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Diffusion Rates for Elevated Releases

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Pacific Northwest Laboratory
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ABSTRACT

A search of the literature related to diffusion from elevated sources has determined that an adequate data base exists for use in developing parameterizations for estimating diffusion rates for material released from free standing stacks at nuclear power plants. A review of published data analyses indicates that a new parameterization of horizontal diffusion rates specifically for elevated releases is not likely to significantly change the magnitudes of horizontal diffusion coefficients on the average. However, the uncertainties associated with horizontal diffusion coefficient estimates under any given set of atmospheric conditions could be reduced by a new parameterization. Similarly, a new parameterization of vertical diffusion rates would be unlikely to significantly alter the magnitudes of diffusion coefficients for unstable atmospheric conditions. However, for neutral and stable atmospheric conditions, a new parameterization of vertical diffusion rates might increase vertical diffusion coefficients significantly. The increase would move ground-level time-integrated concentration maxima closer to the plant and would increase the maxima.

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INTRODUCTION

The continuous-source Gaussian plume diffusion model is a practical choice for use in evaluating the consequences of potential and actual releases from nuclear power plants because of its simplicity and flexibility. The basic model is given by

$$x(x,y,z) = \frac{Q'}{2\pi U \sigma_y \sigma_z} \exp\left\{-\frac{1}{2}\left[\left(\frac{y}{\sigma_y}\right)^2 + \left(\frac{z - h_e}{\sigma_z}\right)^2\right]\right\} \quad (1)$$

where $x(x,y,z)$ is the concentration at a point (x,y,z) , Q' is the rate at which material is released, U is the mean wind speed, h_e is the effective release height, and σ_y and σ_z are the diffusion coefficients, which are usually given as functions of atmospheric stability and distance from the source. The center line of the plume lies along the x -axis. From this starting point models have been developed for a variety of special applications including estimation of annual average concentrations and estimation of concentrations during trapping (fumigation) conditions.

The wind speed can be measured, and the effective release height can be estimated from the meteorological conditions at the release point, the release characteristics and terrain. The remaining parameters required by these models are the diffusion coefficients. Unlike the wind speed and effective release height, which are essentially point values, the diffusion coefficients are integral values that represent the atmospheric conditions within the plume between the source and the receptor. Specifically, the diffusion coefficients are related to atmospheric turbulence. A general formulation for diffusion coefficients can be written as:

$$\sigma(x) = \sigma_0 + \int_0^x i(x) s(x) dx \quad (2)$$

where σ_0 is related to the initial source dimension, $i(x)$ is a turbulence intensity and $s(x)$ is a function that describes the effectiveness of the turbulence in diffusion. At large distances from the source, σ_0 may be neglected if the initial source dimensions are small. Under this condition, the source may be considered to be a point source.

Historically, most diffusion coefficients have been determined from data obtained in experiments using ground-level sources and receptors. These diffusion coefficients have been applied to evaluation of concentrations from both ground-level and elevated releases, even though the turbulence characteristics of the atmosphere are known to vary as a function of the height above ground.

Diffusion data are available for experiments using elevated release points. The objectives of this study are:

- 1) to identify existing data sets that may be used to evaluate diffusion rates for elevated releases,
- 2) to review existing analyses of these data to determine if there appear to be significant differences in diffusion rates for ground-level and elevated releases,
- 3) to evaluate the adequacy of the elevated release data for developing new diffusion coefficient parameterizations for use with elevated releases, and
- 4) to recommend a course of action for the NRC staff with respect to the development and incorporation of elevated release diffusion coefficients in guidance to applicants and licensees.

The next section describes the data base that is available for use in evaluating the diffusion rates for elevated release. Sources of data include experiments in which the releases were made for the specific purpose of obtaining diffusion data and experiments that made use of existing releases. A synopsis of the results of these experiments is presented after the available data sets are described. The final section of the report discusses the adequacy of the data for developing new diffusion parameterizations and contains recommendations related to the development of new parameterizations.

