ATTACHMENT 3

CONCENTRATION COEFFICIENTS IN ATMOSPHERIC DISPERSION CALCULATIONS

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ABSTRACT

The concentration coefficient technique is a method for calculating the concentration field in the atmosphere in the vicinity of a building when an airborne substance is released from or near the building. The operative parameter in the concentration coefficient K which, in the majority of applications, is independent of substance release rate, wind speed, and building size, but is dependent on wind direction, building shape, source configuration, and receptor location. The prediction of real concentrations depends on one's ability to make an appropriate estimate of K and to transform it into a concentration estimate. This paper describes available data sources for K, examines its nature, and illustrates its use by a case study.

INTRODUCTION

Atmospheric dispersion is a mixing process whereby airborne matter is spread over an ever-increasing volume of airspace by the turbulent motion of the atmosphere. A continuous release of matter into a steady wind produces a stationary (time-independent) plume, characterized by nonzero concentrations of the dispersed matter. This paper deals with the calculation of such concentrations in plumes created from sources near building surfaces. Plumes of this type have concentration distributions different from the Gaussian distribution that exists in free-stream plumes lying well above the region of wind disturbance created by the building. The most accurate method for estimating concentrations in stationary plumes from building sources is the concentration coefficient technique.

A concentration coefficient is a nondimensional representation of a real concentration in the same sense that a pressure coefficient is a nondimensional representation of a real pressure. In both cases, the coefficient is found by dividing a measured quantity by an artificial reference quantity constructed from the field boundary conditions. For a pressure field, the reference quantity is the dynamic pressure. For a concentration field, the reference quantity is an artificial concentration C_{ref} (amount/volume) created from the release rate Q (amount/time) of pure matter, the mean wind velocity U (length/time) at a designated location, and a characteristic area A ($length^2$), producing

$$C_{ref} = Q/AU. \tag{1}$$

For a concentration C (amount/volume) at a specified point x,y,z, the corresponding concentration coefficient K (dimensionless) is

$$K = C/C_{ref} = CAU/Q. \tag{2}$$

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The usefulness of K derives from the fact that, in many cases, it remains substantially constant for a wide range of magnitudes of Q, A, and U. This makes it possible to estimate C in the full-scale atmosphere from K obtained in a wind tunnel model test, simply by using Equation 2 with full-scale values of Q, A, and U. The feasibility of the technique rests on the availability of published K data and the validity of applying the data to a full-scale configuration which does not resemble the model configuration in detail.

This paper contains (1) a review of the available data base for estimating K, (2) a section on the nature of K, (3) a case study to illustrate the application of the concentration coefficient technique to a complicated building, and (4) an evaluation of the accuracy of the technique by comparison of the estimated concentrations with concentrations measured in a wind tunnel model test of the study prototype.

DATA BASE FOR K

K is usually reported in the literature as K isopleths in the airspace surrounding a building or group of buildings. Only three fairly comprehensive studies have been made on simple geometric shapes, but these are important because such shapes can be construed to resemble portions of larger, more complicated structures. The experiments that produced the K isopleths were conducted with wind tunnel models; the full reports on testing procedures, data reduction, and data interpretation are given in laboratory project reports References 1, 2 and 3. Abridgements of References 1 and 2 appear in the open literature as References 4 and 5. An abridgement of Reference 3 appears in Reference 6. References 7 and 8 present an up-to-date (1980) compilation of research data on flow and diffusion near buildings and contain some of the K isopleth drawings in References 1 and 3.

NATURE OF K

Presentation

An example of a K isopleth drawing, abridged from Reference 1, is shown in Figure 1. The isopleths are drawn in the plane of each visible building surface and in the airspace in sections above and to the side of the building. Each isopleth is identified by a value of K ranging from zero at some distance from the building to a maximum at the exhaust port. Each isopleth line is, in fact, the intersection of a constant K surface with a building surface or a section in space. A mental reconstruction will show that the space around the building is occupied by a continuous field of K, made visible by discrete constant K surfaces.

