Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

A Preliminary Study on the Resuspension of Radionuclides in Desert Environment

Sung-yeop Kim [a*], Philip A. Beeley [b], Soon Heung Chang [a], Man-Sung Yim [a]
[a]*Dept. of Nuclear and Quantum Eng., KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
[b]*Nuclear Eng. Dept., Khalifa Univ. of Science, Technology and Research, PO Box 127788, Abu Dhabi, UAE*
[*]*Corresponding author: beerun@kaist.ac.kr*

1. Introduction

There are a variety of human exposure pathways following the accident of nuclear power plant. Resuspension is one of the potential pathways when inhalation of radionuclide released to the atmosphere is considered. Resuspension is the process of going back to the atmosphere of the hazardous particles which was deposited on the ground surface. Representative driving forces of the resuspension are wind and mechanical disturbance like traffic, agriculture and etc. There are lots of factors that influence the resuspension: wind speed, climate, surface type and structure, time since deposition, size distribution and density of particles, land use and etc [1, 2].

The importance of the resuspension could be increased in desert environment due to its arid climate condition and low ground surface roughness z_0.

Various empirical models of resuspension were reviewed in this study and appropriate model for the desert environment was evaluated. Furthermore, preliminary resuspension modelling by using health physics code installing resuspension models was carried out.

2. Review of Resuspension Models

Existing models expressing resuspension were described and reviewed in this section. The types of resuspension models could be divided into three approaching methodologies: those using a resuspension factor, those using a dust loading approach and those using a resuspension rate [1].

2.1 Approach Using a Resuspension Factor

$$K\ [m^{-1}] = \frac{Concentration\ in\ air\ due\ to\ resuspension\ [Bq\cdot m^{-3}]}{Surface\ Deposit\ [Bq\cdot m^{-2}]} \quad (1)$$

This is a very useful and convenient way of expressing the resuspension because both concentration in air and surface deposit can be directly measured. It means we can easily calculate concentration in air due to resuspension by multiplying K to the surface deposit which is easily measurable. Many formulae describe the time dependence as exponential except Garland formula which was expressed by the power law.

$$K(t) = K(0)e^{-at} + K(T) \quad (2)$$

where K is resuspension factor [m^{-1}], $K(0)$ is the resuspension factor at time zero [m^{-1}], a is the rate of exponential [$days^{-1}$] of K after deposition as a function of time, t is the time after deposition [days] and $K(T)$ is the long-term resuspension factor [m^{-1}] [1].

2.1.1 Anspaugh Formula (1975) [3]

$$K = 10^{-4}e^{-0.15\sqrt{t}} + 10^{-9} \quad (3)$$

This is a correlation developed by using the data from the Nevada test site where the climate condition is arid.

2.1.2 WASH-1400 Formula (1975) [4]

$$K = 10^{-5}e^{-0.677t} + 10^{-9}\ ;\ \text{t in years} \quad (4)$$

This formula has been developed for the reactor safety study WASH-1400.

2.1.3 Linsley Formula (1978) [5]

$$K = 10^{-6}e^{-0.01t} + 10^{-9} \quad (5)$$

Many of data in this study were from desert condition.

2.1.4 Garland Formula (1982) [6]

$$K = 1.2 \times 10^{-6}t^{-1} \quad (6)$$

This formula has been derived from the wind tunnel experiment with grassland and bare soil condition. There is no long-term factor because the period of experiment was short. But for the early phase analysis, this model has higher credibility. Its verification has been carried out by comparing the data obtained after the Chernobyl accident.

2.1.5 RODOS Formula (1995) [7]

$$K = 5 \times 10^{-8}e^{-0.003t} + 10^{-9} \quad (7)$$

This formula has been derived by fitting the data obtained after the Chernobyl accident. The data of the first 30 days were not included.

2.1.6 KFKI formula (1995) [8]

$$K = 1.04 \times 10^{-7}e^{-0.0073t} + 6.5 \times 10^{-9}e^{-0.0046t} \quad (8)$$

This formula is called a multi exponential model. The second exponential term describes the exponential decrease of the long-term resuspension factor and. This formula is also correlated with the data from Chernobyl accident. However, the data of the first 50 days were not included.

2.1.7 NCRP Report No. 129 Formula (1999) [9]

$$\begin{aligned} K &= 10^{-6}\ (t < 1\ day), \\ K &= \frac{10^{-6}}{t}\ (1 < t < 1000\ days), \\ K &= 10^{-9}\ (t > 1000\ days) \end{aligned} \qquad (9)$$

These models are estimates from U.S. NCRP based on the data from Chernobyl.

2.1.8 Modified Garland Formula (2002) [1]

$$K = 1.2 \times 10^{-6} t^{-1} + 10^{-9} \qquad (10)$$

Modified Garland model kept the power law and supplemented the long-term factor and multiplication factor. Table 1 shows the rule of thumb multiplication factor of the modified Garland model.

