MASTER

A CRITIQUE OF METHODS FOR ESTIMATING PLUME DEPLETION AND DEPOSITION OF AIRBORNE RADIONUCLIDES*

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ABSTRACT

A comparison is made between the methods for estimating plume depletion and deposition contained in *Meteorology and Atomic Energy - 1968* and the methods contained in United States Nuclear Regulatory Commission Regulatory Guide 1.111. Although Regulatory Guide 1.111 is intended only for use in determining compliance with 10 CFR 50, Appendix I requirements for light-water-cooled nuclear reactors, the methods contained in the Guide have the potential of being used for other types of nuclear facilities. Therefore, a comparison of methodologies is in order to identify any potential discrepancies. This comparison of the two approaches has highlighted three major concerns with regard to the Regulatory Guide 1.111 methods:

1. the dry deposition estimates derived from curves in the Regulatory Guide are not dependent on calculations of air concentration;
2. for elevated releases estimates of dry deposition are too large close to the source;
3. the plume depletion curves presented in the Guide are inconsistent with the results that would be expected for a surface depletion model.

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These concerns lead us to recommend that the widely used methods for estimating plume depletion and deposition contained in *Meteorology and Atomic Energy - 1968* still are preferable to Regulatory Guide 1.111 methods for use in making radiological assessments.

1. Introduction

Dry and wet deposition processes affect doses to man from atmospheric releases of radionuclides by nuclear facilities in two ways:

1. deposited material serves as a source of surface and/or food chain contamination;
2. deposition results in a reduction in the amount of material transported downwind in air through plume depletion.

The United States Nuclear Regulatory Commission (NRC) has recently published Regulatory Guide 1.111 (USNRC, 1977) which includes methods for estimating the effects of deposition in dose calculations. Although Regulatory Guide 1.111 is intended only for use in determining compliance with 10 CFR 50, Appendix I requirements for light-water-cooled nuclear reactors, the methods contained in the Guide have the potential of being used for other types of nuclear facilities. Therefore, a comparison between the Guide methods and other methods available for use in radiological assessments is in order to identify any potential discrepancies.

2. Dry Deposition

2.1 The Methods

The most common method for estimating the effects of dry deposition when calculating downwind air concentrations is the mathematical model found in *Meteorology and Atomic Energy - 1968* and often referred to as the source depletion model (Slade, 1968). The term "source depletion" refers to the original derivation of the model in which the materials lost from the plume during atmospheric transport are accounted for by effectively reducing the source strength as a function of distance. The rate of deposition onto ground or vegetation, ω , is then estimated by assuming that ω is directly proportional to the ground level air concentration, x . The proportionality constant is a deposition velocity, v_d ;

that is,

$$\omega = v_d x \quad (1)$$

The NRC approach for estimating the effects of dry deposition is based on a solution to the basic K-theory diffusion equation for an infinite crosswind-oriented line source (Markee, 1967). This model is referred to as a "surface depletion" model because material is removed only from the bottom of the plume. Regulatory Guide 1.111, however, does not contain this model. Instead, it contains two sets of curves, one set to account for plume depletion and one set to estimate the deposition rate onto ground. As an illustration, the NRC plume depletion and relative deposition curves for a release height of 100 m are given in Figs. 1 and 2, respectively.

To account for plume depletion using the NRC methods, the user calculates an air concentration which is then multiplied by the appropriate plume depletion fraction taken from the curves provided in the Guide. To estimate the deposition rate onto ground, however, the appropriate relative deposition rate from the set of curves provided is:

1. multiplied by the quantity of the released material which is blown into the sector of interest; and
2. divided by the arc length of the sector at the downwind location of interest.

2.2 Comparison of Methods

Calculations have been made to compare the output of the methods discussed above. The results of these calculations have raised a number of concerns about the methods contained in Regulatory Guide 1.111. These concerns are discussed below.

2.2.1 Air concentrations used in NRC calculations

As can be seen above, the NRC plume depletion fractions are applied to a user-calculated air concentration, but the NRC deposition estimates are calculated independently of any air concentration supplied by the user. Atmospheric dispersion is built into the NRC deposition curves, but the ground-level air concentration which is related to these curves cannot be found in Regulatory Guide 1.111. In effect, a user of these methods has one air concentration for estimating doses from contaminated

Fig. 1. NRC plume depletion effect for 100 m releases.