The K isopleth surfaces and lines were created by interpolating curves through an array of K data points which had been obtained by transforming measurements of C in a wind tunnel test to corresponding values of K by Equation 2 and plotting them in a space created by dividing all real lengths by the building height H. Therefore each data point represented a nondimensionalized concentration at a nondimensionalized location, i.e.,

$$C\ (x,y,z,) \sim K\ (x/H,y/H,z/H), \tag{3}$$

and the constant of proportionality is C_{ref} of Equation 1.

Reference Quantities

In establishing C_{ref} it is necessary to adopt some convention for the designations of Q, A, and U. Invariably, the source strength Q is the flow rate of pure contaminant passing through the exhaust port cross section. More flexibility is available for A and U.

It is preferable, but not mandatory, that A be associated with a distinctive feature of the flow field around the building. This feature is a local zone of toroidal circulation, called a cavity, lying within a large disturbed flow zone called a wake. The cavity and wake originate, and are coincident, at the upwind edges of the building, but the cavity is finite in length and maximum cross section, while the wake cross section grows continuously with distance downwind until the wake disappears as free stream kinetic energy diffuses into it.

Cavity flow controls dispersion near the building because the contaminant is usually discharged within the cavity or sufficiently close outside to disperse in a flow field that must conform with the cavity shape. The building feature that contributes most to the creation of the cavity flow is the building frontal area projected on a plane normal to the wind. References 1 and 3 both employ the frontal area for A but with a difference that may be significant if the building is long and narrow. The A in Reference 1 is the frontal area of the largest side of the building; it is invariant with wind direction. The A in Reference 3 is the frontal area projected on a plane normal to the wind; it varies with wind direction. The latter is more closely related to cavity size, but the former is simpler to use in calculations. Both are acceptable, but the isopleths in each reference were derived with the designated A and should remain associated with it in subsequent applications.

Two candidates for reference velocity are the exhaust stream velocity V_e and the wind velocity U. Both, acting together, define the total flow field, but the former dominates in the region near the exhaust port while the latter is more important elsewhere in the cavity. The latter is more commonly used because receptors near buildings will be in regions of low concentration away from the port vicinity. References 1 and 3 both use wind velocity at roof height for U. The height specification is not important in Reference 1 because the wind had a uniform mean velocity profile. It is significant in Reference 3 because the profile was of the boundary layer type, i.e., velocity increasing with height from zero at the ground as in the natural atmosphere.

Use of frontal area for A and roof wind velocity for U is suitable for isolated structures as in References 1 and 3. Practicality dictates other choices in other situations. For example, in reporting full-scale tests of dispersion at a nuclear reactor complex in Reference 10, A was defined as the frontal are of the reactor containment structure alone, although many other large buildings in the complex also contributed to cavity formation, and U was defined as the wind velocity at the 6 m (19.7 ft) level on a tower located 600 m (1,969 ft) upwind of the complex. K values derived from this reference must be adjusted for use with A and U specified in other building arrangements.

The only other reference parameter is the length used for nondimensionalizing real distances. Building height H was used for the block buildings in References 1 and 3. The building in Reference 2 was a half-sphere atop a vertical cylinder; the reference length was selected to be the diameter rather than the height. This convention, also, must be retained in locating K values from Reference 2.

Configuration and Similarity

The constancy of K over a range of scales depends on invariance of the normalized flow field in which the dispersion takes place. Such invariance occurs, according to the hydrodynamic equations of motion and dispersion, when the configuration is invariant and a minimum Reynolds Number is observed.

A configuration is a statement of normalized boundary conditions for a specific flow and dispersion field. The field under consideration here is the atmosphere in turbulent motion over the building and surrounding terrain. Although the field is effectively infinite in extent upward and horizontally outward from the building, it is convenient and sufficiently accurate to consider only that portion in an imaginary box on the ground enclosing the building. The walls and roof of the box are set only far enough away from the building to provide wind properties in their planes essentially the same as if the building were absent. A distance of three building heights is usually required in the lateral, vertical, and upwind directions; a larger distance is required in the downwind direction to accommodate the slow decay of wind disturbances created by the building.