Table 1. Multiplication factors to be applied to the results from Garland formula

Condition	MF
Rural conditions, light-medium winds	×1
Arid climate	×10
Urban conditions, light traffic, light pedestrian activity	×10
Urban conditions, heavy traffic	×100
Ploughing in dry conditions	×100
High winds	Additional factor ×2

2.1.9 Maxwell and Anspaugh Formula (2011) [10]

$$K = 10^{-5} e^{-0.07t} + 7 \times 10^{-9} e^{-0.002t} + 10^{-9} \qquad (11)$$

Enormous amount of data has been reviewed as part of developing this model. This model is adopted by various computer codes as the best model for long-term resuspension modelling. However, the model's effectiveness in describing very short term event is not known. [2]

Table 2. Models categorised by formula

Type of Model	Models
Single exponential model	Anspaugh WASH-1400 Linsley RODOS
Dual exponential model	KFKI Maxwell and Anspaugh
Power law model	Garland NCRP Report No. 129 Modified Garland

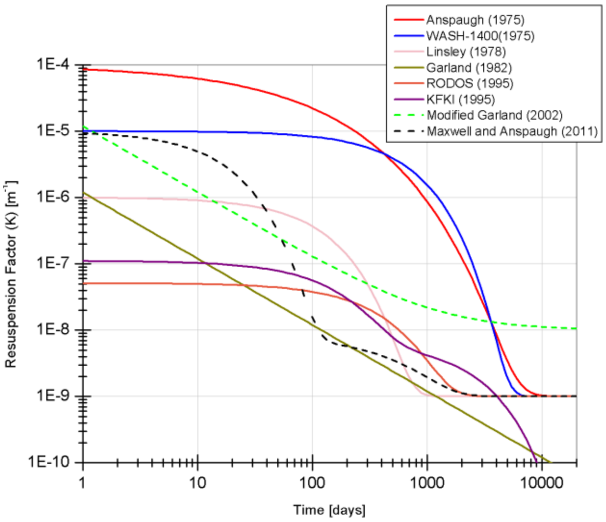

Fig. 1. Various models using resuspension factor

Figure 1 shows a variety of formulae describing time dependent resuspension factor. The models could be categorised as listed in table 2.

2.2 Approach Using a Dust Loading

$$C_a\ [Bq \cdot m^{-3}] = C_s\ [Bq \cdot kg^{-1}] \cdot S_E\ [kg \cdot m^{-3}] \quad (12)$$

where C_a is the estimated concentration of the radioactive materials in air, C_s is the concentration in soil and S_E is the equivalent mass concentration of soil in air or dust-loading. This approach is not applicable for the fresh deposited material because it assumes that the radionuclides are highly associated with soil. In addition, there is no time dependency in the model. Another disadvantage is that the concentrations of deposited radionuclides are usually measured as Bq·m^{-2}. However, this approach could be useful when we consider the mechanical disturbance because the measurement of the resuspention which is caused by mechanical disturbance is often reported as μg·m^{-3}. [1].

2.3 Approach Using a Resuspension Rate

$$\Lambda\ [s^{-1}] = \frac{Resuspension\ Flux\ [Bq \cdot m^{-2} \cdot s^{-1}]}{Surface\ Deposit\ [Bq \cdot m^{-2}]} \qquad (13)$$

As in the case of dust loading approach, the factor in this approach is not easily measurable in the field like and is not adequate for emergency response situation application. [1]

2.3.1 Loosmore Formula (2003) [2]

$$\Lambda = 0.42 \frac{u*^{2.13} d_p{}^{0.17}}{t^{0.92} z_0{}^{0.32} \rho_p{}^{0.76}} \qquad (14)$$

$$\Lambda = 0.01 \frac{u*^{1.43}}{t^{1.03}} \qquad (15)$$

where $u*$ is friction velocity, d_p is particle diameter, t is the time since the windflow began, z_0 is surface roughness and ρ_p is particle density. Above empirical models are derived by fitting three data set obtained by tunnel experiment by Nicholson (1993) [11], Giess et al. (1997) [12] and Garland (1982) [13].

2.4 Discussion

Three kinds of approach to evaluate resuspension have been reviewed in this work. The resuspension factor-based approach is expected to be the best because it can be easily related with the measurement data.

Big differences in the resuspension factor were observed among the models in describing the early phase of resuspension. The RODOS and KFKI model should not be used when describing the early phase of resuspension is important as these models are not including the first 30 days and 50 days of data respectively. The Anspaugh model and the Linsley model gives the value of 10^{-4} m^{-1} and 10^{-6} m^{-1}, respectively, as the initial resuspension factor while both formulae were derived using the data from the arid climate condition. Both the Maxwell and Anspaugh model and the modified Garland model gives the value of 10^{-5} m^{-1} as the initial resuspension factor which is the median value of the Anspaugh model and the Linsley model. Therefore 10^{-5} m^{-1} could be regarded as an appropriate initial resuspension factor for the desert environment.

