) are applied [2,3].

$$(2) \quad DCGL_{op,k} = DCGL_{surr,mod} \times R_{soil} \times (1 - F_{Aggr})$$

$DCGL_{op,k}$: operational DCGL of surrogate radionuclide k

$DCGL_{surr,mod}$: $DCGL_{surr,mod}$ of surrogate radionuclide k

R_{soil} : dose contribution from soil

F_{Aggr} : cumulative dose contribution applied to exclude insignificant radionuclides

$$(3) \quad DCGL_{op,i} = DCGL_W \times R_{soil} \times (1 - F_{Aggr})$$

$DCGL_{op,i}$: operational DCGL of directly measured radionuclide i

DCGL_W: DCGL of directly measured radionuclide i
R_{soil}: dose contribution from soil
F_{Aggr}: cumulative dose contribution applied to exclude insignificant radionuclides

For elevated (small-area) contamination, the DCGL_{EMC} is obtained by Eq. (4) using the Area Factor (AF), derived from the RESRAD-Onsite Contaminated Zone used to obtain each DCGL_W.

$$(4) \quad DCGL_{EMC} = AF \times DCGL_{op}$$

DCGL_{EMC}: DCGL for setting the surface-scan criterion of a Class 1 survey unit
AF: Area Factor
DCGL_{op}: operational DCGL

Classification and Survey Unit Design

Areas are classified by contamination level: Class 1 (residual radioactivity exceeds, or previously exceeded, the DCGL_W), Class 2 (possible contamination but not expected to exceed the DCGL_W), and Class 3 (expected to be 50% or less of the DCGL_W). A survey unit is the basic unit for site-release decisions, subdivided by an area upper limit per Class. For structures, Class 1 is 100 m², Class 2 is 100~1,000 m², and Class 3 has no limit; for land, Class 1 is 2,000 m², Class 2 is 2,000~10,000 m², and Class 3 has no limit.

Establishment of Background Reference Areas

A reference area is set when radionuclides of concern occur in background. It is selected as a demonstrably uncontaminated area with physical, chemical, geological, radiological, and biological characteristics similar to the survey unit.

Measurement Instruments and Protocols Setup

Depending on the measurement technique (surface scan / direct measurement / sampling and analysis), the measurement instruments are identified; NaI (TI) can be used for scanning, ISOCS (ISGS) for direct measurement, and HPGe for sampling.

Minimum Detectable Concentration (MDC) Setup

The required scan MDC must be at or below the DCGL_{EMC} (typically 10~100% of the DCGL_{EMC}), while the direct-measurement and sample-analysis MDCs must be below the DCGL_W (typically 10~50% of the DCGL_W).

Statistical Test Selection

The Sign test and the WRS test are used: the WRS test when radionuclides of concern are present in background, and the Sign test when they are not. The required parameters (Type I/II error, LBGR, standard deviation, relative shift, number of samples, and critical value) and the test procedure are given in Table 1.

Table 1. Parameters and procedure for the statistical tests

Step	Parameter	Sign test	WRS test
1	LBGR	Lower bound of the gray region; half of the DCGL is recommended	

2	Relative shift	1-3 recommended Relative shift $\left(\frac{\Delta DCGL-LBGR}{\sigma}\right)$	
3	Decision error	Type I error (α): rejecting a true null; 5% recommended Type II error (β): accepting a false null; 5% recommended	
4	Statistical test	No background radiation in the survey unit	Background radiation present in the survey unit.
5	Number of samples	$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(\text{Sign } p-0.5)^2}$ - $Z_{1-\alpha}$, $Z_{1-\beta}$: (1- α) and (1- β) percentiles of the standard normal distribution - Sign p: probability that a measurement $\leq$ DCGL when median=LBGR - Nx20% margin is added	$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3(p-0.5)^2}$ - $Z_{1-\alpha}$, $Z_{1-\beta}$: (1- α) and (1- β) percentiles of the standard normal distribution - Pr: probability that (survey unit-reference area) measurement $\leq$ DCGL when median=LBGR - Nx20% margin is added
6	S+/Rank sum	Count samples not exceeding the DCGL (S+)	Z_i = reference measurement + DCGL Rank survey unit and Z_i values, obtain rank sum (Wr).
7	Critical value (CV)	$CV = \frac{N}{2} + \frac{Z_{1-\alpha}}{2} \sqrt{N}$	CV= $\frac{m}{2}(n+m+1) + Z_{1-\alpha} \sqrt{\frac{nm}{12}(n)}$ - n: number of reference-area measurements (N/2) - m: number of survey-unit measurement (N/2)
8	Decision	S+ > CV $\rightarrow$ reject null (criteria met) S+ < CV $\rightarrow$ fail to reject (not met)	Wr > CV $\rightarrow$ reject null (criteria met) Wr < CV $\rightarrow$ fail to reject (not met)

3. Conclusions

This study established an FSS framework based on MARSSIM and presented an implementation and decision-making framework for field application. The FSS determines whether the residual radioactivity of each survey unit satisfies the site-release criteria; to this end, the radionuclides of concern, DCGLs, survey unit setup, reference area, protocol setup, MDC setup, statistical tests, and so on must be finalized during the planning stage. If the FSS is implemented according to the procedure of this study, it is expected that the FSS can be carried out for the pilot site, that the survey results can be compared with the regulatory criteria to determine whether they are satisfied, and that ultimately a basis can be provided for submitting to the regulatory body the decision on whether the site can be released.

REFERENCES

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