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A Proposed Wind Shift Model for the German Reactor Safety Study

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Abstract

Neither the U.S. nor the German Reactor Safety Study in their present form include hourly changes in wind direction. For releases of short duration this assumption should have a relatively small effect on the calculation of accident consequences. For releases of longer duration this assumption could result in an overestimation of centerline radionuclide concentrations.

To account for hourly wind direction changes, a wind shift model has been proposed. Using hourly recorded wind speed and direction data, the model modifies the angular distribution of radionuclide concentrations calculated by a straightline model, and is intended to better represent the concentrations in areas close to the reactor where potential doses might exceed the threshold level for early fatalities.

115 weather sequences were used, both with and without the proposed wind shift model, to calculate probability distributions for early fatalities. The use of the proposed model results in a reduction of the mean and peak values of that distribution by 36% and 29%, respectively.

Vorschlag für ein Modell zur Berücksichtigung von Windrichtungsänderungen in der deutschen Reaktor-Sicherheits-Studie

Kurzfassung

Weder die amerikanische noch die deutsche Reaktor-Sicherheits-Studie berücksichtigen in ihrer jetzigen Fassung Windrichtungsänderungen. Bei Freisetzungen von kurzer Dauer hat dies auch nur einen geringen Einfluß auf die berechneten Ergebnisse. Bei Freisetzungen von längerer Dauer kann dieses einfache Modell jedoch zu einer Überschätzung der Radionuklid-Konzentrationen auf der Achse der Abluftfahne führen.

Um den Einfluß der Windrichtungsänderungen zu erfassen, wird ein Modell vorgeschlagen. Auf der Grundlage der stündlich aufgezeichneten Winddaten modifiziert dieses Modell die Winkelverteilung der Radionuklid-Konzentrationen, die mithilfe eines richtungsstarren Ausbreitungsmodells berechnet wurden. Damit werden die Konzentrationen in der Nähe des Reaktors realistischer abgeschätzt, wo die potentiellen Dosen möglicherweise die Schwellendosen für Frühschäden überschreiten.

Zur Berechnung der Häufigkeitsverteilungen für Frühschäden wurden 115 Wetterabläufe durchgespielt, jeweils mit und ohne Berücksichtigung der Windrichtungsänderungen. Die Anwendung des vorgeschlagenen Modells reduziert den Mittelwert bzw. den Spitzenwert dieser Verteilung um 36% bzw. 29%.

1. Introduction

The atmospheric dispersion and transport models in both the German and U.S. /1/ Reactor Safety Studies (RSS) use sequential hourly values of thermal stability, wind speed and precipitation occurrence to account for weather variations during the progression of a postulated accident. Neither model includes hourly changes in wind direction+), however. For releases of short duration (≤ 1 hour), which are modeled in the German RSS using a single 1-hour puff, this assumption should have a relatively small effect on the calculation of accident consequences. For releases of longer duration, which are modeled by a series of up to three 1-hour puffs, the assumption could result in an overestimation of centerline concentrations. The calculation of early fatalities, which are a threshold effect, may therefore be significantly affected. To account for hourly wind direction changes, a wind shift model has been proposed for use in the German RSS consequence model. The model and its estimated effects on calculated accident consequences are detailed in this report.

+) To account for the dispersive effect of wind direction changes during releases of longer than 0.5 hours duration, the U.S. RSS included an empirically derived expansion factor for lateral (cross-wind) dispersion parameters.

2. Proposed Wind Shift Model

The wind shift model proposed here is a geometric model. Using hourly recorded wind speed and direction data, it modifies the spatial (angular) distribution of radionuclide concentrations calculated by the "straightline" atmospheric dispersion model+). The proposed model is independent of the atmospheric dispersion calculation and is intended to better represent the concentrations in areas close to the reactor (termed here the "near distance region") where potential doses might exceed the threshold level for early fatalities. Latent cancer fatalities are calculated in the German RSS using a linear dose response approximation with hourly wind direction changes.