The configuration has three components. The geometric configuration is the shape of the faces of the box, five of which are orthogonal imaginary planes and one, the bottom, is an irregular solid surface conforming to the terrain and building exterior contours, continuous except for the exhaust and intake ports. The dynamic configuration is the distribution of velocities along the box faces. (Density and temperature are ignored in the present context because differentials between building and atmospheric air are too small to make significant changes from the flow patterns that would exist under isothermal conditions.) The source configuration is the distribution of concentration across the exhaust port.

Two configurations are said to be the same if the properties of one convert into the properties of the other when multiplied by a single constant. The constant is the ratio of magnitudes of a characteristic property. For geometric similarity, it is the ratio of reference

lengths. For dynamic similarity, it is the ratio of reference wind velocities. For source similarity, it is the ratio of reference source concentrations, which is proportional to the ratio of source strengths when geometric and dynamic similarity are present.

The minimum Reynolds Number, formed from the reference length, the reference velocity, and the density, restricts the amount of turbulent energy converted to heat by molecular interaction to a very small value, thereby preserving the turbulent character of the field. This criterion is important in setting wind tunnel test conditions because the small model size creates a small Reynolds Number. It is automatically observed when model-generated K isopleths are used for estimating full-scale concentrations because the full-scale flow field will have a higher Reynolds Number than that in the test.

In practice, exact similarity of configurations between model and full scale is not possible or necessary, provided that substantial similarity is achieved in major features. For example, in model testing of a given prototype building, minor surface irregularities are omitted and larger protrusions, recesses, and even other buildings located outside the exhaust-intake path are replicated only in crude block form. When using model-derived isopleths to estimate full-scale concentrations for another building configuration, greater deviation from similarity is to be expected; however, considerable deviation can be tolerated without too great a penalty in reduced accuracy.

Characteristic Values of K

As an aid in estimating K when exact similarity is absent, it is useful to be aware of two regions where K takes on characteristic values (apart from K = 0 outside the plume).

One such region is the vicinity of the exhaust port. The exhaust mixture crosses the plane of the port through exhaust area A_e with uniform velocity V_e and concentration C_e, carrying contaminant flow Q, all related by

$$C_e = Q/A_eV_e. \tag{4}$$

The corresponding K value is found by setting C in Equation 2 equal to C_e in Equation 4 to obtain

$$K_e = (A/A_e)(U/V_e). \tag{5}$$

For example, in Figure 1 the model building was a 0.38 m (15 in) cube with A = 0.145 m^2 (1.56 ft^2), the exhaust port was a 0.0127 m (0.5 in) diameter circle with A_e = 0.000127 m^2 (0.00136 ft^2), and U and V_e were each equal to 1.22 $m\text{-}s^{-1}$ (4 fps), yielding $K_e \cong$ 1,146. The same configuration for a full-scale building in the atmosphere would have the same K_e, since A would be scaled by the same factor as A_e and U by the same factor as V_e.

It should be noted that K_e is a function of the building/port area ratio and wind/exhaust velocity ratio. If either of these should change, K_e would also change and the Figure 1 isopleths would no longer be exactly transferable to the full-scale building. However, if the change still resulted in complete capture of the contaminant in the cavity, the changes in the isopleth pattern would be localized to the exhaust vicinity.

Another region where K takes on a special value is at the downwind end of the cavity. Despite a small variation of concentration with height, which is responsive to exhaust port conditions, a fairly uniform average concentration C_w is created in the swirly, highly-turbulent cavity flow. C_w is given by

$$C_w = Q/A_wU_w \tag{6}$$

where A_w is the maximum cross-section area of the wake normal to the wind direction and U_w is the average wind velocity in the contaminated region just downwind of the cavity, and K_w follows by combining Equation 6 with Equation 2:

$$K_w = (A/A_w)(U/U_w), \tag{7}$$

Measurements show that $A_w \cong 2A$ and an average $U_w \cong U/3$; Equation 7 then yields $K_w = 1.5$. That this is a realistic value may be seen in Figure 1; K is about 1.5 to 2 over the downwind face of the cube where the exposure is mainly to well-mixed cavity concentrations in the return flow.