ELEVATED RELEASE DIFFUSION RATE DATA BASE

Elevated release diffusion experiments have been conducted at many locations using a wide variety of tracers and techniques for data collection. As a result, the experiments could be classified in many ways. However, as the number of classes increases, the number of tests in each class decreases and differentiation between the effects of natural random variations and true differences in mean diffusion rates becomes difficult.

For the present purposes, the elevated diffusion data base is divided into just two classes. The first class contains those experiments that correspond most closely to the diffusion tests used to develop diffusion rates for ground-level releases. Typically, these experiments involve point sources, carefully selected tracers, sampling locations and test conditions, and detailed supporting meteorological measurements. The experiments in this class will be referred to as the conventional elevated release diffusion experiments. The second class contains experiments conducted under conditions that are less ideal. Typically, experiments in this class make use of sources of opportunity, which may be too large to be considered point sources for close-in measurements. The experiments in this class will be referred to as the in situ experiments.

Comparing characteristics of the experiments in the two classes further, the conventional experiments are likely to have more ground-level concentration measurements than the in situ experiments, and are more likely to have been conducted in relatively simple topographic settings. A relatively large number of the in situ experiments have been conducted in valleys, near coasts and in other complex topographic settings. Perhaps as a result of complex terrain settings, the in situ experiments have tended to make more extensive use of techniques, such as aircraft sampling and LIDAR, to sample the elevated plume directly.

The remainder of this section describes the available elevated release data base. The conventional elevated release diffusion experiments are described first and in somewhat more detail than the in situ experiments.

CONVENTIONAL ELEVATED RELEASE DIFFUSION EXPERIMENTS

Elevated release diffusion experiments at 14 locations have tentatively been placed in the conventional experiment category. These experiments are listed in Table 1 by location. The experiments at Porton, Brookhaven, Idaho Falls, Harwell and 16 early experiments at Hanford are described by Islitzer and Slade (1968). Stewart's (1968a and 1968b) experiments in Canada were similar to the Porton Experiments. The experiments at Karlsruhe and Julich followed the general design of the Idaho Falls and Hanford experiments, but were conducted over terrain with more relief and larger surface roughness elements. Of the more recent experiments, the Danish experiments of Gryning and Lyck (1980) are most similar to the early conventional experiments.

TABLE 1. Conventional Elevated Releases Diffusion Studies

Location	Number	Heights (m)	Duration (min)	Distances (km)	Stability	References
Hanford, WA	167	7-111	30-60	0.1-12.8	all	Barad and Shorr 1954; Hilst 1957; Hilst and Simpson 1958; Elderkin, Powell and Nickola 1974; Nickola 1977; Doran, Horst and Nickola 1978; Nickola 1979
Julich, Germany	44	50, 100	60	to 11.0	N	Vogt and Geiss 1974
Karlsruhe, Germany	33	60, 100	20-120	0.1-50.0	N	Thomas et al. 1976; Thomas and Nester 1976
Brookhaven, NY		108	30-90		all	Smith 1956; Singer and Smith 1966
Idaho Falls, ID	16	46	30	0.1-3.2	U	Islitzer 1961
Porton, UK	19	150	30	0.03-0.15	S-U	Hay and Pasquill 1957
Canada	7	18-92	4-42		U-S	Stewart 1968a and 1968b
Riso, Denmark	5	60	60	5.0	N	Gryning and Lyck 1980
Copenhagen, Denmark	10	115	60	2.0-6.0	N-U	Gryning and Lyck 1981
Harwell, UK		68	60	0.15-10.0	all	Stewart, Gale and Crooks 1958

Experiments completed or planned for which data are not yet available

Mountain Home, ID 18 releases from 30 to 70 m elevation, ERA funded study

Idaho Falls, ID NRC funded study for model validation 1981

Lake Michigan NRC funded study for model validation 1982

Four Corners to be conducted by NOAA in 1983.

Four sets of experiments are listed at the bottom of Table 1. The data from these experiments are not readily available at this time, but should become available in the near future.

