An Initial Review of Several Meteorological Models Suitable for Low-Level Waste Disposal Facilities

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National Oceanic and Atmospheric Administration

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Several mathematical models of the meteorological aspects of effluent releases have been examined for relevance to Low Level Waste disposal programs. The principle models, by Dames and Moore, Inc., Science Applications, Inc., Argonne National Laboratory, and Oak Ridge National Laboratory, contain provisions for various combinations of wind erosion, area, and point source configurations as well as deposition and elevated releases. Methods employed by these models are compared for relevance, availability of supporting data and potential benefit versus cost.

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AN INITIAL REVIEW OF SEVERAL METEOROLOGICAL MODELS SUITABLE FOR LOW LEVEL WASTE DISPOSAL

1. SCOPE OF THE PROBLEM

"Disposal" of low-level radioactive waste as defined by rule 10CFR Part 61.1 of the U. S. Nuclear Regulatory Commission is defined as "the isolation of radioactive wastes from the biosphere inhabited by man and containing his food chains by emplacement in a land disposal facility." The role of subsequent pathways of migration of the buried wastes are addressed in Parts 61.13 and 61.41. For the eastern U.S., with generally plentiful and sometimes excessive rainfall rates, the possibility of rainfall percolating to the depths of buried material and hence to domestic water supplies must be addressed in selecting a proper burial site. In many arid areas of the western U.S., however, even the heaviest rainfalls are taken up by the dry soil and subsequently evaporated or transpired with little or no underground movement. Hakonson, et al. (Ref. 1) has described the progression of plant and animal intrusion throughout the years and estimated (Ref. 2) that, after climax vegetation is acheived, 10^{-3} to 10^{-4} of the inventory of biologically active waste will be transported to the surface each year. Gases formed aerobically or anaerobically from buried biological wastes are often transported to the surface through cracks in the soil, by seepage through the porous overburden, and leakage from sump pipes. Matuszek (Ref. 3) has stated that as the water pathway becomes less of a problem, the air pathway will increase in significance.

Prior to burial, operational incidents may release radioactive material into the air by ruptured containers or fire. Low level radioactivity may remain on the ground subject to wind and water erosion.

The air pathway of burial waste to the environment may vary widely. In areas of heavy rainfall, trenches may fill with water and spill over to the surface (the "bathtub effect"), distributing radioactive material throughout the soil depth as well as at the surface. Vegetative uptake will deposit material primarily on the surface, although substantial redistribution through the soil will also occur as root mold must, and as material diffuses downward from the surface. These are "area" sources of effluent generated by wind erosion. Cracks in the soil leading to the surface from sources of gaseous wastes could be treated as "line" sources if identifiable, but as a practical matter will probably be considered as area sources about the trench site. Accidents would generally be treated as point sources or even "puffs" should the interval of release be short enough.

2. SITE INSTRUMENTATION

The most valuable contribution of a meteorological model to the management of low level waste will probably be made prior to the installation of any meteorological instrumentation. Climatological data from the nearest weather stations are assembled to provide the best approximation to wind speed, direction, temperature, and rainfall. With the help of soil scientists and using engineering estimates of containment procedures, the initial estimates of chronic and episodal air concentrations, deposition and wind erosion are made. This must be accomplished as part of the site selection process.

When a site has been selected, the "preoperational" phase begins. For a minimum of a year, meteorological data may be taken, compared with data from surrounding stations and climatological corrections made as necessary. Lockhart (Ref. 4) outlined an estimate of the necessary meteorological instrumentation. In order of priority he proposed wind direction, wind speed, horizontal deviation of wind direction (σ_θ), precipitation, solar radiation, dry bulb temperature, dew point temperature, soil temperature and the difference in air temperature between two levels (ΔT). Several other variables were listed but fall primarily into the classification of soil probes.

Lockhart's suggestions for instrumentation reflect the need for simplicity coupled with the possible requirements of hydrologic models (Ref. 5), (Ref. 6). Meteorological instrumentation is expensive, and data storage and reduction even more so. Fortunately, many mathematical models employed in assessing the meteorological characteristics of a site require only the minimum investment outlined above. Although many elaborate models exist which require a network of sensors, the basic models examined here are based on the general "Gaussian" plume formulation, requiring only wind speed, direction and some measure of atmospheric stability. It might be noted, in passing, that with these goals in mind solar radiation data appears of less immediate relevance than net radiation, which is rarely included in lists of desirable data.