Most of models agree with that the long-term resuspension factor should be 10^{-9} m^{-1}.

Recently, Japan Atomic Energy Agency (JAEA) reported that using dual exponential model is the best formula to correlate the data measured after the accident of Fukushima Daiichi nuclear power plant. [14]

Based on these observations, use of the Maxwell and Anspaugh model is judged to be applicable to the desert environment.

3. Preliminary Modeling of resuspension by using Maxwell and Anspaugh Formula

3.1 Methods

HotSpot 3.0 code developed by Lawrence Livermore National Laboratory was used to calculate environmental transport of radionuclides including resuspension and to estimate the effective dose from resuspended materials. The code is equipped with four different resuspension models: A constant value, the WASH-1400 approach, the NCRP report No. 129 method, and the Maxwell and Anspaugh model. The Maxwell and Anspaugh Formula was used in our calculation.

The source term was chosen as the release of 10^{16} Bq of Cs-137 which is the same amount released from the Fukushima accident [15]. The release was assumed to be from the ground and plume rise was not considered. The wind speed was set at 4 m/s based on the annual average wind speed of Al Rowais climate post near Barakah site in Abu Dhabi. Solar information was selected as “sun high in the sky” and the surface roughness was assumed at 3 cm which is the minimum allowed value in the HotSpot code [16]. However, the surface roughness length is expected to be lower ranging between 0.03 cm and 0.1 cm. Dose conversion factors (DCFs) from Federal Guidance Report No. 13 were used [17].

3.2 Results and Discussion

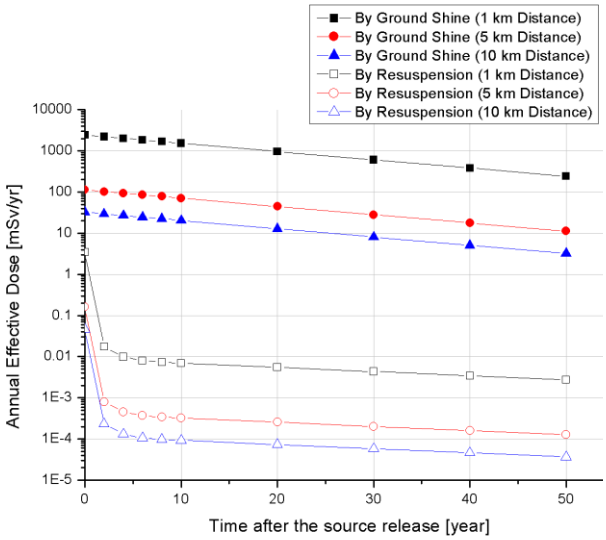

Fig. 2. Annual effective dose exposed from ground shine and resuspension at 1km, 5km and 10kn away from the source following the time after the source release

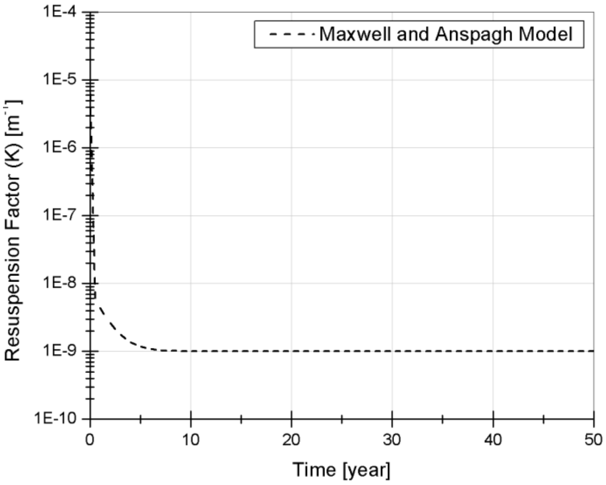

Fig. 3. Mexwell and Aspaugh model for resuspension

The annual effective dose exposed from ground shine and resuspension in various distances after the release is described in Figure 2. This result was calculated without consideration of the outdoor activity time. It is found that the annual effective dose of resuspension is about five orders of magnitude lower than that of ground shine. A steep gradient of the decrease in annual dose from resuspension appears until about 10 years after the source release because the concentration of radionuclide resuspended to the air decreases as time passes as represented by the Maxwell and Anspaugh model.

Even though the importance of resuspension in a short-term (about few years) analysis is higher than that of a longer term event, it is important to be aware that the portion of the dose from resuspension is small when compared with the dose from ground shine. The annual dose from resuspension is found to be 0.14 % of the annual dose from ground shine in the first year and 0.00045% in 10th year.