The Hanford, Julich and Karlsruhe data sets are described in the following paragraphs. The remainder of the large data sets, Brookhaven and Idaho Falls, are adequately described by Islitzer and Slade (1968).

The Hanford Experiments

The largest single set of elevated release diffusion experiments was conducted at Hanford, Washington from 1963 through 1973. These experiments involved the release of a variety of tracers including ZnS, flouroscein, rhodamine dye and krypton-85 from heights ranging between 7 and 111 m above ground. The releases were generally 30 minutes in duration. Concentration measurements were made at a height of 1.5 m at distances to 12.8 km and at several levels on towers to a distance of 3.2 km. The diffusion and supporting meteorological data for the experiments from 1967 through 1973 have been published by Nickola (1977); the data for the earlier experiments are being prepared for publication in the near future.

During the Hanford experiments, an effort was made to collect diffusion data for the full range of atmospheric conditions. Table 2 shows the distribution of releases by release height and time-of-day. Time-of-day gives a general indication of atmospheric stability. Many of these releases were made in multiple release experiments in which simultaneous releases were made at two or more elevations.

TABLE 2. Distribution of the Elevated Releases at Hanford by Release Height and Time-of-Day.

<u>Time</u>	<u>7 m</u>	<u>26 m</u>	<u>56 m</u>	<u>111 m</u>
0000-0159		17	25	9
0200-0359	11	8	8	3
0400-0559	7	8		
0600-0759	1			
0800-0959	1	4	5	
1000-1159		12	15	1
1200-1359		5	10	
1400-1559		2	8	
1600-1759		1		
1800-1959				
2000-2159				
2200-2359		1		

The supporting meteorological data available for the Hanford experiments include complete surface weather observations, wind and temperature profiles from the surface to 125 m, and additional turbulence data in the lowest 20 m of the atmosphere.

The Julich Experiments

The second largest set of elevated diffusion experiments was conducted at the Julich Nuclear Research Center in the Federal Republic of Germany (Vogt and Geiss 1974). The Julich Nuclear Research Center is located in the north-western portion of the country, near the border between the Federal Republic of Germany and Holland. The vicinity of the Center consists of woodlands with foliated trees and conifers and arable land and pastures. As a result, the surface roughness is significantly larger than that found at Hanford.

The tracer releases were made at the 50 and 100 m levels of a meteorological tower using copper sulfate tagged with copper-64 dispensed in solution through atomizers. The resulting aerosol was less than 5 microns in size. Release durations were generally one hour. Ground-level samples were collected at 100 locations on a sampling grid that extended to a distance of about 11 km from the release point. Of the 44 releases, 28 were made from the 50 m level of the tower, and the remaining 16 were made from 100 m. Meteorological conditions for the releases tended to be neutral to slightly unstable although some experiments were conducted in moderately stable and moderately unstable conditions. The general atmospheric stability was estimated using the scheme proposed by Pasquill (1961). Meteorological data are available for determination of diffusion coefficients using other parameterizations.

The Karlsruhe Experiments

Thomas et al. (1976) and Thomas and Nester (1976) describe 25 diffusion experiments conducted at the Karlsruhe Nuclear Research Center up to 1974. The experiments consisted of releases of tritiated water vapor and halogenated hydrocarbons from a 100 m stack. Ground-level concentration measurements were made at distances from approximately 0.1 to 5 km from the stack. Thomas et al. (1976) indicate that an additional 8 experiments with releases at 60 m have been conducted and that future experiments might include releases from elevations up to 200 m.

The terrain in the vicinity of the Karlsruhe Nuclear Research Center is generally flat, but the site is covered with buildings and trees. As a result, the roughness length, z_0 , reported for the Karlsruhe site is about 1.1 m. This is significantly larger than values of 0.03 and 0.01 m reported for the Hanford and Idaho Falls Sites, respectively.

The Karlsruhe experiments were conducted during the day. Most of the data were collected during neutral atmospheric conditions. However, one of the experiments was conducted in slightly stable conditions, and six were conducted in slightly to extremely unstable conditions based on Pasquill's (1961) stability classification scheme. Again, complete meteorological data are available for use in developing new parameterizations for elevated release diffusion rates.