3. LIMITS OF THE GAUSSIAN PLUME MODEL

The models examined in this paper employ the "Gaussian" plume concept, i.e., over a sufficient time (generally considered on the order of one hour or more), the horizontal and vertical meanderings of a plume will be regular enough to establish a "normal" distribution of material about an established mean position. Other models such as "particle-in-cell" (PIC) or trajectory emulating models deal with more basic physical processes at the expense of more detailed requirements of input and much greater computational effort.

Theory, observation and practice have established the Gaussian model as an eminently employable tool for predicting long term mean airborne concentrations from various sources of pollution. The parameters of dispersion with distance (σ_y,σ_z) most commonly employed, generally known as the Pasquill-Gifford (P-G) curves (Ref. 7), are especially suited to model the "worst case" conditions in which transport is controlled by processes above the so-called surface boundary layer, which comprises the lowest 50-100 meters of the atmosphere.

All models have far less reliability in estimating concentrations at specific times or specific periods, (e.g. they are very poor *a-posteriori* predictors). Wind direction, speed, and stability conditions are never of sufficient accuracy or density to satisfy the demands of the modeling required for great accuracy as the time scales diminish. No realistic Gaussian plume model has yet been demonstrated for time scales of several hours or less.

Recently a number of dispersion models were compared using the same data base at Savannah River (Ref. 8). The models were evaluated on their abilities to calculate the concentration of Krypton-85 up to a distance of 150 km over a 2½ year period. The time intervals involved ranged from twice daily to annual. No model covered the entire period. The annual to monthly period models were generally Gaussian whereas the twice daily to weekly were largely of the PIC or trajectory type.

A brief summary of the average results of each model type is given below:

TYPE	R	AVERAGE BIAS pCi/m^3	RMSE pCi/m^3	SLOPE
Annual	.85	-24	31	1.33
Monthly	.51	-16	44	0.78
Weekly	.45	-33	134	1.10
Twice Daily	.40	1	161	0.48

Where R = correlation coefficient
RMSE = root mean square error
Slope = slope of least squares fit to predicted/observed concentrations

The reduction in the correlation coefficient with decreasing time intervals is apparent from the summary. To establish some criteria for evaluating the results given above, the average annual concentrations vs distance were correlated. In the absence of any meteorological variables, the correlation was R = 0.89. This result, contrary to expectation, may be explained by the fact that, at Savannah River, the wind blows almost uniformly from all directions. In areas characterized by strongly prevailing winds, wind speeds and direction would play a much greater role in the observed and calculated concentrative patterns. Moreover, average wind speed and average vertical mixing (σ_z), two important meteorological parameters would be necessary inputs to a basic model even though, being constants, they would not affect the correlation coefficient.

The average background concentration of Krypton-85 is 15 pci/m^3, a figure exceeded by the RMSE in all models.

The best of each type of model for each time period is listed below. The annual and monthly intervals of the best models are a substantial improvement over their average counterparts.

MODEL	TYPE	R	Average Bias pCi/m^3	RMSE pCi/m^3	SLOPE
AIRDOS-EPA	Annual-Gaussian	.98	-29	31	1.7
ASTRAP	Monthly-Trajectory	.75	0.2	18	0.6
ATAD	Weekly-Trajectory	.48	2	62	0.6
DRAX2	Twice Daily-Trajectory	.49	-0.5	201	0.7

The Airdos-EPA model apparently owes its high correlation to its employment of varying mixing heights, a feature missing in most annual-Gaussian models. The slope of 1.7 and large average bias indicate, however, that it consistently overpredicts the concentration.

The ASTRAP model is being developed by Argonne National Laboratory and is not yet available or even fully documented. It is basically a trajectory model, requiring more inputs than the standard Gaussian type; its direct applicability to Low Level Waste problems is limited since its emphasis is on regional problems.

While the overall results seem disappointing, their import is clear; the accuracy of meteorological modeling increases with the time scale of the model. Dispersion models are excellent in defining the limits of a problem, particularly as time scales grow long. Unfortunately, meteorological data obtained on-site combined with the best models available do rather poorly in validation tests as time scales decrease.

