A Comparison of Models to Assess the Atmospheric Dispersion of Resuspended Radionuclides on the Nevada Test Site

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

Copyright License By acceptance of this article, the publisher and/or recipient acknowledges the
U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper.

Approved for Public Release

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LEGAL DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced from the best available copy.

Printed in the United States of America

DISCLM-2.CHP (1-91)

A Comparison of Models to Assess the Atmospheric Dispersion of Resuspended Radionuclides on the Nevada Test Site

J. R. Green
Westinghouse Hanford Company

R. E. Eckart
University of Cincinnati

Date Published
November 1994

Presented at
American Nuclear Society Topical Meeting on
Decommissioning, Decontamination and Environmental Restoration
Washington, D. C.
November 1994

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Westinghouse
Hanford Company

P.O. Box 1970
Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

Copyright License By acceptance of this article, the publisher and/or recipient acknowledges the
U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper.

Approved for Public Release

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

at

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

A COMPARISON OF MODELS TO ASSESS THE ATMOSPHERIC DISPERSION OF RESUSPENDED RADIONUCLIDES ON THE NEVADA TEST SITE

Janet R. Green
P.O. Box 1970, MS G2-02
Westinghouse Hanford Company
Richland, Washington 99320

Roy E. Eckart
Dept. of Mechanical, Industrial and
Nuclear Engineering
University of Cincinnati
Cincinnati, Ohio 45221

ABSTRACT

A study of computer codes was made to determine the suitability of their use for modeling radionuclide dispersion from attachment to fugitive dust at the GMX safety shot area of the Nevada Test site. Two codes, the Industrial Source Complex 2 Long Term Model (ISCLT2) and the Fugitive Dust Model (FDM), were subsequently chosen to model the GMX site. Dose calculations were performed using the output values generated by the computer codes. The concentration values produced by the two codes were within a factor of two of each other and were not significantly different. The FDM, however, was felt to be a more useful code for use in calculating doses caused by attachment to fugitive dust.

1.0 INTRODUCTION

In the 1950s and 1960s Areas 5 and 11 on the Nevada Test Site (NTS) were the sites for a number of "safety shot" tests. These safety tests utilized non-nuclear explosives to destroy nuclear devices and resulted in the scattering of plutonium (Pu) and americium (Am). Since the area is an arid desert, the primary mechanism for off-site migration of these contaminants, and for the possible dose to individuals, is the resuspension of radionuclides and their subsequent off-site transport. Therefore, in order to make estimates of doses to postulated onsite and offsite individuals, the resuspension and transport of radionuclides must be considered.

Two codes were used to model a "safety shot" area on the NTS. These were the Industrial Source Complex 2 Long Term Model (ISCLT2) (U.S. EPA 1992) and the Fugitive Dust Model (FDM) (U.S. EPA 1990). These codes were chosen due to their abilities to model large area sources of fugitive dust emissions. The area on the NTS modeled is called the GMX site. It is located in Area 5, which is in the southeastern corner of the NTS. It is relatively small, has been contaminated by 22 non-nuclear above-ground tests and can be represented as a square approximately $9.6 \times 10^5 \text{ m}^2$.

2.0 PLUTONIUM AEROSOL CHARACTERISTICS

Using measured vertical gradients of the plutonium-aerosol concentrations Shinn (Shinn *et al.* 1986) has tabulated

the plutonium-aerosol characteristics at GMX as shown in Table 1. The enhancement factor is the ratio of the specific activity found in the aerosol to the specific activity found in the soil and the AMAD is the activity median aerodynamic diameter. Long-term monitoring studies on GMX and the NTS have shown suspended soil and plutonium concentration distributions to both be log-normal with the size distribution for the suspended plutonium having a narrow geometric standard deviation (GSD). Work by Shinn (Shinn *et al.* 1986) (Shinn 1994) has determined an AMAD of $3.3 \mu\text{m}$ (range of $2 - 5 \mu\text{m}$) with a GSD of 4.2 (range of $3 - 6 \mu\text{m}$).