IN SITU ELEVATED RELEASE DIFFUSION EXPERIMENTS

The in situ elevated diffusion experiments can be subdivided in almost as many ways as there are experiments. One of the most useful subdivisions is the group of experiments that have used LIDAR to observe the characteristics of the elevated plumes. Seven of these experiments are listed in Table 3.

TABLE 3. LIDAR Plume Studies

<u>Location</u>	<u>Height (m)</u>	<u>Distances (km)</u>	<u>References</u>
Keystone, PA	245	2.0-21.0	Johnson 1969; Johnson and Uthe 1971
Ostiglia, Italy	120	1.0	Bacci, Elisei and Longhetto 1974
Sacramento, CA			Uthe and Johnson 1976
Alberta, Canada		0.2-2.0	Hoff and Froude 1979
St. Louis, MO		to 130	Uthe and Wilson 1979
Cumberland, TN	305	35	Uthe, Ludwig and Pooler 1980
Nanticoke, Canada	200	to 40	Hoff et al. 1982

The two-dimensional, vertical cross-sections of plumes that can be obtained with LIDAR can be used to estimate both the horizontal and vertical diffusion coefficients. The LIDAR experiments are particularly valuable because LIDAR is a measurement technique that is capable of giving reliable, quantitative information on vertical diffusion coefficients at distances of more than a few hundred meters from the source. Other techniques for measuring vertical concentration profiles are generally limited in usefulness to the immediate vicinity of the source.

Useful data appear to have been collected in the studies listed above, but only limited analyses of the data have been published. As a result, estimates of vertical diffusion coefficients must be made indirectly from ground-level concentration measurements and diffusion models. The cost of reduction and analysis of LIDAR data may be the reason for the small amount of quantitative data in the open literature.

A large number of in situ elevated source diffusion experiments are described in the open literature. Table 4 lists a number of the studies by location. Most of the plumes in these studies are from stacks with flow rates that are much larger than the flows from free-standing stacks at nuclear power plants. As a result, the data from these studies need to be corrected for

TABLE 4. Other In Situ Elevated Release Experiments

Location	Height (m)	Distances (km)	References
Brookhaven, NY	108	to 300	Peterson 1968; Brown, Cohen and Smith 1972
Canada	160		Whaley 1974
Huntington Canyon, UT	183	10	Start, Dickson and Wendell 1975
Trail, British Columbia	87-122	2-12	Whaley and Lee 1977
Athabasca River Valley, Alberta	76-106	2-25	Whaley and Lee 1978
Widows Creek, AL	83-305	3.2	Hanna 1980
Pincher Creek, Alberta		0.5-20	Whaley, Lee and Gainer 1980
Tilbury, UK	100		Moore 1974
Various		4-200	Gifford 1980

initial plume dimensions before being used to estimate diffusion coefficients near the release point. This correction should include compensation for growth of the plume due to entrainment of ambient air during the initial phase of plume rise as well as for the dimension of stack from which the plume was released. Unfortunately, a correction of the sort required is also a potential source of error in estimating diffusion rates.

SYNDPSIS OF THE CONVENTIONAL ELEVATED RELEASE DATA

This section summarizes the data available for estimating horizontal and vertical diffusion rates for elevated releases. Estimates of the elevated diffusion rates are also compared with diffusion rates for ground-level releases under similar atmospheric conditions.

HORIZONTAL DIFFUSION RATES

Horizontal diffusion coefficient parameterizations are generally a power law function of distance, i.e.

$$\sigma_y(x) = ax^b \quad (3)$$

where x is the downwind distance and a and b may be functions of stability. Equation (3) follows from (2) when the intensity of turbulence is assumed to be independent of x and $s(x)$ is assumed to have the form

$$s(x) = c\left(\frac{x}{x_0}\right)^\alpha \quad (4)$$

where c is a constant with a value of about one, x_0 is a reference distance that can be a unit distance such as 1 m, and the exponent α has a value of about -0.1. This parameterization has been used for both ground-level and elevated releases.