4. THE DAMES AND MOORE STUDY

Dames and Moore, Inc. has published Data Base for Radioactive Waste Management, NUREG/CR-1759, Vol. 3, (Ref. 9) primarily as "a tool to enable determination of specific values of parameters that can be controlled and/or specified through technological or administrative action so as to assure the disposal of LLW in accordance with goals for management and disposal of LLW" (p. 1-3, Vol. 3). The emphasis is on exploring controllable factors rather than to calculate the effects of meteorological variability. Quoting the report again, "The methodologies are focused toward helping to establish generic criteria for LLW management and disposal rather than calculating impact at a particular disposal facility" (p. 1-6, Vol. 3). Accordingly, the meteorological sections are of a general nature, based on the Gaussian plume equation with deposition and wind erosion calculated by generally acceptable methods.

The method employed by the Dames and Moore study is that of a series of "transfer factors," soil-to-air-transfer, soil-to-water transfer, etc. The meteorological factors entered are few, consisting only of annual average wind speed, concentration/emission (χ/q) multiplied by the population for each referenced distance, and a soil particle size distribution. The (χ/q) factor is computed (external to the main model) through an accepted algorithm for deriving sector averaged concentration.

The meteorology employed in this report is quite conservative, i.e. the "puff" model (p. 3-91, Vol. 3) does not permit growth with time or distance, the accident-fire scenario (p. 3-92, 94, Vol. 3), assumes "F" (very stable conditions), and centerline concentrations.

An exception to the conservatism is the use of 4.1×10^4 mg $m^{-2}s^{-1}$ as the nominal wind erosion factor. Western soils are far more likely to erode at an order of magnitude or more than implied by the above value, as determined by Shinn et al., in Nevada (Ref. 10).

The values used on page A-15 appear to be simply a copy of their reference (Ref. 6), NUREG-0706 Vol. 3, which assumed that only 3 percent of the particle mass is associated with particles smaller than 20 microns in diameter, a questionable assumption in many locations.

The model employs a wind resuspension model based on an equation proposed by Gillette (Ref. 11) and modified by Travis (Ref. 12). The key word is resuspension, i.e. material recently deposited and therefore remaining on, or close to, the surface. A convenient unit to use in the case of resuspension is the "resuspension rate" which has the units of fraction resuspended per second, a function of the inverse of the time an average particle will remain on the surface after its initial deposition. The experimental data was derived from deposited material such as plutonium (Ref. 13), DDT (Ref. 14), and calcium molybdate (Ref. 15). In these experiments, the slope of material resuspended increased with wind speed as much as to the sixth power or more. This contrasts with the commonly accepted value for wind erosion varying as the third power (Ref. 16). However, the circumstances are entirely different, in that resuspension of surface material is being compared with erosion of indigenous soil. Cultivated soil may also erode at a high rate (Ref. 10), but employing the Travis -Gillette equations as a general wind erosion model is not justifiable.

In summary, the Dames and Moore approach incorporates a simple, almost elementary approach to meteorology which is very effective in establishing nominal values of atmospheric contaminants impacting on populations over a kilometer downwind. If soil erosion (from wind) or gaseous effluents through the soil are anticipated to be significant pathways, this study will not suffice. Similarly, site-specific problems of population, meteorology, and soil conditions cannot be examined.

5. THE SCIENCE APPLICATIONS STUDY

The meteorology of the Science Applications, Inc. Study (Ref. 17) is a simple Gaussian approach with a singularly complex wind erosion subprogram (ERODE). This subprogram is "essentially a modification of the WEROS (Wind Erosion) program developed by the U.S. Department of Agriculture to predict soil loss from the great plains..."(Ref. 18) (p. 6-20, Vol. 2). This approach, based on many years of observation, appears to be more sound than the Travis - Gillette algorithm used in the Dames and Moore study cited above. The total amount of wind erosion is calculated from the large particles which creep along the surface to the smaller and intermediate particles which become airborne for varying distances. A critical factor in both approaches for estimating the amount of airborne material is the distribution of soil size particles on and near the soil surface: a distribution which is seldom, if ever, known except in a few special studies. The fraction of material with diameters smaller than twenty microns is considered "respirable," i.e., capable of deep penetration into the lungs. Particles of twenty to one hundred microns are assumed to be suspended in high winds, but not as hazardous to respiratory functions. The distribution of soil size is, therefore, an important parameter in the WEROS approach as it is in the Travis-Gillettte equation. Unfortunately the fraction of eroded soil which becomes airborne is "left as an input that ranges from 0 to 100 percent..."