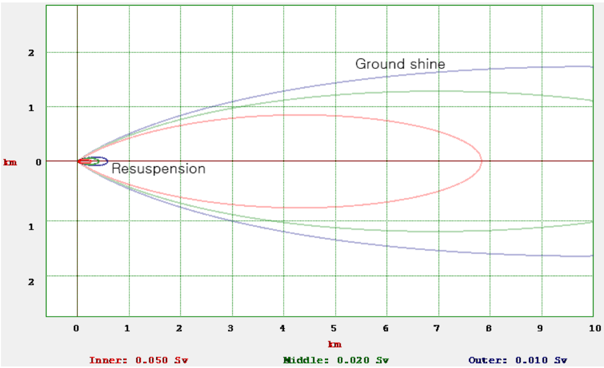

Fig. 4. Comparison of the annual effective dose by distance exposed from ground shine and resuspension right after the source release

The estimated annual effective dose of both resuspension and ground shine in the first year after the release is described in Figure 4. It is found that the contribution of resuspension to the annual dose is small but its importance could increase in a shorter-term and shorter-range assessment.

4. Conclusions and Recommendations

Based on the review of various resuspension models, the Maxwell and Anspaugh model was found to be the most appropriate model for desert environment application. Our test case analysis showed that the contribution of resuspension to annual dose is very small compared to that of ground shine. But importance may increase in the analysis of a shorter-term and shorter-range event.

Future plan of this research work includes the development of new resuspension model (e.g., the Lagrangian dispersion model) for environment-specific application by carrying out relevant experimental studies

REFERENCES

[1] C. Walsh, Calculation of Resuspension Doses for Emergency Response, NRPB-W1, National Radiological Protection Board (NRPB), 2002.

[2] G. A. Loosmore, Evaluation and Development of Models for Resuspension of Aerosols at Short Times after Deposition, Atmospheric Environment Vol. 37, p. 639-647, 2003.

[3] L. R. Anspaugh, J. H. Shinn, P. L. Phelps, N. C. Kennedy, Resuspension and Redistribution of Plutonium in Soils, Health Physics, Vol 29, p. 571-582, 1975.

[4] U.S. NRC, Reactor Safety Study, WASH-1400 (NUREG 75/014), 1975.

[5] G. S. Linsley, Resuspension of the Transuranium Element: A Review of Existing Data, NRPB-DL10, National Radiological Protection Board (NRPB), 1978.

[6] J. A. Garland, Resuspension of Particulate Material from Grass: Experimental Programme 1989-1980, AERE-R 10106, London, 1982.

[7] H. Muller, F. Gering and G. Prohl, Model description of the Terrestrial Food Chain and Dose Module FDMT in RODOS PV4.0, RODOS(WG3)-TN(99)17, 1999.

[8] KfK and NRPB, COSYMA: a New Package for Accident Consequence Assessment, EUR 13028, Luxembourg, 1991.

[9] NCRP, Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-specific Studies, NCRP Report No. 192, 1999.

[10] R. M. Maxwell, L. R. Anspaugh, An improved model for prediction of resuspension, Health Physics, Vol. 101(6), p.722-730, 2011

[11] K. W. Nicholson, Wind Tunnel Experiments on the Resuspension of Particulate Material, Atmospheric Environment, Vol. 27A, p. 181-188

[12] P. Giess, J. H. Goddard, G. Shaw, Factors Affecting Particle Resuspension from Grass Swards, Journal of Aerosol Science Vol. 28, p. 1331-1349, 1997

[13] J. A. Garland, Some Recent Studies of the Resuspension of Deposited Material from Soil and Grass, Elsevier, Santa Monica, pp. 1087-1095, 1982

[14] S. Takahara, M. Iijima, K. Shimada, A. Hidaka, T. Homma, Method for Estimating the Dose Distribution of People to be returned in Long-term Contaminated Areas, International Experts' Meeting on Radiation Protection after the Fukushima Daiichi Accident: Promoting Confidence and Understanding, Vienna, Austria, 17–21 February 2014,

[15] H. Shiraki, Estimation of radioactive release resulting from Fukushima Dai-ichiNPS accident, Tokyo Electric Power Company (TEPCO), 2012.

[16] S. G. Homann, F. Aluzzi, HotSpot Health Physics Codes Version 3.0 User’s Guide, National Atmospheric Release Advisory Center, Lawrence Livermore National Laboratory, Livermore, CA, 2013.

[17] K. F. Eckerman, R. W. Leggett, C. B. Nelson, J. S. Puskin, A. C. Richardson, Federal Guidance Report No. 13: Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Oak Ridge National Laboratofy, U.S. Environmental Protection Agency, 1999.