A common variation of (3) involves the use of measured wind direction fluctuations directly in the leading coefficient rather than estimating the coefficient indirectly through a stability classification scheme. In this case (3) becomes

$$\sigma_y(x) = a^*\sigma_\theta x^b \quad (5)$$

where a^* is a constant and σ_θ is the standard deviation of the horizontal wind direction fluctuations. In this case, the exponent b is generally not a function of stability. This variation of (3) is justified because when σ_θ is expressed in radians, it is a good approximation of the lateral intensity of turbulence.

Elevated diffusion data for Hanford (Doran, Horst and Nickola 1978) and the National Reactor Testing Station (NRTS) at Idaho Falls (Islitzer 1961) have been summarized using (5). When a value of σ_θ is supplied, horizontal diffusion coefficients estimated with this relationship can be compared with those estimated from (3).

Figure 1 compares the horizontal diffusion coefficient curves for Hanford, NRTS, Brookhaven, Julich and Karlsruhe elevated diffusion data with the corresponding curves used by the NRC to estimate diffusion coefficients for ground-level releases. The NRC curves have been attributed to Eimutis and Konicek (1972) and are currently used in the MESODIF-II (Powell, Fox and Wegley 1979), PAVAN (Bander 1982), and XOQDOQ (Sagendorf, Goll and Sandusky 1982) models. The values of σ_0 given for Stability Classes B, D, and F in Regulatory Guide 1.23 (USNRC 1974) have been used to reduce the Hanford and NRTS relationships to the form of (3). Brookhaven diffusion classes B₁, C and D have been assumed to correspond to the NRC B, D and F stability classes, respectively.

During unstable conditions (Class B), the parameterizations are within a factor of two of one another for distances from 100 to 10⁵ m.

The spread of the relationships for diffusion coefficients in neutral atmospheric conditions (Class D) is somewhat larger than for unstable conditions, but all curves still lie within a factor of two of the center of the band. The Karlsruhe tritiated water (HTO) curve departs significantly from the others. The flat slope of the curve suggests that the plumes may have had relatively large initial plume dimensions that have not been taken into account properly. The diffusion coefficients measured by Gryning and Lyck (1980) for distances of 5x10³ and 10⁴ m fall within the envelope of the curves that are shown.

With the exception of the Julich relationship, the horizontal diffusion coefficient curves for stable atmospheric conditions (Class F) are within a factor of two of an average value. The departure of the Julich relationship from the others for stable atmospheric conditions is marked. Thomas et al. (1976) and Thomas and Nester (1976) do not report any data for Karlsruhe for Class F conditions, but their data for Class E conditions tend to support the larger diffusion rates reported for the Julich data. It should be noted that the Julich and Karlsruhe data sets for stable atmospheric conditions are small.

No consistent pattern that can be attributed to release height is apparent in comparing these curves for the full range of atmospheric conditions. The NRC relationships are included to provide a reference for evaluating the other relationships. The Hanford, NRTS and Brookhaven curves, which are directly related to atmospheric turbulence, give diffusion coefficient estimates that are near those obtained with the corresponding NRC relationships.

Surface roughness is not considered explicitly in estimating diffusion coefficients, but mechanical turbulence generated by wind passing over the surface roughness elements does affect the measured direction fluctuations. As a result, the schemes using wind direction fluctuations implicitly include consideration of surface roughness. Thus, the Brookhaven curves are relatively consistent with those from Hanford and NRTS even though there are significant differences in surface roughness between the sites.