(p. 6-22, Vol. 2) leaving a factor of uncertainty greater than an order of magnitude. The dimensions of the eroded field are not incorporated into the diffusion equation as an area source, nor are area or line sources applied to any part of the atmospheric model.

The basic atmospheric diffusion equation employed is cited as a "Gaussian plume model...as described in ...(Ref. 7)... and used in a number of computer programs such as XOQDOQ" (Ref. 19), (p. 610, Vol. 2). The Gaussian plume is modified for puff, plume or sector-averaged applications in the manner usually applied to these codes, i.e., some derivative from Meteorology and Atomic Energy-1968 (Ref. 7), and/or Hosker (1973) (Ref. 20). Dry deposition, washout and rainout can be calculated, again following the references cited above.

Noteworthy in effort are the various "scenarios" proposed in Vol. 1, in which numerous accident conditions are proposed. The various subprograms, (Aquifer, Geology, Erosion, Atmospheric, Agriculture and Direct) are listed as required or not required for simulation of the incident. Some 302 "scenarios" are identified, such as "No. 238: Chronic escape to atmosphere of radionuclides during the inspection prior to loading on transport vehicle of drums, boxes, cartons, and loose bundles." The required subprograms for this scenario are Atmospheric and Agricultural.

One may summarize the meteorological section of the Science Applications product as being a very detailed application of the Gaussian model. It differs significantly from other models in its application of the U. S. Department of Agriculture's methods to estimate soil erosion. Slinn (Ref. 21) endorses this approach stating that "...many difficulties associated with predicting [the resuspension factor] are already solved for us [by Agricultural Handbook No. 346]." Unfortunately, the fraction of the soil actually suspended is left as a "user input" subjecting the calculations to an order of magnitude of uncertainty. The lack of onsite area source modeling is, in common with the Dames and Moore Study, potentially troubling if outgassing from the trench area is considered a potential problem.

6. THE URANIUM DISPERSION AND DOSIMETRY CODE

Although the Uranium Dispersion and Dosimetry Code, NUREG/CR-0553 (Ref. 22) was principally assembled to "provide estimates of potential radioactive exposure to individuals and to the general population in the vicinity of a uranium processing facility," the meteorological section is versatile enough to warrant its application to other areas. Its Gaussian formulation is supplemented by a variable mixing height, the vertical dispersion coefficients are limited to realistic numbers, an elementary plume rise equation is provided and area sources are treated. The principle disadvantage of the UDAD code is its heavy reliance on the Travis - Gillette formulation for wind erosion, which, as discussed above, is heavily dependent on parameters which are not likely to be known. For example, the "Threshold Velocity," U_{*t}, a parameter dependent upon the wind speed required for initiation of particle movement along the ground, is a function of grain density and grain size if the surface is uniform in grain content and flat geometrically. With rare exceptions, the backfill over low level waste areas will consist of a potpouri of soil types. As a practical matter, U_{*t} may only be obtained by observation: in the absence of an observational program, some simple default technique, (such as U_{*t} = 30 cm/s) would simplify the input and approximate the U.S.D.A.'s model employed by the Science Application model.

Area sources are approximated by assuming virtual point sources and adjusting the inventory of emissions to the wind experience from each direction.

Unlike the previous two models, however, the UDAD model does not couple to sub-soil or water erosion pathways. The model is, however, suitable as a subprogram to more comprehensive programs such as the Dames and Moore, or as an alternative to the Science Applications atmospheric program. It is, in fact, incorporated in a simplified form in the Dames and Moore study and is the basic algorithm for the meteorological subprogram of MILDOS (see below). The model documentation is complete and easy to follow. Defaults are included for many parameters likely to be unknown.