Table 1. GMX Pu Aerosol Characteristics

GMX Area	$10.4 \times 10^6 \text{ ft}^2 (9.66 \times 10^5 \text{ m}^2)$
Plutonium Flux	$1.9 \times 10^{-5} \text{ Bq/m}^2\text{-s}$
Resuspension Rate	$7.9 \times 10^{-13} \text{ s}^{-1}$
Resuspension Factor	$2.0 \times 10^{-10} \text{ m}^{-1}$
^{239}Pu specific activity in surface soil (Bq/g)	310 Bq/g
^{239}Pu aerosol (Bq/m ³)	$4.6 \times 10^{-3} \text{ Bq/m}^3$
Enhancement Factor	0.87
Mass Loading	$17 \mu\text{g/m}^3$
AMAD	$3.3 \mu\text{m}$

Using an AMAD of $3.3 \mu\text{m}$ with a GSD of 4.2 μm it is possible to make a plot of the particle distribution on log-probability paper as shown in Figure 1. The values plotted are: 16 percentile - $0.79 \mu\text{m}$ particle diameter ($3.3 / 14.2$); 50 percentile - $3.3 \mu\text{m}$ particle diameter; 84 percentile - $13.9 \mu\text{m}$ particle diameter (3.3×4.2). From the plot, particle size classes and the fraction of emissions contained in each class can be determined. The mean diameters of these classes can then be found using the equation (U.S. E.P.A. 1992):

$$d = 0.25(d_1^3 + d_1^2 d_2 + d_1 d_2^2 + d_2^3)$$

Table 2 lists the particle size classes, fraction of emissions found in each class and the mean diameters for each class.

A mean value of $9.22 \mu\text{m}$ is calculated for the log-normal distribution using methodology from *Statistical Methods for Environmental Pollution Monitoring* (Gilbert 1987).

Figure 1. Probability Semi-Log Plot

Table 2. Particle Size Distribution

Fraction	Size (μm)	Median Diameter (μm)
0.19	0.11 - 0.96	0.63
0.2	0.96 - 2.3	1.72
0.2	2.3 - 4.7	3.63
0.2	4.7 - 10.1	7.71
0.19	10.1 - 96	62.8

The Radionuclide Inventory and Distribution Program (RIDP) took measurements at the GMX Site on the NTS and determined radionuclide concentrations as shown in Table 2 (McArthur 1991). Ratios are used to develop a source term from measured $^{239/240}\text{Pu}$ quantities.

Table 3. Nevada Radionuclide Ratios (McArthur 1991)

	^{241}Am	^{238}Pu	$^{239/240}\text{Pu}$
nCi/m ²	202	30	1414
Ratio to $^{239/240}\text{Pu}$	1/7	2/100	1

3.0 COMPUTER CODES

A literature review was conducted to identify computer programs that might be candidates for modeling the GMX area at the NTS. Some of the codes reviewed were

MESORAD, GENII, MATHEW-ADPIC, CAP88-PC, ISCLT2, and FDM. Many of these codes were discarded due to their inability to model area sources and particle size distributions.

3.1 The Industrial Source Complex 2 Long Term Model

The ISC2 models are widely used for modeling the distribution of contaminants into the atmosphere from industrial sources. These contaminants include SO_2 , CO, and PM10 (particulate matter with an aerodynamic diameter less than 10 μm). The code has been extensively benchmarked and has undergone full quality assurance procedures conducted by the EPA. The long term version, ISCLT2 was used for this study.

The ISCLT2 model uses a steady-state sector-averaged Gaussian plume equation. Monthly, seasonal or annual STAR data are used and emissions from the source are partitioned into 16 compass sectors with the frequencies of the wind blowing into that sector. STAR data files which include information for stability categories A through G were supplied by the National Weather Service. ISCLT2, however, allows for the use of only 6 stability categories so categories F and G were combined. Area sources in the ISCLT2 code are modeled using a virtual point source algorithm with the release rate term (Q) in units of emissions per unit area ($\text{g m}^{-2} \text{sec}^{-1}$). It is assumed that the radionuclides are attached to fugitive dust particles. The ISCLT2 program is used to calculate the transport of the dust and at the receptor site, the contaminated dust is converted to units of activity.

The source term was calculated using the values given in Table 1. To arrive at a mass flux, the plutonium flux is multiplied by the inverse of the specific activity and enhancement factor, to give $7.0 \times 10^{-8} \text{ g/m}^2 \text{sec}$.

The point source dispersion terms, σ_y and σ_z in the ISC2 short term model are calculated from equations which generate lines to fit Pasquill-Gifford curves. However, sector averaging in the long term version means that a lateral uniform distribution is used in place of σ_y . The value for σ_z is calculated using the above mentioned equations for downwind distance x. A vertical virtual distance x_v is added to x for the σ_z calculation as an area source correction factor. Uncertainties in the results of unstable category A are one of the disadvantages of the sector-averaging method.