Although Figure 1 is specific to a cubical building, similar K patterns appear with block buildings having different proportions but all having roof exhausts. For example, three sets of K isopleths for a block building having sides in the ratio 1:3:3 and with different faces presented to the wind are shown in Reference 4, Figures 20, 21, and 22. All have K values of about 1.5 at the lee face, although smaller values appear in the lower half of the tall narrow building because of strong horizontal infusion of fresh air near the ground. (Note that the K_e ($\equiv K_{max}$) values in Figures 20 and 21 are incorrect; they should be interchanged.)

In Reference 6, for block buildings in a boundary layer, isopleths at the downwind wall have about the same average value of 1.5 as in Reference 4, although the range (from large at the roof to small at the ground) is greater. The difference is due to the difference in configurations. The Reference 6 buildings had very small exhaust ports and were immersed in a deep boundary layer. The wind stream separated at the upstream building edges but reattached to the roof and walls and separated again at the downwind edges to form a lee cavity that was smaller than the Reference 4 cavity, with $A_w \cong A$. This alone would double C_w and K_w. However, because the release was in the smooth flow, some of the contaminant diffused upward before reaching the cavity and was not recirculated to the lee wall. The loss of contaminant and the reduced A_w contributed in opposite ways to fortuitously producing an average K_w that was about the same in both tests.

Round buildings, such as nuclear reactor containment structures, produce smaller cavities than sharp-edged buildings; therefore, K_w should be larger, according to Equation 7. Reference 5, Figure 5.29c, shows K_w averaging about 3 at the end of the cavity (about 2.25 diameters downwind of the building center.

The prevalent appearance of an average K of 1.5 at the lee face of a sharp-edged building is a powerful generalization that may be used in design of wall and ground intakes when the exhaust is on the roof, but a few words of caution are warranted. The existence of $K_w \cong 1.5$, stemming from Equation 7, implies that all of the released contaminant is trapped in the wake and flows downwind through A_w. This is true for exhausts whose jet velocity, diameter, and elevation are insufficient to thrust the contaminant through the cavity boundary. Figure 1 is an example of this condition. However, large-diameter high-velocity jets from stub stacks on roof-mounted fans often have sufficient momentum to penetrate the boundary, allowing some of the contaminant to escape and leaving the balance to create a reduced Q, say fQ, which creates K_w. The estimation of f is beyond the scope of this paper since it requires familiarity with the interaction of jet plumes with roof cavity flow. Appendix A provides some comments on this subject.

<u>Values of K in Roof Cavities</u>

Roof dispersion patterns are controlled by two factors; the presence or absence of a roof cavity at the exhaust port and the strength of the exhaust jet. If a cavity is present and the jet is weak, the pattern is similar to Figure 1. If a cavity is absent, or if there is a cavity and the jet is strong enough to penetrate the boundary, the pattern is that of a plume from a short stack.

A roof cavity will be created whenever a sharp roof edge is presented to the wind. If the edge is normal to the wind, the cavity will extend the entire width of the roof and part or all of its length, depending upon the building proportions and the approach wind velocity profile. If the edge is at an angle to the wind, the cavity will cover a portion of the roof contiguous to the edge, the size of the coverage decreasing with greater departure of the edge angle from normal.

The portion of a roof not covered by a cavity may be considered as a region of smooth flow in the direction, and at the velocity of, the approach wind. Such regions occur in normal orientation downwind of the cavity when the building proportions and approach wind velocity profile are such as to create flow reattachment. Guidelines for estimating the reattachment region may be found in References 7 and 9. Smooth flow regions also occur at the center of the roof in orientations other than normal. Figure 2 (abridged from Reference 4) shows K isopleths for a cube in 45° orientation; the smooth flow region lies between the K = 0 isopleths, and the cavities are at the lateral corners. The plume, which is well formed over the building, descends rapidly after passing the downwind corner and is wholly captured in the cavity. The

average K on the lee face is about 3, owing to local downward diffusion of high plume concentrations, which augment the more diffuse concentrations in the return flow.