7. THE MILDOS MODEL

MILDOS--A Computer Program for Calculating Environmental Radiation Doses from Uranium Recovery Operation, (Ref. 23) "estimates impacts from radioactive emissions from uranium milling facilities. Only airborne releases of radioactive materials are considered: releases to surface water and groundwater are not addressed in MILDOS." The meteorological model is identical to UDAD (see above), and carries virtually identical subroutines in the computer model. Nomenclature of the meteorological subroutines are identical in both models, (POLUT, TAILPS, and INDEX), and there are only slight differences in the subroutine coding.

8. OTHER METEOROLOGICAL MODELS

The four models discussed above are coupled to master programs to compute radioactive dosages to human populations and to assess specific insults to individual organs and skin via specific radionuclides. The models discussed below are "stand alone" models which would be employed as subprograms to the models above if their meteorological aspects were considered deficient.

9. THE AIR TRANSPORT MODEL

The Air Transport Model (ATM) (Ref. 24) as it is commonly known is available as A Comprehensive Atmospheric Transport and Diffusion Model, ORNL/NSF/EATC-17. This model was originally designed to be a subprogram to a large air and soil interactive program published as the Universal Transport Model (UTM) (Ref. 6), a model developed to simulate contaminant transport through the hydrologic cycle, but is widely applied in air pollution modeling. It employes multiple point source, area, and line modeling. Originally up to ten point sources could be modeled, but current versions available at Oak Ridge National Laboratory exceed over fifty inputs. Washout, rainout, dry deposition, and wind erosion are included. Its use is aided by an excellent manual.

The area source modeling is more accurate than UDAD's since it employs several transformations that distinquish whether the receptor is distant, adjacent to or located within the source area. ATM's wind erosion equation is modeled after the basic equations of Bagnold (Ref. 16), but, in common with the USDA's "WEROS" (Ref. 18), does not calculate airborne material, per se. Other aspects of the code are provisions for fallout, washout, plume depletion, changes in surface conditions and a maximum concentration estimate from multiple sources. Considering its more elaborate area source subroutine, for onsite modeling of gaseous seepage, this seems to be the best model currently available with the possible exception of the Environmental Protection Agency's "PAL" algorithm described below.

10. THE SINGLE SOURCE (CRSTER) MODEL

This extensively used model is heavily weighted toward the problem of stack emmission modeling. It would require extensive revision for application toward low level waste disposal problems. This is one of the UNAMAP (User's Network for Applied Modeling of Air Pollution) available from the U.S. Environmental Protection Agency. CRSTER (Ref. 25) is included here because its very wide use in air pollution modeling requires at least a comment for those who have only a tangential knowledge of air pollution modeling.

11. HIWAY-2

The similarity between the long rows of waste trenches, and highways as parallel sources suggests the employment of an air pollution model for roadways such as HIWAY-2 (Ref. 26). In many respects, HIWAY-2 provides excellent modeling of a low level waste facility. Although area sources per se are not modeled, the manual suggests using a multiple lane (e.g. ten) system to provide a similar source configuration. Although a few simplifying assumptions are made (e.g. three stability conditions instead of five), they should not prove detrimental to the overall results. The model, which is a basic Gaussian approach, can be employed either in the interactive or batch modes, and would, with only slight alterations, provide an excellent model for estimating maximum concentration from area and trench source "incidents." It would require more effort to employ HIWAY-2 in currently existing models, such as the Science Associates study, than to employ general approaches such as the Air Transport Model, principally due to assumed initial conditions, such as the immediate mixing of a pollutant due to traffic, and the removal of other traffic-specific parameters. In common with each of the models cited above, the vertical spreading of the plume is assumed to be Gaussian. Depletion due to fallout, washout and deposition is not treated.

