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Analytical Evaluation of Surface Roughness Length at a Large DOE Site

Kevin R. O'Kula

Washington Safety Management Solutions LLC
P. O. Box 5388
Aiken, SC 29804-5388
Email: kevin.okula@wsms.com; Phone: 803.502.9620

David C. Thoman

Washington Safety Management Solutions LLC
P. O. Box 5388
Aiken, SC 29804-5388
Email: dave.thoman@wsms.com; Phone: 803.502.9721

INTRODUCTION

In Gaussian dispersion model calculations performed for accident analysis purposes, the axial dispersion parameters, σ_z, account for the vertical spread in the atmospheric cloud with downwind distance, and are a function of stability category. Dispersion parameters are usually developed using mathematical fits of experimental data where tracer gases are released and the downwind concentrations measured under varying conditions. It is desirable that dispersion parameters be based on testing over regions of transport that are approximately equivalent to the region where the analysis is being applied. Various adjustment procedures are typically applied to scale dispersion parameters for applicability in situations were the environments differ. In most cases, the scaling is based on a parameter, the surface roughness length (z_o), a measure of the amount of mechanical mixing introduced by the surface roughness elements over a region of transport.

In nuclear facility safety analysis for large Department of Energy (DOE) sites, the evaluation of an appropriate z_o value is requisite step. Due to the size of many DOE sites, and the varying surface elements that can be present, values for the same site can differ depending on the distance to the receptor and the region between the postulated source and the receptor(s) in question.

The objective of this paper is to evaluate the surface roughness length at the Savannah River Site for accident analysis applications. In this regard, single receptor locations are usually of interest, and separate evaluations are discussed. The three cases of interest include:

- Offsite – Baseline General Public
- Offsite – Sensitivity due to Deforestation
- Onsite – Industrial cluster.

METHODOLOGY FOR EVALUATION OF z_o

The centerline, maximum dose in a Gaussian plume model is proportional to the lateral and vertical dispersion parameters (σ_y, σ_z) and the wind speed (u) for a downwind distance, x, as [1]

$$Dose(x)\,{}^{centerline}_{\max} \propto \left[\frac{1}{\pi \cdot u \cdot \sigma_y \cdot \sigma_z}\right] \quad (1)$$

One common approach to adjust the σ_z for the site of interest is to apply an American Meteorological Society (AMS) model. [2] This model adjusts the vertical dispersion parameters for the area of interest using a ratio of the surface roughness length to the 1/5th power as follows:

$$\sigma_z^{new} = \sigma_z^{obs}\left[\frac{z_o^{new}}{z_o^{obs}}\right]^{0.2} \quad (2)$$

where

σ_z^{new} = the vertical dispersion parameter for the region of interest

σ_z^{obs} = the vertical dispersion parameter from the experimental field observations

z_0^{new} = the surface roughness length for region of transport of interest, and

z_0^{obs} = the surface roughness length for the reference parameter set (experimental field observations).

Surface Roughness Length - General Approximation and Varying Surface

An initial requirement is to estimate z_o for characteristic types of ground cover. A common data set referenced in many Gaussian models is the Prairie Grass series. [3] In these tests, a 3-cm surface roughness length is normally attributed to the experimental site. Other representative surface roughness lengths, [4] the corresponding vertical dispersion parameter ratio, $\sigma_{z,\,new}/\sigma_{z,}(3\text{ cm})$, and the dose reduction applying the MACCS2 code [5] are noted in Table 1.

Table 1. Representative Surface Roughness Lengths and Dose Reduction (Based on Eqns. 1, 2, and [4])

Surface Type	Surface Roughness Length, (cm)	$\sigma_{z,\,new}/\sigma_{z,}(z_o=3\text{ cm})$	Reduction in Dose, relative to z_o=3 cm
Lawns	1	-	-
Tall grass, crops	10-15	1.3 – 1.4	21% - 28%
Countryside	30	1.6	37%
Suburbs	100	2.0	50%
Forests	20 – 200	1.5 – 2.3	32% - 57%
Urban	100 - 300	2.0 – 2.5	50% - 60%

For plume travel over regions of varying surface types, an approach suggested by Hanna is applied. [6] The method weights all roughness surfaces equally, without dependence on nearness to the source, and gives no weight to the roughness upwind of the source. It is particularly suited for evaluating varying "patches" of varying terrain and open areas, e.g. industrial clusters, forested regions, and relatively flat grasslands. The effective z_o is estimated from

$$\ln z_o\Big|^{effective} = \frac{1}{x_{total}} \sum (\Delta x_i) \cdot \ln z_{oi} \qquad (3)$$

where x_{total}= total distance from the DOE facility source to the receptor, and Δx_i= distance to boundary characterized by surface roughness length, z_{oi}.

Industrial Cluster Method

Many DOE sites have regions where multiple buildings and facilities are clustered. For this surface type, described as an industrial cluster, Hanna recommends that dispersion conditions be evaluated from at least two directions (90° separation) from the source to downwind receptors. A set of models is then applied that consider

- Average obstacle height, H_r
- Total area considered, A_t
- Plan area, (area covered by structures), A_p
- Dimensionless plan scaling parameter, $\lambda_p = A_p/A_t$
- Frontal area, (area normal to a given wind direction), A_f
- Dimensionless frontal scaling parameter, $\lambda_f = A_f/A_t$.