The ISCLT2 program has a vertical settling term for large particles. This term calculates losses due to gravitational settling as well as losses due to dry deposition. The mass flux is divided into a number of particle size classes. Median diameters, settling velocities and reflection coefficients for each class are input for use in the calculations of the vertical term. The median diameters shown in Table 2 were used to calculate the settling velocity for each class using the following equation:

$$V_s = \frac{20gr^2}{9\mu}$$

where

V_s = settling velocity (cm sec⁻¹)

ρ = particle density (g cm⁻³)

g = acceleration due to gravity (9.806 m s⁻²)

r = particle radius (cm), .5 times the mass median diameter

μ = absolute viscosity of air (1.83x10⁻⁴ g cm⁻¹ sec⁻¹).

Settling velocities for the five particle size classes are given in Table 4 along with other ISCLT2 input parameters. Reflection coefficients indicate the quantity of material that is reflected back into the atmosphere. These are estimated from curves in the ISCLT2 manual (U.S. EPA 1992) that are dependent upon settling velocity.

One of the features that the ISC2 codes offer is complex terrain modeling. Unfortunately, the use of complex terrain options and gravitational settling are mutually exclusive in the code. Another feature of the ISC2 codes that may be of some interest in the future for modeling the NTS is its ability to vary the emission rate. Varying the emission rate with wind speed and season could add another degree of accuracy in the creation of a more complete NTS dispersion model.

ISCLT2 allows for the input of mixing height by stability category. Following EPA guidelines for the use of ISCLT2, 1.5 times the mean afternoon mixing height was input for category A, categories B, C, and D use the mean afternoon mixing height, and categories E and F use 10,000 m. EPA guidelines for temperatures were also followed. For stability categories A, B and C, the average maximum daily temperature was used. For categories D and E the minimum daily temperature was used, and for stability category F the annual average daily temperature was input. Table 4 contains values for mixing height and temperature by stability category. Both the mixing height values and temperatures were supplied by the NWS Nuclear Support Office.

Some of the important points about the ISCLT2 model are as follows:

- ISCLT2 is used for modeling gases as well as particles and has extensive input requirements.
- The code is based on the Gaussian plume model.
- EPA quality assurance and code validation procedures have been conducted.
- The program uses monthly, seasonal or annual STAR data for stability categories A - F or hourly meteorological data.
- Mixing height and temperature data are available for each stability category.
- The program uses sector averaging and models area sources as virtual points. Area sources can only be rectangular in shape.
- The ISCLT2 model includes gravitational settling and

dry deposition as loss terms.

- It does not include precipitation scavenging.
- Complex terrain can be modeled but the algorithm is incompatible with gravitational settling losses.
- Dose calculations are not included.

Table 4. ISCLT2 and FDM Input Parameters

Wind File	Annual STAR data file from NWS					
Stability Category	A	B	C	D	E	F
Mixing Hgts, m	3675	2450	2450	2450	10000	10000
Temperature, K	297	297	297	282	282	290
Emission Rate	7.0E-08 g m ⁻² sec ⁻¹					
Release Height	1 m					
Settling Velocities	1.89e-5	1.41e-4	6.28e-4	2.83e-3	1.88e-1	
Fraction	0.2	0.2	0.2	0.2	0.2	
Reflection Coeff.	0.95	0.9	0.9	0.9	0.4	

3.1.2 The Fugitive Dust Model

The other code that was chosen for this study was the Fugitive Dust Model (FDM). The FDM is based on a combination of the Eulerian approach and the classical Gaussian plume model, and has been designed to incorporate an improved gradient transfer algorithm (U.S. EPA 1990). It specifically deals with particles and allows the incorporation of user-defined size distributions and settling velocities. It also uses site specific meteorological data and has a well-developed area algorithm. It does not calculate washout or rainout and would not be suitable for use in wet climates.