12. PAL

A model specifically tailored to landfill applications would best approximate the conditions encountered in LLW problems. However, a discussion with the Environmental Protection Agency* indicated that no formal model is now employed specifically for landfills but they use the

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*Irwin, J. S., Private communication, Environmental Sciences Research Laboratory, EPA, Research Triangle Park, NC, July 30, 1982.

algorithm Point Area Line source (PAL) (Ref. 27). PAL was designed to address problems most often encountered in urban areas such as industrial complexes, sports stadiums, parking lots, shopping areas and airports. The section dealing with area sources consists of a series of line sources (similar to HIWAY-2), and uses the standard Gaussian P-G curves. PAL was designed specifically "to assess the impact on air quality, on the scale of tens to hundreds of meters." In addition to point and area sources, it provides for "special curved path, special line and curved path" source configurations ("special" in these cases means variable with distance). Of the Gaussian approaches examined and available under UNAMAP, this algorithm is the most directly applicable to low level waste sites; however, as in HIWAY-2, deposition and wind erosion subroutines are not included.

13. A NON GAUSSIAN APPROACH

The models described above all employ a basic Gaussian approach using some form of estimate of dispersion coefficient known collectively as the "Pasquill - Gifford" (P G) curves. In the Air Transport Model, these and other sets of curves are entered as "data sets" to be interrogated by the computer for appropriate distances and weather conditions. By employing data sets, a theoretical model for vertical dispersion described by J. D. Wilson (Ref. 28) as a "Trajectory - Simulation Model" (a misnomer in this context) may be generated with considerable ease in the large computers in use today. The principle advantage of this approach is the tabulation given for plane and line sources in Wilson's paper. Thus area or line sources may be modeled directly without resorting to virtual point, multiple point or line source algorithms. The fetch across the area source could be as small as ten meters to as large as ten kilometers (neutral conditions). The vertical dispersion coefficients, derived theoretically, agree very well with the presently used P-G curves. The models cited above which employ a Gaussian formulation of line and area sources would profit by replacing their present algorithm with some version of the "Trajectory-Simulation" model. This would represent a "state of the art" improvement.

14. SOME RESERVATIONS

There are some common features of the models discussed here that generate some doubt as to their applicability in a situation of major interest, namely trace gas leakage at ground level and dispersion over distances less than 100 meters. The first feature of concern is the common use of dispersion routines and stability classification schemes indicative of transport at levels above the surface boundary layer, (SBL), rather than in it. The surface boundary layer is the lowest layer of the atmosphere, which responds to local variations of surface texture and thermal characteristics. It is the lower part of the more familiar mixed layer, and constitutes a layer typically less than 100 m thick in which fluxes are usually taken to be constant with height.

In usual dispersion model applications, stack heights (or plume rise) are such that emissions are injected (or quickly rise) above the surface boundary layer. Dispersion models that ignore its presence are therefore usually adequate. However the present interest in slow, surface emissions reverses the usual emphasis. In this case, surface boundary layer physics are likely to be especially important. The model of Wilson (Ref. 28) is especially attractive because it is based upon SBL formulations for near-source behavior.

A second concern results from the intent of the models to address the dispersion of particles. In fact, much current interest is in trace gas emissions, especially of tritiated water vapor. Water vapor is the most common trace gas in the atmosphere, usually present in concentrations a hundred times those of carbon dioxide. The surface is both an active source and sink.

Emissions of tritiated or deuterated water vapor will enter the natural water cycle almost immediately. They will be carried with natural water as it is deposited at night (via dewfall and condensation) and is evaporated and transpired in daytime. Surface emissions of D_2O (for example) will be immediately diluted and mixed with the carrier H_2O in the air. The gas will be exchanged between the air and the surface as water is exhanged, with no known evidence to suggest a strong fractionation. In simple terms, the situation will be similar to emitting a perfect tracer material, non-sedimenting and non-buoyant, but with a large turbulent deposition velocity. The surface deposition of this material will depend on surface biological factors and dewfall rates that are not considered in any of the models considered above, yet all of these matters are well understood by those familiar with these particular specialities.

These reservations must be considered for short time-scale problems, particularly so if experiments are proposed or evaluated. "Modeling" in this context is very different from the procedures dependent on the central limit theorem as Gaussian models are. Models, to be valid in the shorter time and distance scales, will increasingly be addressed to specific pollutants and/or locations with the physics of the problem dominating the computational efforts.