In evaluating a proposed design, the wind direction should be allowed to rotate through 360° and the locations of exhaust port and intake observed with respect to roof cavities. In any one direction, if both exhaust plume and intake are in the cavity, a K value at the intake should be selected from among the published K isopleths and adjusted for the difference between the design K_e and the published K_e. Note that this adjustment is greatest near the source, where K_e is dependent on A_e and V_e, and will not be necessary at the lee wall unless the fraction of Q retained in the cavity changes. If the exhaust plume and the intake are outside the cavity, dispersion should be calculated as in the open atmosphere.

An ambiguity in the foregoing discussion is the criterion for establishing when an exhaust plume is fully trapped in the cavity and when it can be considered to have escaped into the free stream. Appendix A offers some suggestions in this regard.

CASE STUDY

An estimate was made recently of dispersion of contaminated air released in several possible modes near the surface of the reactor enclosure building of a nuclear power plant. The estimate was followed by a wind tunnel test of the same plant. The estimate and the test results provide an opportunity to illustrate how the K concept is applied in practice, to evaluate the predictive technique in general, and to demonstrate how seemingly small deviations between the conceptual and real configurations can produce significant changes in the concentration field.

Configuration

The facility has two reactors, designated Units 1 and 2, each in its own enclosure building but served by a common control building and serving a common turbine building, all joined to form the irregular building in the center of Figure 3. Two large natural draft cooling towers (N), two mechanical draft cooling towers (M), an electrical switchyard, and various buildings surround the central structure.

The ventilation exhaust system for each unit has two internal pathways, only one of which will be in use at a given time. Each pathway terminates in a small louvered penthouse, designated inboard vent (IV) or outboard vent (OV), on the roof of the unit's auxiliary building. A design alternative under consideration was a stack release whose port was at the elevation of the roof of the enclosure building. A fourth (accidental) release mode was seepage through the exterior walls of the enclosure building.

The receptor was considered to be in the control room in the interior of the control building. The contaminant could enter the control room via fresh air intakes spanning the west wall of the control building at an elevation of 13.7 m (45 ft) above ground, or, if the intakes are closed, by infiltration through the roof of the control building. An estimate of concentration at the center of the wall intake (B) and at the center of the porous roof area (D) was desired.

The prototype wind condition was a natural boundary layer in neutral stability with U = 1.52 $m\text{-}s^{-1}$ (5 fps) at anemometer height of 58.5 m (192 ft). This corresponds to a wind speed of 1 $m\text{-}s^{-1}$ (3.3 fps) at the 10 m (32.8 ft) elevation, a conventional assumption for nuclear reactor accident dispersion calculations. (The atmospheric stability usually assumed in such calculations is strongly stable, with a consequent difference in the approach wind turbulence and mean velocity profile. However, the wind disturbance created by the building overwhelms the approach wind characteristics, making the assumption of neutral stability valid.)

Selection of Reference K Isopleths

In selecting the appropriate set of K isopleths, it is necessary to evaluate the controlling features of the flow between source and receptor. Both IV and OV for each unit are located at the surface of a large composite structure consisting of the unit's combined enclosure and auxiliary buildings. The small louvered penthouses over the exhaust ports destroy any upward momentum in the exhaust jets, ensuring that the release is at the surface of the structure. Receptors B and D are located about one structure diameter from its center. By

inspection, the critical wind directions (producing highest receptor concentrations) appear to be WSW for Unit 1 and NNE for Unit 2. The receptors are in the lee of the structure in these wind directions. The effect of the four cooling towers, whose wakes and internally-generated external air circulations alter the approach wind characteristics in a complicated manner, are not considered in the estimate.

The configuration suggests that, in each wind direction, the receptors are at the bottom of a large building cavity which is contaminated by releases from small surface ports. The isolated containment structure tests of Reference 2 fulfill these criteria. Moreover, Reference 2 provides the only available set of isopleths in space downwind of a building. Figure 6 is a reproduction of one of several K-isopleth drawings in Reference 2; it represents an upwind mid-height release location.

