

## Development of Surface Roughness Database for All NPP Sites in Korea to Perform Level 3 PSA and EPZ Evaluation

Sung-yeop Kim <sup>a,b,\*</sup>

<sup>a</sup>Korea Atomic Energy Research Institute, 111 Daedeok-daero 989beongil, Yuseong-gu, Daejeon 34057, Republic of Korea

<sup>b</sup>University of Science and Technology, 217 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea

\*Corresponding author: sungyeop@kaeri.re.kr

\***Keywords** : surface roughness, complex terrain, offsite consequence analysis, Level 3 PSA, emergency planning zone

### 1. Introduction

The topography of Korea is composed of complex terrain, which may present significantly different conditions compared to the environments of other countries where nuclear power plants are installed. Therefore, it is important to accurately reflect these topographical characteristics to enhance the accuracy and reliability of offsite consequence analysis. The characteristics of complex terrain can be mathematically expressed as surface roughness, which is a key factor influencing both atmospheric dispersion and surface deposition.

Offsite consequence analysis codes such as MACCS [1] and RCAP [2] utilize site-representative surface roughness in their calculations. Consequently, methodologies and tools for calculating site-representative surface roughness are required. KAERI has developed KSURF (Surface Roughness Length Calculator for Korean Topography) [3], a tool for calculating site representative surface roughness. This study utilized KSURF to calculate the representative surface roughness for each site and established a database that can be used for future Level 3 PSA implementation and EPZ evaluation.

### 2. Methods and Results

#### 2.1 Calculation of Surface Roughness Using KSURF

In this study, surface roughness length and color were input as values and colors representing each land cover, as shown in Fig. 1.

No.	Land Cover (Korean)	Land Cover (English)	Length (cm)	Color	Checked
1.	Waters (수역)	Waters	0.1	Light Blue	<input checked="" type="checkbox"/>
2.	Urban (시가화지역)	Urban	100	Purple	<input checked="" type="checkbox"/>
3.	Bare Land (나지)	Bare Land	1	Yellow	<input checked="" type="checkbox"/>
4.	Wetland (습지)	Wetland	5	Green	<input checked="" type="checkbox"/>
5.	Grassland (초지)	Grassland	3	Light Green	<input checked="" type="checkbox"/>
6.	Forest (산림)	Forest	100	Dark Green	<input checked="" type="checkbox"/>
7.	Rice Field (논)	Rice Field	10	Gold	<input checked="" type="checkbox"/>
8.	Other Field (밭)	Other Field	5	Light Yellow	<input checked="" type="checkbox"/>
0.	Sea (해역)	Sea	0.1	Blue	<input checked="" type="checkbox"/>
					<input type="checkbox"/>

Fig. 1. Surface Roughness Length and Color for Each Land Cover

When users input the site boundary distance and calculation boundary distance, the representative surface roughness within the boundary can be calculated using either the arithmetic mean or geometric mean. Even though KSURF can calculate both the arithmetic mean and geometric mean as representative surface roughness, but it is believed that applying the geometric mean is more appropriate.

Based on expert consultation, this study set the boundary for calculating surface roughness related to atmospheric dispersion at 8 km and the boundary for surface deposition at 80 km.

In calculations related to atmospheric dispersion, the terrain within the site is expected to have an impact, so the area inside the site was included. In calculations related to surface deposition, the deposition amount within the site is not considered in the offsite consequence analysis, so the area inside the site was excluded.

The representative surface roughness of each nuclear power plant (NPP) site was calculated as presented in Table 1.

Table 1. Representative Surface Roughness of Each NPP Site

NPP Site	8 km (Including Onsite Area)	80 km (Excluding Onsite Area)
Kori	48 cm	44 cm
Shin-Kori	47 cm	44 cm
Saeul	45 cm	44 cm
Hanul	54 cm	65 cm
Shin-Hanul	52 cm	65 cm
Wolsong	55 cm	48 cm
Shin-Wolsong	53 cm	48 cm
Hanbit	14 cm	25 cm

For sites located in close proximity, the surface roughness values were found to be similar. At the Kori and Wolsong sites, the average value within 8 km was calculated to be larger, while at the Hanul and Hanbit sites, the average value within 80 km was calculated to be greater.