FDM is specifically designed to model the transport and diffusion of fugitive dust. It is based on the equation (U.S. EPA 1990):

$$\frac{\partial \chi}{\partial t} + \frac{\partial}{\partial x} K_x \frac{\partial \chi}{\partial x} - u \frac{\partial \chi}{\partial x} + \frac{\partial}{\partial y} K_y \frac{\partial \chi}{\partial y} + \frac{\partial}{\partial z} K_z \frac{\partial \chi}{\partial z} + v_s \frac{\partial \chi}{\partial z}$$

where

χ = concentration (g/m³)

K_x, K_y, K_z = eddy diffusivity in x, y and z, (m²/sec)

t = time, sec

u = wind speed (m/sec)

v_s = gravitational settling velocity (m/sec).

This equation is very similar to the equation developed for the gradient transport theory, but it includes wind transport in the x direction and the vertical settling of dust. It is solved for χ in a method similar to that used for the Eulerian approach. In addition, the eddy diffusivity K is assumed to be constant in all directions and a relationship between K and σ_z is defined. An inconsistency in mass conservation develops due to these assumptions and is corrected for by the use of a correction term. A deposition algorithm is also added and while the final equations in the FDM resemble the Gaussian plume equation

they are in fact unique to the FDM. Validation studies for the FDM were performed and are well documented.

Many of the input parameters used were common to both codes. All data presented in Tables 1, 2 and 4 were used both in ISCLT2 and FDM code with the exception of the settling velocities which are calculated by the FDM code. Five particle size classes were input, although FDM can deal with up to 20 particle size classes. Dry deposition values were calculated by the code using the deposition algorithm incorporated in the model. Deposition, as calculated by the code, is dependent on the size of the particle, stability category, temperature and roughness height. Roughness height is a parameter input by the user that is based on a figure given in the FDM User's Manual. For desert areas the roughness height is equal to 0.06 cm. The user has the option of entering a global particle density or individual densities for each particle size class, for the GMX site a global density of 1.9 g/cm³ was used.

Much like ISCLT2, the FDM contains an option to vary emission rate. The user can vary dust flux with wind speed by inputting a wind speed proportionality factor. This feature was not used for this project, but could conceivably increase the accuracy of dust transport in future studies at the NTS. The FDM can also model complex terrain, but unlike the ISCLT2 code, however, this function does not interfere with the deposition algorithm.

The FDM area source algorithm has several features which make it unique among the codes studied for the GMX modeling. Although the area modeled was square to facilitate the use of other codes, the FDM areas can be irregular in shape and oriented in any fashion. The area source algorithm computes concentrations by first moving the origin to the receptor and considering that area of the source that is upwind of this new origin. The area upwind is then divided into line sources perpendicular to the wind direction and integrated.

The points to note concerning the FDM include the following:

- The code is based on a modified Gaussian plume model.
- An improved gradient transfer deposition algorithm which models losses due to gravitational settling and dry deposition is available. It specifically deals with particle size distributions.
- Losses due to precipitation scavenging are not included.
- Hourly meteorological data or monthly, seasonal or annual STAR data for classes A - F can be used.
- Mixing height and temperature data is available by stability category.
- The area algorithm in FDM avoids some of the uncertainties of the sector averaging approach by approximating the area with line sources and integrating.

- Complex terrain modeling is available.
- Dose calculation are not included.

4.0 DOSE CALCULATION METHODOLOGY

Fifty year committed effective dose equivalents (CEDE) for a one year uptake were calculated using the methodology recommended by the International Congress on Radiological Protection in Publication Number 30 (ICRP 30). Only the dose due to inhalation was calculated.

Dose conversion factors (DCF) are taken from tabulated DOE recommendations for ²⁴¹Am and plutonium oxides (DOE 1988) and represent values for the intake of particles with an AMAD of 1 μm. The ICRP 23 recommended yearly breathing rate of 8400 m³/yr was used. The equation used to calculate dose is:

$$\text{Dose} = \text{IR} \times \text{Source} \times \text{DCF}$$

where

Dose = CEDE for inhalation from a specific radionuclide, mrem/yr

$$\text{IR} = \text{inhalation rate} = 8400 \text{ m}^3 \text{ yr}^{-1}$$

$$\text{Source} = \text{activity from one radionuclide (pCi m}^{-3}\text{)}$$

$$\text{DCF} = \text{dose conversion factor (mrem pCi}^{-1}\text{)}.$$

The conversion for the output which is in mass per unit volume to activity per unit volume is made in the following manner:

$$\text{Source} = \text{ML} \times \text{EF} \times \text{SA} \times \text{CF} \times \text{Ratio}$$

where

$$\text{Source} = \text{activity for a specific radionuclide, pCi/m}^3$$

$$\text{ML} = \text{mass loading, g/m}^3$$

$$\text{EF} = \text{enhancement factor, .87 unitless}$$

$$\text{SA} = \text{specific activity, 310 Bq/g}$$

$$\text{CF} = \text{conversion factor, pCi/37 Bq}$$

$$\text{Ratio} = \text{ratio per radionuclide in the Nevada mix.}$$

A spreadsheet was used to calculate CEDEs in mrem/yr by radionuclide, summing doses over all radionuclides gave a total CEDE from inhalation.