The method of classifying atmospheric conditions used with the Julich and Karlsruhe data sets does not use turbulence data directly. Rather, it uses

FIGURE 1. Comparison of Horizontal Diffusion Coefficient Curves for Elevated Releases

synoptic meteorological information and a general classification scheme developed by Pasquill (1961) and Gifford (1961). Had the wind direction fluctuation data in the Julich and Karlsruhe data sets (Vogt and Geiss 1974, Thomas et al. 1976 and Thomas and Nester 1976) been used to determine the diffusion conditions, the classes for the individual releases would have tended to be less stable. For example, the conditions for 22 release periods at Julich were classified as D on the basis of the synoptic classification scheme. If classification had been on the basis of wind direction fluctuations at the release height and the class definitions in Regulatory Guide 1.23 (USNRC 1974), the stability class for three of these experiments would have been D; the remaining 19 experiments would have been classified as C.

The analysis of the Hanford data by Doran, Horst and Nickola (1978) provides further support for the conclusion that the release height has little, if any, effect on horizontal diffusion. They found that the errors in estimating horizontal diffusion coefficients for releases from heights of 26 and 56 m were smaller on the average when low level wind direction fluctuations were used to make the estimates than when release height wind direction fluctuations were used.

VERTICAL DIFFUSION RATES

The estimation of vertical diffusion rates from experimental data is more complicated than the estimation of horizontal diffusion coefficients. In general, the cost of obtaining a sufficient number of elevated samples within plumes to compute the vertical diffusion coefficients directly is prohibitive. As a result, the vertical diffusion coefficients are usually estimated indirectly using concentration measurements made near ground-level, computed horizontal diffusion coefficients, and diffusion models. Errors in the diffusion model, horizontal diffusion coefficients and concentration measurements lead to errors in the vertical diffusion coefficient estimates. Thus, more uncertainty exists in vertical diffusion rate estimates than is found in the estimates of horizontal diffusion rates. This uncertainty increases the difficulty in identifying any effects that release height might have on vertical diffusion rates.

The NRC uses a parameterization attributed to Eimutis and Konicek (1972) that is similar to (3) for estimating vertical diffusion coefficients in its diffusion models. The parameterization is

$$\sigma_z(x) = ax^b + c \quad (6)$$

where a , b and c are functions of stability. The values of a and b for (6) are different than those for (3). The additive constant, c , is needed to match segments of the model for three different distance ranges. The coefficients and exponents for the parameterization were selected using ground-level release diffusion data. For releases in stable conditions and for short distances, the values are based, in part, on actual measurements of the vertical diffusion

coefficients. In general, however, the values for the coefficients and exponents are based on vertical diffusion coefficients estimated indirectly using models. The vertical temperature gradient is the NRC's primary method for classifying atmospheric conditions for selecting the coefficients and exponents for the relationships.

Power law relationships identical to (3) that are functions of distance only have been used to summarize the Brookhaven, Julich and Karlsruhe vertical diffusion coefficient estimates. As in the case of the horizontal diffusion coefficients for Julich and Karlsruhe, the classification of atmospheric conditions for selecting the coefficients and exponents for the relationships is on the basis of synoptic variables. Visual characteristics of the horizontal wind direction trace are used to select the coefficient and exponent values for use in the Brookhaven relationship.

Vertical diffusion rates at NRTS during unstable atmospheric conditions were summarized by Islitzer (1961) as a function of the standard deviation of the elevation angle of the wind and distance. The relationship is the same as (5), except that σ_ϕ replaces σ_θ .

Doran, Horst and Nickola (1978) do not provide a relationship to summarize the Hanford vertical diffusion coefficient estimates. However, they do provide measured vertical diffusion coefficients at 200 and 400 m for several experiments. The measured vertical diffusion coefficients compare favorably with predictions made using a theoretical model developed by Chaudhry and Meroney (1973) for ground-level releases. Data that can be used to estimate vertical diffusion coefficients for many of the Hanford elevated releases are contained in the Hanford-67 data volume (Nickola 1977).

Figure 2 compares vertical diffusion coefficient curves for the elevated releases at Brookhaven, Julich and Karlsruhe and compares them with the corresponding curves currently used by the NRC. Vertical diffusion coefficient estimates for Hanford and from the Riso experiments of Gryning and Lyck (1980) are shown with the neutral and unstable curves.