The four models used in this evaluation are:

1. Hanna and Britter [6]
2. Macdonald et al. [7]
3. "Rough, rule-of-thumb", Hanna and Britter [6]; and
4. Lettau [8].

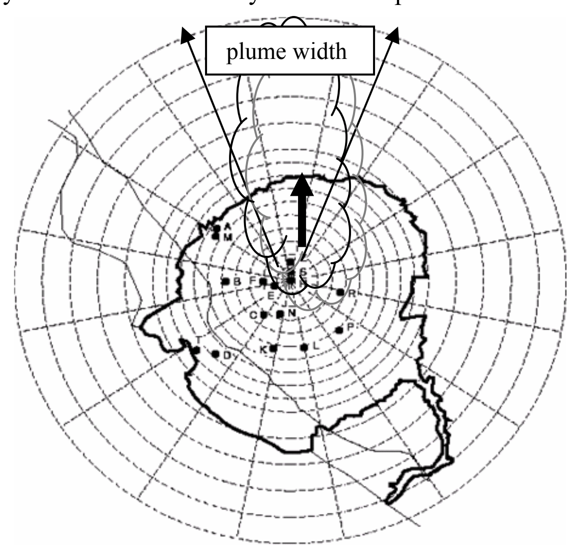
These approaches are applied to selected areas for accident analysis purposes for the Savannah River Site (SRS).

RESULTS

The methodology for evaluation of z_o is applied to three SRS prototypic situations: (1) Offsite – Base; (2) Offsite – Sensitivity due to forest clearing; and (3) Onsite – Industrial cluster.

Case 1 - Base Case. Figure 1 shows plume growth for a hypothetical release from a SRS facility, moving towards the reservation boundary. The z_o for this region of transport would be based on the heavily forested nature of most of SRS. For offsite cases, a forest value of 100 cm is the baseline value selected (Table 1).

Case 2 – Proposed Forest Clearing. The second case addresses a plan where surface features will be affected by a proposed checkerboard forest clearing pattern for NNW, N, and NNE sectors. The overall z_o for the path of the cloud is based on Equation 3 that applies a z_{o1} for forested areas (100 cm) and z_{o2} for cleared forest (30 cm) lengths. Rays are constructed every 5° or so to span the



Equation 2

Figure 1. Hypothetical plume is moving toward "site north" boundary of SRS.

space of planned clearing and Equation 3 applied. The regional results can be evaluated based on the arithmetical or geometric mean. For a hypothetical case of planned clearing where approximately 20 parcels of 450 acres total are to be cleared, the change in the dose to the receptor is about a 3% increase.
Case 3 – Onsite/Industrial cluster. The 100-m receptor, region of transport, z_o results for two SRS areas are shown in Table 2 for two directions, site north (0^o) and the direction perpendicular (90^o) to site north. Other directions were not investigated due to the close agreement for the two orthogonal directions analyzed in each case, and also due to the similar layout of most SRS area buildings and roadways with respect to "site north" orientation. The Table 2 results show that an average structure height of 6.2 m and a surface roughness length of 0.3 m are characteristic of the two areas.

The surface roughness length and structure height parameter value results for modeling dispersion must be considered jointly when comparing to a base set of input conditions. It can be shown that 6.2 m (minimum building height set in dose calculations) and 0.3 m surface roughness length lead to an equivalent dose result to a 1-m surface roughness length without crediting any building wake effect. As in the case of other inputs to consequence analysis calculations, varying a parameter in isolation without evaluating the self-consistency of a set of input parameter values is often misleading and can lead to erroneous results.

Table 2. Onsite z_o Results for SRS Onsite Receptor

Model	**Exterior Area**		**Interior Area**	
Direction	0^o	90^o	0^o	90^o
1. Hanna and Britter, m	0.26	0.35	0.25	0.24
2. MacDonald, m	0.07	0.07	0.07	0.07
3. 0.1 x H_r, m	0.62	0.62	0.62	0.62
4. Lettau, m	0.26	0.35	0.25	0.24
Four-method average, m	0.30	0.35	0.30	0.29
Two-direction average, m	0.3		0.3	
Average height of structures, m	6.2		6.2	

CONCLUSIONS

The surface roughness length, a parameter used in atmospheric dispersion/consequence analysis, has been evaluated for SRS conditions for both offsite and onsite receptors. A 1-m z_o is justified as the baseline value due to the heavy forest cover over most of the Site. In the case of planned forest clearing, an averaging technique can be applied to determine the overall effect. This can be weighted by a 360^o windrose if being applied to the direction-independent offsite receptor.

For the onsite receptor at 100 m, two representative areas were examined that factored in structure height, building density, and surface area for incident wind. Two wind directions were evaluated for each of the two areas, and found to have insignificant difference. The average building height and width, building density, and calculated surface roughness length, demonstrate that a 1-m surface roughness height (ignoring building wake effects) is technically justified.

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