5.0 RESULTS

Each code was run with receptors in 16 compass directions at 1 and 10 km. The ISCLT2 and FDM outputs were converted from concentration per unit volume to activity per unit volume using the above methodology. The largest dose for ISCLT2 is a CEDE of 0.0042 mrem/hr at 1 km in the west-northwest. The largest dose for the FDM is 0.0059 mrem/yr also in the west northwest. The two codes show no significant difference in results.

Figure 2 graphs the calculated dose rate at 1 km. The graphs show a fairly even distribution with doses in the west and west northwest higher than elsewhere. The high distributions in the west sector are not what would be expected at the NTS where winds from the west predominate. However, both models were found to be driven by stability categories F

both models were found to be driven by stability categories F and G, which are dominated by low speed winds from the east. Removal of these two stability categories and renormalizing the STAR data gave a new distribution with the highest dose rates in the east.

An explanation of the dominance of the low speed wind categories is found in the Gaussian plume equation. The concentration downwind is inversely proportional to the standard deviations, σ_y and σ_z . These values are much higher for the unstable categories. For instance, the Turner Workbook σ_z values at 1 km for stability category A are approximately 600 m, whereas for stability category G the value is about 10 m. The standard deviations in the y direction also show a wide range of values, with σ_y for category A equal to 300 m and for category G equal to 40 m. The large standard deviation values for the unstable categories reflect the spreading out of the plume that occurs in these conditions. The unstable categories are also subject to higher wind speeds which cause even greater dispersion. Higher concentration levels, therefore, will occur at those receptor sites immediately influenced by the more stable F and G categories. For the GMX site joint frequency data, the highest concentrations will therefore be found in the west.

6.0 CONCLUSIONS

The ISCLT2 and FDM codes were used to model the GMX site on the NTS. The two codes show no significant difference in results, although the FDM does give slightly higher values. The FDM demonstrated some advantages over the ISCLT2 code. Since the FDM deals only with modeling fugitive dust emissions, the input deck is relatively smaller than that required by the ISCLT2 code. The FDM code also contains a more flexible area algorithm which can be used to model area source of different shapes. The FDM incorporates velocity settling calculations and allows for the input of up to 20 particle size classes. Benchmarking the code would prove a useful exercise in further determining the inclusion of the FDM code in dose calculation models pertinent to arid regions such as the NTS.

7.0 REFERENCES

Gilbert, Richard O. (1987) *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York.

McArthur, R.D. (1991). "Radionuclides in Surface Soil at the Nevada Test Site." U.S. DOE, Las Vegas, NV.

Shinn, J.H., Homan, D.N. and Hofmann, C.B. (1986). "A Summary of Plutonium Aerosol Studies: Resuspension at the Nevada Test Site." LLNL, UCRL-90746.

Figure 2. Calculated Dose Rates (mrem/yr)

Shinn, J.H. (1994). Conversation, LLNL, CA.

U.S. Department of Energy (DOE) (1988). "External Dose-Rate Conversion Factors for Calculation of Dose to the Public", DOE-EH-0070.

U.S. Environmental Protection Agency (EPA) (1990). "User's Guide for the Fugitive Dust Model (FDM) (revised): Volume 1: User's Instructions." Mountlake Terrace, WA. PB90-215203.

U.S. Environmental Protection Agency (EPA). (1992). *User's Guide for the Industrial Source Complex (ISC2) Dispersion Models, Vol. I, II and III*. EPA-450/4-92-008a.

DISTRIBUTION

Number of copies

ONSITE

1	<u>U.S. Department of Energy - Richland Operations Office</u>	
	S. K. Moy	S7-55
5	<u>Westinghouse Hanford Company</u>	
	J. R. Green (2)	G2-02
	Document Clearance Administration (3)	A3-36