The proposed wind shift model is shown schematically in Figure 1. As in the atmospheric dispersion model, the wind (weather) conditions at all downwind locations during any given hour are assumed to be identical to those recorded at the site during that hour. Part A of the figure vectorily presents 5 consecutive hours of assumed wind speed and direction data. Using this data, part B shows estimated trajectories for three consecutive hourly puffs that would be used to model a continuous release of 3-hour duration, the trajectories representing the centerline of the puff. Part C indicates the assumed paths of the three puffs when hourly wind direction changes are not included. Part D shows the same paths when predicted by the proposed wind shift model.

Using the data in A, the model calculates a rotation angle for each downwind radial interval within the near distance region. Outside this region, all the puffs are again assumed to travel in the original direction of the first hour's release. The calculation of the angle by which the concentration within a given interval

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+) In the German RSS consequence model the spatial distribution of the released atmospheric contaminants, normally treated using a Gaussian distribution function, is modeled with four distinct concentration steps /2/.

is rotated, is exemplified in Figure 2. In that figure the estimated trajectory (Part B of Fig. 1), the straightline model (Part C) and the wind shift model (Part D) are shown for the first puff.

This wind shift model assumes straightline dispersion within an interval and approximates the angle of the actual path by a rotation angle. For the definition of this rotation angle the following reasoning is assumed: The atmospheric dispersion model estimates radionuclide concentrations at the midpoint of each downwind radial interval+), assuming the puff follows a straightline, e.g., point A on the interval from c to d. It is assumed that in most cases the concentrations that would occur at an equal distance along the "actual" path or trajectory of the puff (point B) would be closely approximated by these estimates. In Figure 2, interval endpoints a, b, c, and d, resp. a, b', c', and d' are shown at equal distances along both the straightline path, respectively the estimated trajectory. To better represent the location of point B, a rotation angle is computed for each radial interval based on the angular location of the interval's endpoints along the estimated trajectory. For example, endpoint c' lies at angle φ to the original direction (straightline axis) and endpoint d' lies at angle $\emptyset$. The rotation angle calculated for this interval is the average of these two endpoint angles $\frac{\emptyset + \varphi}{2}$. The concentrations calculated at A are therefore rotated to C, which is closer approximation to their "actual" location at B.

It should be noted that the model proposed above is incapable of accurately treating large wind shifts ($> 90^o$), especially as they approach 180^o. However, Thomas /3/ shows that wind direction changes of this nature are very unlikely. The probability of a shift greater than 90^o within a 2-hour period is less than 10 percent, averaged over all thermal stabilities. The risk of early fatalities calculated using a large sample of weather sequences, should be little affected by this deficiency.

+) These midpoint concentrations are used to represent the radionuclide concentrations across the entire interval.

3. Calculational Procedure

Radionuclide concentrations are calculated for circular ring sectors, within which the concentration is assumed to be uniform. These circular ring sectors are defined by the downwind radial intervals and rays which approximate the $y = \gamma \cdot \sigma_y\ (r)$ curve within this interval. $\sigma_y\ (r)$ is the dispersion parameter in the horizontal (cross-wind) direction. In the German RSS, $\gamma = 0.5,\ 1.0,\ 2.0,$ and 3.0 were taken as a basis defining $1 + 2 \times 3$ areas arranged symmetrically about the centerline. This is exemplified for one puff in Figure 3.

For releases of longer duration, which are modeled by a series of up to three 1-hour puffs, the procedure has to be repeated accordingly. Because of changing weather conditions,

- shift of wind direction
- change of thermal stability category

the corresponding circular ring sectors constructed for the different puffs may not match. The resulting displacements due to wind shifts and the different size of the sectors due to changing σ_y-values define a manifold of new, generally smaller, sub-sectors. Within these new areas the concentration is again assumed to be uniform.

It is obvious that only in the case where the central sector of the different puffs define a common sub-sector, the concentration within this common sub-sector is the same as when the wind shift is neglected.

4. Effect of Wind Shift Model on Calculated Accident Consequences

Early fatalities calculated with and without the proposed wind shift model were compared using the German phase A consequence model. Calculations were performed for a core-melt accident with large containment leakage of 3-hour duration, and negligible plume rise. The near distance region was assumed to extend to 24 km, a uniform population density was assumed, and 115 weather sequences were used to calculate a probability distribution for early fatalities. The mean and peak values of that distribution were reduced by 36% and 29%, respectively, when using the wind shift model. The corresponding reductions for the combined or total (all accident categories) early fatality probability distribution would depend on the relative contribution from releases of long duration.