With the exception of the Karlsruhe relationship, the curves for unstable conditions (Class B) provide vertical diffusion coefficient estimates that cover a range of less than a factor of two. The Julich estimates are larger than the NRC estimates based on ground-level data, but the Brookhaven curve estimates vertical diffusion coefficients that are about the same as those estimated by the NRC curve.

For neutral atmospheric conditions (Class D), there is a definite separation in the estimates. The Brookhaven, Julich and Karlsruhe curves estimate vertical diffusion coefficients that range from about a factor of 1.5 higher than the NRC estimates to almost an order of magnitude higher. The Julich estimates are largest, and the Brookhaven estimates are closest to the NRC estimates. Measured vertical diffusion coefficients at 200 and 400 m for 26 and 56 m releases at Hanford tend to fall between estimates made using the Brookhaven and NRC curves. Estimates of vertical diffusion coefficients at about 5×10^3 m made by Gryning and Lyck (1980) range from a low that corresponds

FIGURE 2. Comparison of Vertical Diffusion Coefficient Curves for Elevated Releases

with estimates made with the NRC curves to a high that corresponds with estimates made using the Julich and Karlsruhe curves.

For stable atmospheric conditions (Class F), the Brookhaven and NRC curves give similar vertical diffusion coefficient estimates. These estimates are significantly smaller than those derived from the Julich curves and measured coefficients at 200 and 400 m at Hanford.

Comparing the curves and data over the full range of atmospheric conditions, the potential differences between diffusion coefficients for elevated releases and those for ground-level releases appear to be least for unstable conditions and increase with increasing atmospheric stability. This trend is in the proper direction to be an effect of release height, but the comparison is not conclusive. Other factors that could contribute to the differences include: variations in the methods of determining and classifying atmospheric conditions, differences in topography, and differences in the models used to estimate the vertical diffusion coefficients from the available data.

By comparing crosswind-integrated concentrations for simultaneous releases at different heights, Nickola (1979) provides evidence that the effects of release height on diffusion are more than can be accounted for by differences in the wind speed with increasing elevation. Nickola (1979) also shows that peak ground-level concentrations downwind of elevated releases occur closer to the source than would be expected using vertical diffusion coefficients developed from ground-level releases. This difference can be partially explained if vertical diffusion for elevated releases occurs at a faster rate than for ground-level releases.

The conventional elevated release data base is sufficient that a consistent analysis of the available data might result in a clearer understanding of the effects of release height on vertical diffusion. The data most likely to yield usable results are those collected in experiments with simultaneous releases from two or more elevations. In order to obtain conclusive results from analysis of data from experiments run at different locations at different times, it will be necessary to resolve differences between the experiments related to surface conditions and characterization of the atmosphere.

CONCLUSIONS AND RECOMMENDATIONS

Evaluation of the data base identified in a literature search and consideration of the uses of diffusion coefficients in the evaluation of routine and accidental releases of radioactive effluents from nuclear power plants leads to the following conclusions and recommendations:

CONCLUSIONS

The data base available for use in parameterizing diffusion rates for elevated releases from nuclear power plant stacks is probably larger than the data base that was used in the initial development of the parameterizations currently used to estimate diffusion rates for ground-level releases. The data base includes measured ground-level concentrations and horizontal diffusion coefficients computed directly from the measurements for release heights between ground-level and 100 m and for distances to 10 km and beyond. Supporting meteorological data in the data base consist of wind and temperature profiles and, in many cases, turbulence measurements.

Development of parameterizations of horizontal diffusion coefficients for elevated releases is an easier task than the development of parameterizations for vertical diffusion coefficients. The primary reasons for the difference are 1) horizontal diffusion coefficients can be computed directly from the available data and 2) a generally accepted framework for the parameterization of horizontal diffusion coefficients exists. The framework is shown in (2). Parameterization of vertical diffusion coefficients for elevated releases requires selection of a framework from among several alternatives and extensive manipulation of the data to account for differences in experimental conditions.