<u>Matching of Configurations</u>

The Reference 2 building, identified as the EBR-II containment structure, is a circle in plan view. Circular approximations to the Unit 1 and Unit 2 composite structures are shown as dashed circles of 61.0 m (200 ft) diameter in Figures 4 and 5. (The orientation of these figures is such that the wind passes from left to right across the page.) The upper parts of the figures are elevation sections through the centers of the circles, with the EBR-II building shown in its correct proportions. The placement of the EBR-II building was such as to match the major dimensions of the composite structures in plan view and at the top in elevation. This resulted in an EBR-II base at 16.8 m (55 ft) below plant grade.

The K isopleths in Reference 2 are presented as seven drawings, each corresponding to a small surface source at a different location: top; midheight upwind, side, and downwind. The appropriate set for use herein was chosen to provide matching source locations. For Unit 1 in a WSW wind (Figure 4), the vents clearly are at the upwind location but the height is uncertain. For Unit 2 in a NNE wind (Figure 5) the vents are midway between the side and downwind locations and, again, the heights are uncertain.

To establish the effective vent height in proportion to the structure height, it is important to consider the effective grade in the region of the cavity. The grade establishes the frontal cross-section area A, which creates the cavity cross-section area A_w. Both these areas contribute to the establishment of the average K_w at the downwind end of the cavity from which the return cavity flow toward receptors B and D arises (see discussion in connection with Equations 6 and 7).

The effective cavity grade is shown in Figures 4 and 5. It was calculated by an averaging algorithm that took into account roof elevations along the section line as well as at $\pm$ 22.5° in azimuth from the section line as representative of the average height of the cavity base. For Unit 1-WSW the effective cavity grade was 18.3 m (60 ft) above plant grade, and the EBR-II net A above cavity grade was 2,017 m^2 (21,713 ft^2). For Unit 2-NNE, the corresponding values were 7.6 m (25 ft) and 2,667 m^2 (28,710 ft^2).

The height of the vents in proportion to the building height above cavity grade in Unit 1-WSW configuration is shown in Figure 6. It corresponds well to the midheight EBR-II source height. Similar agreement is obtained in the Unit 2-NNE configuration (not shown), although the vents are slightly above the source due to the lower effective grade.

It remains to be established that the K isopleths for midheight sources in Reference 2 can be used in the present case in view of the violation of the requirement of geometric similarity, i.e., the building height/building diameter ratios are different. The only argument I can offer is the observation previously made that the average K value of the lee wall for block buildings have height/width ratios of 1 and 1/3 is about 1.5 for both, and the distributions over the wall from top to bottom are similar (higher at the top, lower at the bottom; see Reference 4, Figures 20 and 21). By analogy, a vertical contraction of the EBR-II isopleths in the same proportion as the height contraction should be permitted. It was not necessary to re-draw the isopleths to a contracted vertical scale as long as the receptors were placed in the correct vertical relation in Figure 6.

The placement of B and D horizontally in Figure 6 was done straight-forwardly by dividing real downwind and crosswind distances by the scaled EBR-II diameter to obtain the x/D and y/D coordinates. Vertically, both receptors were placed in the base plane, even though the proportionate height procedure put B below grade and D above in the Unit 1-WSW configuration and both above in the Unit 2-NNE configuration. The rationale for this in the case of D was that isopleths in the ground plane do not change during vertical contraction of the field, and, since D

was a point in the roof plane, it was more reasonable to leave it in the ground plane than to set it above a mathematical rigidity. In the case of B, a location below grade is meaningless since no isopleths exist there.

The presence of Unit 1 in the cavity of Unit 2 in the NNE wind direction creates a complex interference flow pattern whose effect on the isopleth pattern could not be predicted; it was ignored for the estimate.

Estimates of K at Intakes B and D

The interpolated values of K at B and D for IV and OV sources are given in the upper part of Table 1. The Unit 1-WSW values were obtained from Figure 6. The Unit 2-NNE values were obtained from similar figures based on Reference 2, Figures 11 and 14. At the wall (B), K ranged from 2.5 to 3.4. At the roof (D), K ranged from 2.3 to 2.8.