5. Summary and Conclusions

A wind shift model has been proposed for use in the German RSS consequence model. The model is a geometric model, and uses recorded hourly wind speed and direction data to calculate a rotation angle for the radionuclide concentrations in each downwind radial interval.

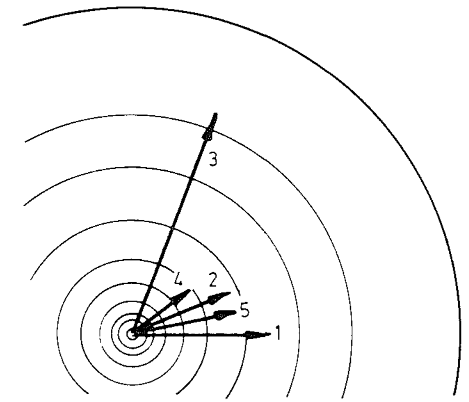
115 weather sequences were used, both with and without the proposed wind shift model, to calculate probability distributions for early fatalities in the case of a 3-hour duration release. The use of the proposed model results in a reduction of the mean and peak values of that distribution by 36% and 29% respectively.

References

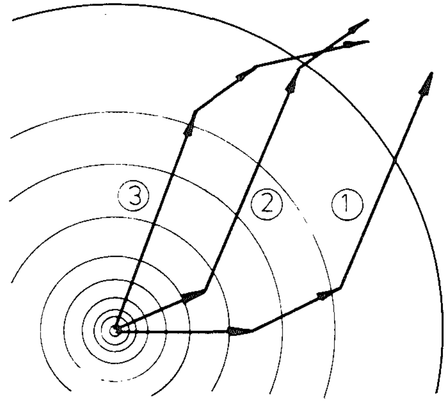
/1/ Reactor Safety Study, App. VI : Calculation of Reactor Accident Consequences,
Report WASH-1400 (1975)

/2/ D.C. Aldrich, A. Bayer, M. Schückler
Effect of Cross-Plume Concentration Model on Calculated Accident Consequences
Report KfK-2767 (1979)

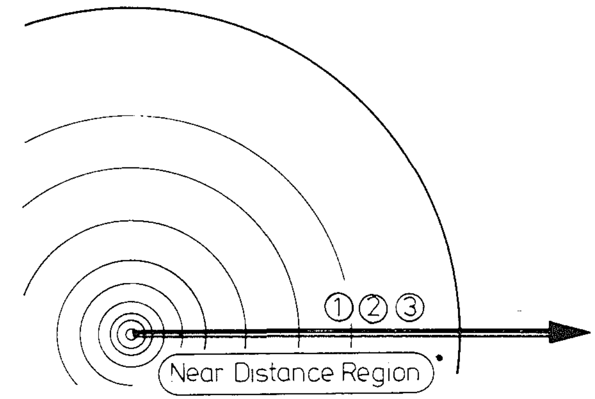
/3/ P. Thomas
Beständigkeit der atmosphärischen Ausbreitungsbedingungen in Abhängigkeit der Tageszeit
Report KfK-2214 (1975)



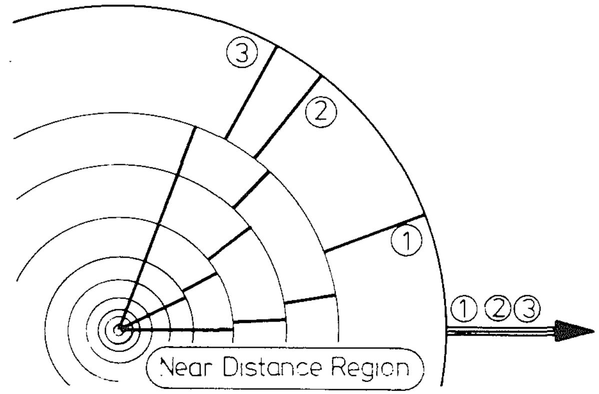
A. Hourly (1, 2, 3 . . .) Wind Speed and Direction Data