A new parameterization of horizontal diffusion rates specifically for elevated releases is not likely to result in diffusion coefficients that are significantly different, on the average, from horizontal diffusion coefficients that are currently being estimated using parameterizations based on ground-level release data.

A new parameterization of vertical diffusion rates specifically for elevated releases may give diffusion coefficients that are larger than the coefficients now being estimated on the basis of parameterizations developed from ground-level release data. The differences between diffusion coefficients estimated with a new parameterization and current estimates are likely to be a function of atmospheric stability. Comparison of the elevated release diffusion coefficient curves with the NRC ground-level release curves indicates that the differences should be small for unstable atmospheric conditions and may approach or exceed a factor of three for stable conditions. An increase in vertical diffusion coefficient estimates of this magnitude during stable atmospheric conditions could significantly affect ground-level concentrations of material released from isolated stacks at nuclear power plants. It would

result in ground-level time-integrated concentration maxima occurring closer to the plant than with current vertical diffusion coefficient estimates, and the concentration maxima would be larger.

RECOMMENDATIONS

The development of an elevated release parameterization for vertical diffusion coefficients should receive higher priority than the development of an elevated release parameterization for horizontal diffusion coefficients. The higher priority for the vertical diffusion coefficient parameterization is justified by three considerations: 1) the changes in diffusion coefficient estimates likely to occur with a new parameterization are larger for vertical coefficients than horizontal coefficients, 2) vertical diffusion coefficients affect both the position and magnitude of peak concentrations resulting from elevated releases, and 3) vertical diffusion coefficients are needed in the evaluation of the consequences of both long-term and short-term, accidental releases.

When a parameterization is developed for vertical diffusion coefficients for elevated releases, the parameterization should be based on turbulence measurements (e.g. σ_z) or a quantity that is fundamentally related to turbulence (e.g. the ratio between the release height and the Monin-Obukhov length, or the Richardson number). Precedents exist for the use of turbulence measurements in estimating vertical diffusion coefficients (e.g. Islitzer 1961 and Singer and Smith 1966). In addition, Doran, Horst and Nickola (1978) have shown that vertical diffusion coefficients can be predicted successfully using similarity theory and the Monin-Obukhov length. The current data base is sufficient to make an attempt to develop a parameterization for elevated release vertical diffusion coefficients worthwhile.

At the time an elevated release parameterization is developed for vertical diffusion rates, consideration should be given to developing a corresponding parameterization for horizontal diffusion rates. The primary reason for upgrading the horizontal diffusion coefficient parameterization is to reduce the uncertainty in coefficient estimates used in evaluation of the consequences of accidental releases. The new parameterization should follow from (2). An American Meteorological Society workshop (Hanna et al. 1977) has recommended this approach; and Doran, Horst and Nickola (1978) and Irwin (1983) have shown that the approach reduces the scatter of diffusion coefficient estimates compared to approaches that require selection of a stability or diffusion classes as an intermediate step in estimating diffusion coefficients.

The use of stability or diffusion classes in estimating diffusion coefficients should be avoided. Their use should be limited to summarization of data for climatological purposes; current on-line data processing techniques make it possible to compute and store quantities that are fundamentally related to diffusion for use in evaluating diffusion coefficients for assessing the consequences of accidental releases. Reduction of the uncertainty in diffusion coefficient estimates provides sufficient reason to avoid the unnecessary use of these classes. In addition to the work of Doran, Horst and Nickola, which

shows the added uncertainty caused by stability classes, numerous studies have demonstrated the general inconsistencies between various methods of selecting stability classes on an hour-by-hour basis. Among these studies are: Luna and Church (1972). Skaggs and Robinson (1976). DeMarrais (1978), Lalas, Catsoulis and Petrakis (1979), Sedefian and Bennett (1979), and Mitchell (1982).

Kretzschmar and Mertens (1980) have shown that the inconsistencies that exist on an hour-by-hour basis are masked by the averaging process. Thus, the use of stability classes may be acceptable for evaluation of routine releases, even though they are undesirable in the evaluation of accidental releases.

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