Fig. 2. NRC relative deposition for 100 m releases.

air and another air concentration for estimating doses from contaminated ground surfaces and food stuffs. This represents an internal inconsistency in the NRC methods in that estimates of air concentration and deposition are not related to each other.

The effect of this internal inconsistency can be illustrated by back calculating an effective air concentration using Eq. (1) and the deposition rate calculated from the NRC relative deposition curves. Shown in Fig. 3 is the result of such a calculation for a release height of 100 m made using annual average meteorology appropriate for Oak Ridge, Tennessee, U.S.A. (Hilsmeier, 1963). A value of $v_d = 7.0 \times 10^{-3}$ m/sec was used based on the values of v_d used in deriving the NRC curves (Table 1) averaged over the meteorological conditions prevailing around Oak Ridge, Tennessee. The calculated air concentrations are averaged for one 22.5° sector. Also shown is the air concentration for the same sector calculated using the Gaussian plume model as implemented by the AIRDOS-II computer code (Moore, 1977) and the NRC plume depletion curves. These results indicate that the two methods not only may give substantially different values of air concentration but also different dispersion behavior.

2.2.2 Deposition from elevated sources

A comparison of the annual average ground deposition rate for a release height of 100 m between the NRC approach and the commonly used models as implemented by AIRDOS-II is shown in Fig. 4. Annual average meteorology appropriate for Oak Ridge and a value of $v_d = 7.0 \times 10^{-3}$ m/sec were again used in making these 22.5° sector-averaged calculations. One sector is shown.

The results shown in Fig. 4 indicate that deposition rate calculated using the NRC approach seems too high near the source, since the plume has probably not yet reached the ground on an annual average basis at a downwind distance of 100 m. As a result, use of the NRC deposition curves could lead to an overestimate of ground surface exposure near the source of release. For nuclear facilities with large exclusion areas such as those generally found in the United States, such an overestimate may not be a major problem. However, for facilities with smaller exclusion areas, this large near-in surface exposure may not be so easily dismissed.

Fig. 3. Annual average air concentration estimates for Oak Ridge, Tennessee, meteorology from the NRC relative deposition and plume depletion curves for 100 m release assuming a release rate of 1 pCi/sec and a deposition velocity of 7×10^{-3} m/sec.

Table 1. Parameter values used in the generation of the relative deposition and plume depletion curves contained in NRC Regulatory Guide 1.111

Atmospheric stability category	Deposition velocity, m/sec	Height of limit to vertical mixing, m	$\bar{u}$, m/sec ^a	
			H = 0 m	H = 100 m
A, B, C	8.8×10^{-3}	1000	8	12
D	1.2×10^{-2}	1000	8	20
E, F, G	1.2×10^{-3}	200	1.2	3.5

^aValues for $\bar{u}$ taken from Markee (1967); all other values supplied by NRC staff.

Fig. 4. Annual average ground deposition rates from Oak Ridge, Tennessee, meteorology calculated by AIRDOS-II and the NRC curves assuming a release rate of 1 pCi/sec and a deposition velocity of 7×10^{-3} m/sec.

2.2.3 Plume depletion curves

One of the characteristics of the source depletion model is that the effect of deposition is instantaneously distributed throughout the entire vertical extent of the plume. This artificial enhancement of vertical dispersion is not, however, a characteristic of the seemingly more realistic surface depletion model upon which the curves contained in Regulatory Guide 1.111 are based. One would expect the best agreement between these models for unstable conditions (Pasquill categories A, B, and C) with decreasing agreement as atmospheric stability proceeds through neutral (Pasquill category D) to stable conditions (Pasquill categories E, F, and G). In addition, one would expect a surface depletion model to leave more total material airborne with increasing distance than a source depletion model since deposition is only affecting the lower portions of the plume (Horst, 1977).