15. SUMMARY AND RECOMMENDATIONS

The meteorological content of several models commissioned by the Nuclear Regulatory Commission for the study of containment of Low-Level Wastes has been examined. The models are of the Gaussian type formulation for air concentration, but vary in their employment of methods to determine the wind erosion of particles. The wind erosion equations employed are especially varied in their applicability, and often seem to be of the same order of resolution as the model itself. In July 1983, as part of their National Resources Inventory, the U.S. Department of Agriculture (USDA) intends to have published average wind erosion data on a county basis for the entire United States*, the data to be updated every five years. Monthly wind erosion data is currently available for the ten great plains states for the months of November through May from the USDA. This data, based on observation and supplemented by more current wind erosion modeling

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*Elliot-Taylor, S., Personal Communication, Soil Conservation Service, U. S. Department of Agriculture, August 2, 1982.

techniques, should supplement and, in the absence of detailed soil information, substitute for the wind erosion algorithms employed in the site-selection modeling process.

Comments on the uncertainties of the Gaussian approach may be supplemented by several reviews of various air transport models (Ref. 29), (Ref. 30), (Ref. 31); these also serve to acquaint the researcher with additional codes and models not commonly referenced in the open literature.

All of the models would profit from an ability to treat surface line and area sources in a more realistic manner. The on-site and boundary line concentrations are best evaluated currently by some application of ATM or HIWAY-2, or PAL. We would recommend, however, that a more fundamental approach to area and line sources configuration be employed. The "Trajectory-Simulation" model of Wilson (Ref. 28) can readily replace the area and line source approximations of present models, and is quite well suited to models which employ multiple source configurations such as the ATM or PAL. Wilson's model fills the void between the source and the first one hundred meters - a region wherein the P-G curves have been heretofore estimated. Beyond one hundred meters, Wilson's curves are similar enough to the P-G models that current Gaussian methods may be employed with only slight changes in calculated concentrations.

The progression of a low-level waste disposal site from a series of trenches to a vegetative area over a time span of a century represents a challenge to meteorological modeling which has not yet been fully addressed. Off-gassing of tritium, for example, presents a problem since the stomatal resistance of vegetative surroundings changes with time. Deposition velocities become quite high (five to ten cm s^{-1}, occasionally twenty cm s^{-1} or higher) compared to the deposition of passive substances. Mathematical models employed in unique situations should be capable of addressing local surface boundary scaling problems in a realistic manner. Heretofore this has been addressed as a research problem on a rather isolated basis, but a significant advance in physically realistic, yet routine modeling of small area sources is now possible. The meteorological information required from on-site instrumentation would be no more than is currently recommended for deployment over low-level waste areas. Therefore no additional expenses will be incurred in future data handling or instrument maintenance.

The physical behavior of soils requires a great deal of study beyond our present knowledge. Gillette* has cited several broad areas of research fundamental to the advanced studies of resuspension. First, where wind speeds are of a gusty nature, the soil is non-homogeneous or where the fetch of otherwise erodable material is too small to provide a steady saltation rate, our present equations are inapplicable. Second, soil physics *per se* must be included as a discipline to determine the movement and breakage of soil particles, particularly when foreign material is introduced by deposition, spillage, etc. The problems are difficult, particularly since the time scales occur over months and years. No comprehensive model is likely to be forthcoming soon, however, since Gillette estimates the current U.S. efforts on wind erosion are being studied by

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*Personal communication with Gillette, May 1983.

less than six researchers. The model and the ensuing evaluation of results therefrom should reflect this lack of certainty in an appropriate manner, e.g., the operating manuals, and/or statements in the printed results.

An updated model could be made to function in several modes ranging from interactive for addressing emergency or "worst case" conditions to climatological, (week, year, decade). The Air Transport Model, modified by the data set supplied by J. D. Wilson, would provide a fundamentally sound meteorological model of low-level waste sites capable of calculating concentrations or dosages. PAL modified in a similar manner would also be suitable, but additonal modification for wind erosion and deposition would be required.

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16. ABSTRACT *(200 words or less)*

Several mathematical models of the meteorological aspects of effluent releases have been examined for relevance to Low Level Waste disposal programs. The principle models, by Dames and Moore, Inc., Science Applications, Inc., Argonne National Laboratory, and Oak Ridge National Laboratory, contain provisions for various combinations of wind erosion, area, and point source configurations as well as deposition and elevated releases. Methods employed by these models are compared for relevance, availability of supporting data and potential benefit versus cost.

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