Fig. 1 and Fig. 2 show the image results for the Hanul site and the Hanbit site, respectively. As confirmed in the figures, the surface roughness of the Hanul site is derived relatively low due to the high proportion of land cover

types with low surface roughness, such as rice fields and grassland.

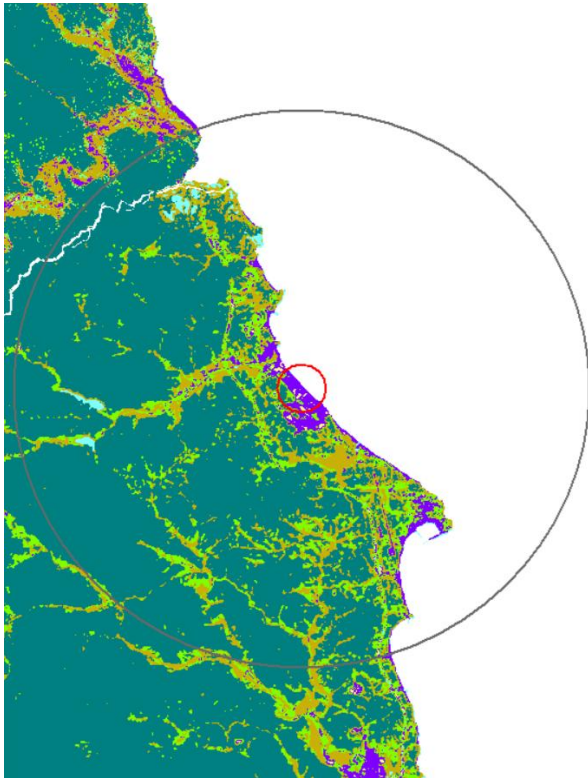


Fig. 2. Image Output of KSURF for Hanul Site  
 (Red Line: Site Boundary, Gray Line: 8 km)

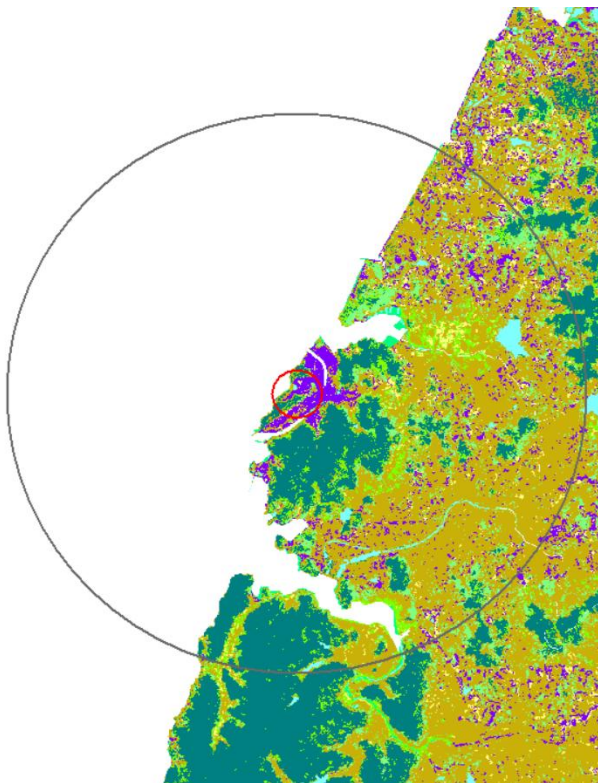


Fig. 3. Image Output of KSURF for Hanbit Site  
 (Red Line: Site Boundary, Gray Line: 8 km)

## 2.2 Pilot Application of Hanul Site

### 2.2.1 In the View Point of Atmospheric Dispersion

The default surface roughness provided in the MACCS code is 10 cm, and the corresponding vertical diffusion correction factor is 1.27. Using the representative surface roughness of 54 cm within 8 km of the Hanul site, the vertical dispersion scaling factor is calculated to be 1.79.