B. Estimated Trajectories of Three Consecutive 1-Hour Puffs (1), (2), and (3)



C. Straightline Atmospheric Transport Model



D. Wind Shift Model Within Near Distance Zone

Figure 1: Schematic Showing Effect of Proposed Wind Shift Model for a Release of 3 -Hour Duration

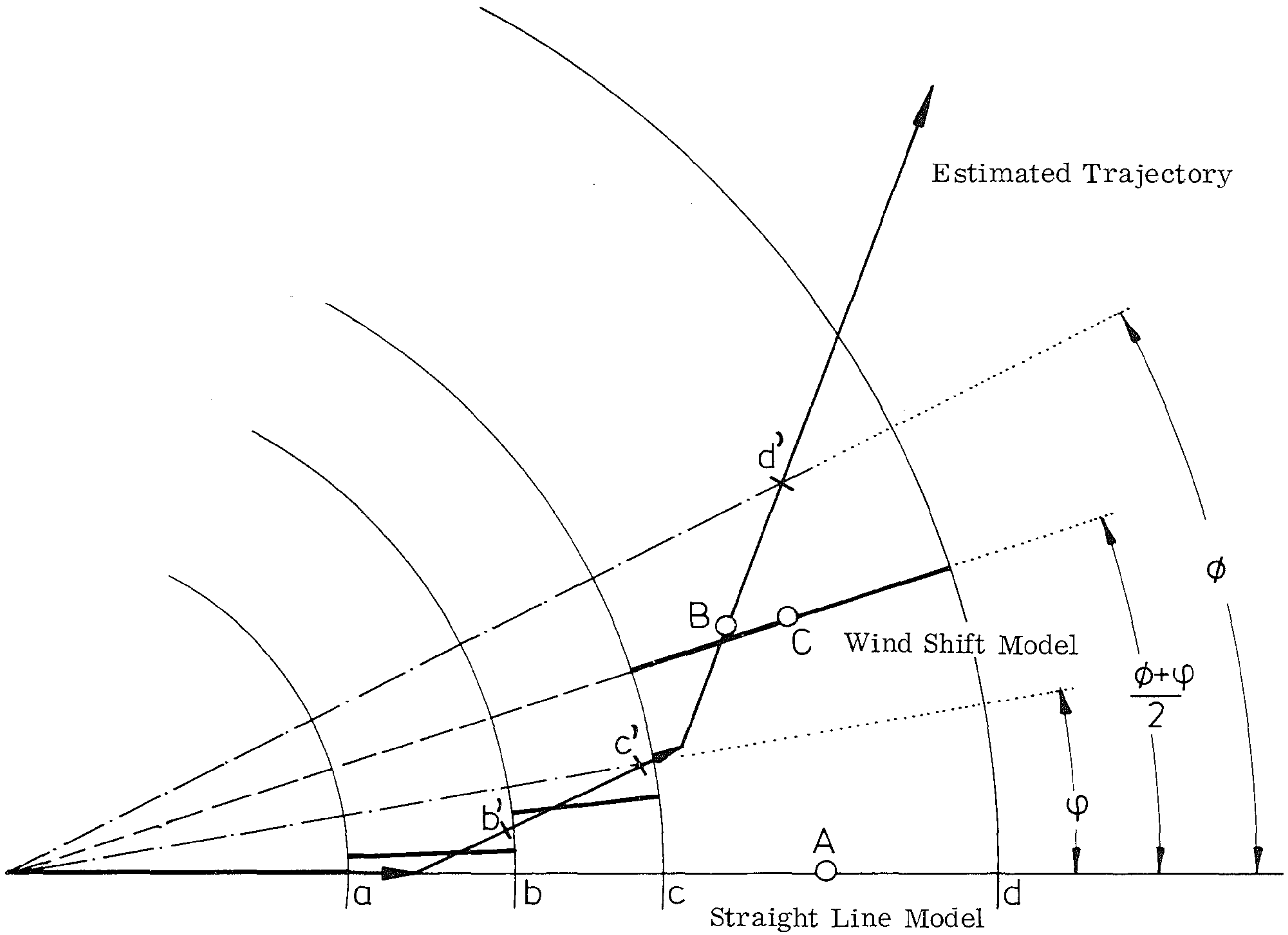


Figure 2: Schematic Showing Calculation of Rotation Angle for Wind Shift Model

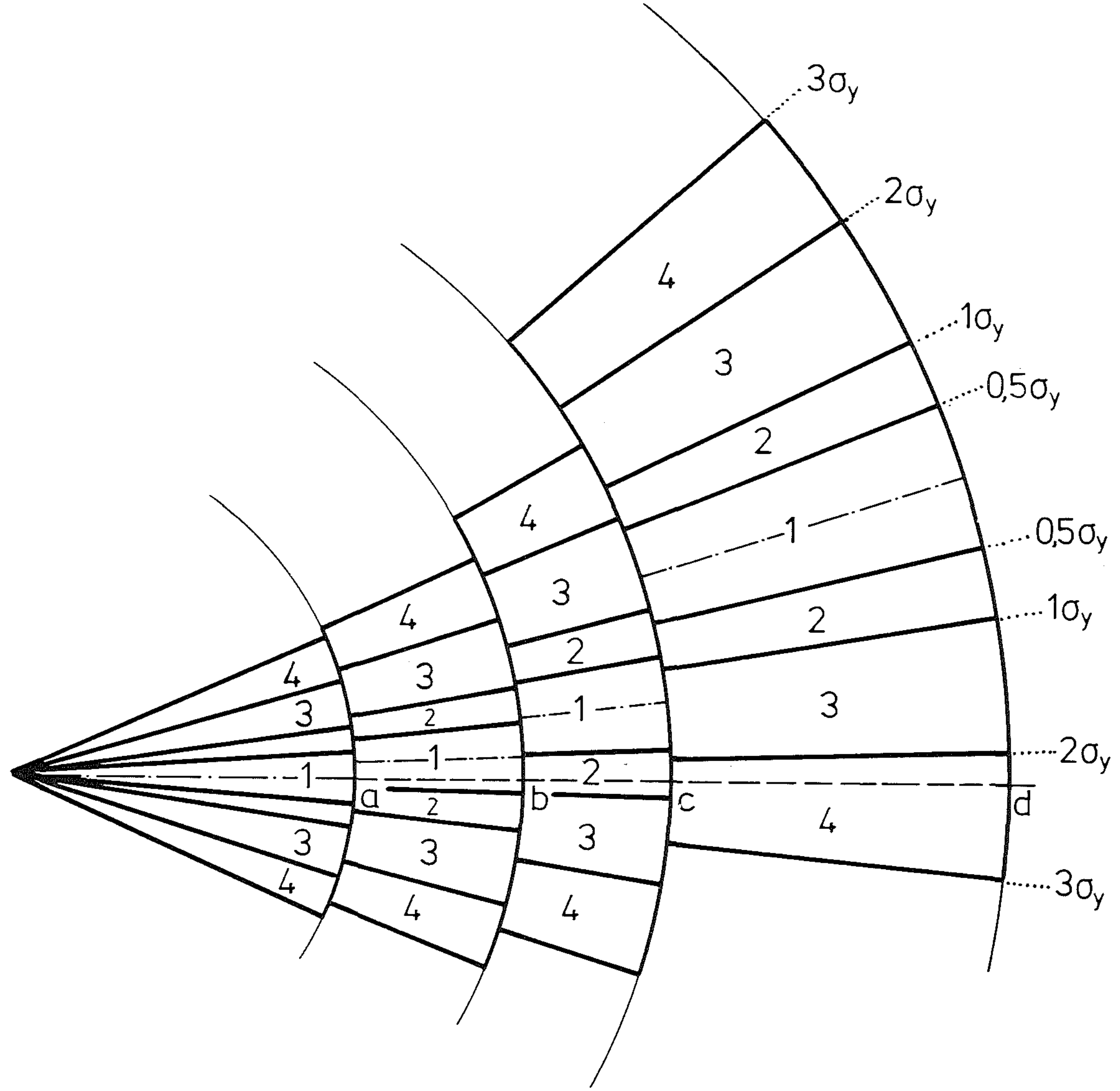


Figure 3: Schematic Showing of Circular Ring Sectors, within which the Concentration is Assumed to be Uniform