A comparison between the NRC plume depletion curves and three representative curves calculated by the source depletion model as implemented by AIRDOS-II (Moore, 1977) is given in Fig. 5. The input parameters used to generate the NRC curves were also used to generate the AIRDOS-II curves (Table I). It can be seen that the best agreement between the source depletion and NRC curves is for stable conditions and the worst agreement is for unstable conditions. Also, for two out of the three cases considered, the NRC curves leave less material airborne than does the source depletion model. Both of these results are contrary to expectation. For annual average meteorology dominated by unstable conditions, this could result in the NRC curves giving a lower estimate of dose due to air exposure than the source depletion model. However, the greatest differences between the two approaches are found at large downwind distances where the results of any atmospheric dispersion model are open to serious question (Hoffman et al., 1978).

3. Wet Deposition

Regulatory Guide 1.111 recommends continued use of the washout rate concept to account for deposition and attendant plume depletion via wet deposition processes (Slade, 1968). The washout rate, λ , represents the

Fig. 5. Plume depletion fraction calculated by AIRDOS-II and the NRC curves.

fraction of particles or soluble gases removed by scavenging from a vertical column of air per unit time during rain or snow. Slinn (1978) recommends, however, the use of a wet deposition velocity, v_w , to account for precipitation scavenging,

$$v_w = w_r p_0 \quad (2)$$

where w_r = washout ratio (dimensionless),

p_0 = precipitation rate (rainwater equivalent, cm/year).

Figure 6 shows a comparison between these two methods for one 22.5° sector and a release height of 100 m as calculated by the AIRDOS-II computer code using annual average meteorology for Oak Ridge. Values of $\lambda = 3 \times 10^{-5} \text{ sec}^{-1}$ and $v_w = 0.013 \text{ m/sec}$ were used in this comparison based on precipitation data also from the Oak Ridge area (Hilsmeier, 1963). At distances less than 1 km, the washout rate approach gives higher deposition rates than does the wet deposition velocity approach. Beyond 1 km, however, differences between the results of the two methods are less than a factor of 2.

4. Validation Needs

Comparisons such as these can provide guidance for the making of scientific judgements concerning the methods involved. However, only validation studies can be used to determine the true errors associated with these or any other methods of estimating deposition and plume depletion. Studies are needed which concurrently measure the amount of deposition, the amount of plume depletion, and the parameters needed for model input for a variety of depositing materials and deposition conditions. These studies will be neither easy to carry out nor inexpensive, especially for elevated releases, but until such data become available, it is impossible to determine the true uncertainty associated with any model of the deposition-depletion process.

5. Conclusions and Recommendations

In this study results from using the dry deposition and plume depletion methods presented in NRC Regulatory Guide 1.111 have been compared with results from the models commonly used for estimating

Fig. 6. Annual average ground deposition rates for Oak Ridge, Tennessee, meteorology calculated using a washout rate, λ , and a wet deposition velocity, v_w .

deposition and plume depletion. It is not possible to assign an uncertainty to these results because of a lack of validation data. However, this comparison has raised a number of concerns about the NRC approach:

1. the dry deposition estimates derived from the curves in Regulatory Guide 1.111 are not dependent on calculations of air concentration;
2. for elevated releases estimates of dry deposition are too large close to the source;
3. the plume depletion curves presented in Regulatory Guide 1.111 are inconsistent with the results that would be expected for a surface depletion model.

The effect of these conclusions on radiological exposure estimates may be substantial, depending upon the meteorological and other parameters being considered.

A comparison was also made between the washout rate approach and the wet deposition velocity approach to estimating deposition and plume depletion effects from wet deposition processes. It was found that beyond a downwind distance of 1 km the two methods gave essentially the same deposition rates for the annual average meteorological conditions considered.

In view of the concerns noted above about the NRC methods for estimating the effects of dry deposition, it is our recommendation that the commonly used approaches be retained for use in making radiological assessments. The method to be used for estimating the effects of wet deposition will depend upon the needs of the user and the type of precipitation data available, but the commonly used method continues to seem acceptable. Until validation data become available, the continued application of the common assessment methodologies described in *Meteorology and Atomic Energy -1968* appear to be the most practicable course of action to take.

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