The relative error of the results when analysis was performed using MACCS default values and Hanul site surface roughness is shown in Table 2. The high surface roughness of the Hanul site causes greater vertical diffusion, resulting in lower results. In cases where emergency response is executed in the emergency phase, the population evacuates before the plume arrival, so no relative error appears. The long-term phase shows a greater difference in results compared to the emergency phase, which is likely because calculations are performed over a much longer period in the long-term phase.

Table 2. Relative Error of Cancer Fatality Risk when Surface Roughness of Hanul Site is Reflected to Vertical Dispersion Scaling Factor

		Relative Error of Cancer Fatality Risk
Emergency Phase	Emergency Response	0%
	No Emergency Response	-2.3%
Long-Term Phase		-14.6%
Total		-14.4%

### 2.2.2 In the View Point of Surface Deposition

When the surface roughness length is 10 cm, the dry deposition velocity is 0.0134 m/s. Applying the surface roughness of 65.14 cm for the Hanul site yields the dry deposition velocity of 0.0241 m/s.

As presented in Table 2, higher dry deposition causes greater groundshine and resuspension inhalation during both the emergency and long-term phases. From the perspective of surface deposition, the impact of the long-term phase is also more pronounced.

Table 3. Relative Error of Cancer Fatality Risk when Surface Roughness of Hanul Site is Reflected to Dry Deposition Velocity

		Relative Error of Cancer Fatality Risk
Emergency Phase	Emergency Response	0%
	No Emergency Response	+9.0%
Long-Term Phase		+36.7%
Total		+36.4%

### 2.2.3 Overall Perspective

The relative error from a comprehensive perspective incorporating both atmospheric dispersion and surface deposition is shown in Table 4.

Table 4. Relative Error of Cancer Fatality Risk when Surface Roughness of Hanul Site is Reflected to both Vertical Dispersion Scaling Factor and Dry Deposition Velocity

		Relative Error of Cancer Fatality Risk
Emergency Phase	Emergency Response	0%
	No Emergency Response	+7.5%
Long-Term Phase		+23.4%
Total		+23.1%

### 3. Conclusions

This study derived representative surface roughness for all Korean nuclear power plant sites using the previously developed KSURF software and constructed a database. Calculations were performed with 8 km and 80 km calculation boundaries set for atmospheric dispersion and surface deposition, respectively. These calculation boundaries may be modified following future expert review and discussion.

A pilot application was conducted by applying the calculated surface roughness for the Hanul site. When applied to atmospheric dispersion, the increased vertical dispersion coefficient resulted in lower atmospheric concentrations and a lower risk of cancer fatality. However, when applied to surface deposition, the high surface deposition velocity increased groundshine and resuspension inhalation, leading to a significantly higher risk of cancer fatality. Considering both effects, the cancer fatality risk increases, indicating that surface roughness has a greater impact on radiation exposure due to surface deposition in this study. Additionally, this study showed that the long-term phase has a greater impact than the emergency phase.

This study is significant as it is the first to calculate representative surface roughness, a key factor affecting both atmospheric dispersion and surface deposition, for all nuclear power plant sites in Korea. The surface roughness database derived in this study can be utilized to perform Level 3 PSA and evaluate emergency planning zones (EPZ) in the future. Furthermore, the methodology and software presented in this study are expected to be widely applicable internationally.

### Acknowledgement

This work was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KoFONS) using financial resources

granted by the Nuclear Safety and Security Commission (NSSC) of Korea (No. RS-2023-00240452).

### REFERENCES

- [1] Sandia National Laboratories, MACCS user guide (V. 4.2), SAND2023-01315, Sandia National Laboratories, Albuquerque, NM, 2023.
- [2] S.J. Han et al., RCAP code user's manual – draft version, KAERI/TR-7700/2019, Korea Atomic Energy Research Institute, Daejeon, Republic of Korea, 2019.
- [3] S.Y. Kim, S.C. Jang, K.I. Ahn, S.W. Hwang, Development of Software to Estimate Representative Surface Roughness Length in Korea, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 23-24, 2019.