K values for the stack releases were not estimated because of uncertainty as to how much of the released Q would enter the cavity. Fractional capture was thought to be quite likely since the stack release elevation was 12.5 m (41 ft) higher than the vents, and the stacks were uncapped.

K values for the seepage release are given in Table 2. They were obtained by averaging the K values at B and D from all seven of the drawings of Reference 2, with the side release drawings yielding two values, one for the receptors on the same side as the source and the other for the receptors on the opposite side. The rationale for this procedure is that a seepage release would occur over the entire exterior surface of the enclosure building. The averaging procedure over all sources was considered to be the best representation. The average K ranged from 5.9 to 10.1.

The estimating procedures described above differ from those in the pre-test estimate in two respects. One is in the placement of D at the base instead of at the proportional elevation; this produced only a minor change in the estimate. The other is the use of a nine-point average for the seepage release instead of a single release at the downwind midheight source. This change was made because the wind tunnel test showed higher values of K by a factor of 2 to 3 than were originally predicted. Hindsight sparked the realization that use of a midheight source alone omitted the important base release contribution.

WIND TUNNEL MODEL STUDY

The test was conducted in neutral stability on a 1/240 scale model with tunnel wind velocity $U = 3.1\ m\text{-}s^{-1}$ (10 fps) at the 58.5 m (192 ft) elevation and all other velocities (source and cooling towers) doubled to maintain their correct relation to the wind velocity. The N towers were made operational with internal axial flow fans, drawing tunnel air in at their bases and discharging it through their tops. The M towers were made operational by an external compressor that provided the correct outflow, but the air source was outside the tunnel.

The test program provided concentration measurements at a total of 42 taps in the west wall and roof of the control building for eight release configurations (IV, OV, stack, and seepage on two units) and 16 wind directions with M and N on and off (all combinations were not tested). Some tests were also done with Unit 2 removed.

The test results were reported, in accordance with conventional practice in nuclear plant evaluation, as full-scale CU/Q (m^{-2}). K was found by applying Equation 2 to obtain

$$K = A(CU/Q)_{test} \tag{8}$$

with A as given previously for the WSW and NNE directions.

To provide K values for comparison with estimates, four wall taps (Nos. 15-18) were averaged to represent B, and 16 roof taps (Nos. 27-42) were averaged to represent D. The lower parts of Tables 1 and 2 show test values for B and D in the Unit 1-WSW and Unit 2-NNE configurations.

In the Unit 2-NNE configuration, the maximum test K for a vent release occurred at D with N and M off; its value was 2.6. The estimate for the same configuration was 2.3. For the seepage release with N and M off, the test value was 11.8; the comparable estimate was 9.7. The agreement is good (although the estimating procedure was changed in retrospect, as discussed previously).

On the other hand, very poor agreement was found in the Unit 1-WSW configuration. The maximum test K for a vent release was 0.1, whereas the estimate was 2.8. The maximum test K for the seepage release was 16.6 at D with N on and M off; the estimate was 5.9. The magnitudes of the discrepancies and the fact that they occurred in opposite directions warrants an attempt at explanation.

In the Unit 2-NNE configuration, the vents were at the point of flow separation at the south end of the auxiliary building roof. This ensured complete descent of the release into the cavity, and the near presence of Unit 1 in the lee of Unit 2 created a blockage that strengthened the cavity circulation. These two factors provided for complete capture of the release in the cavity flow, producing the expected value of K.

In the Unit 1-WSW configuration, the vents were at the upwind corner of a diagonally-oriented building and the plume developed vertically upward in traversing the roof, thereby placing some of the effluent above the capture zone downwind of the enclosure building roof. Second, Unit 2 was in a position to deflect some of the wind passing around the west side of Unit 1 into the cavity region. Third, the turbine building intercepted the downflow at the end of the cavity and turned it downwind instead of back to Unit 1. The combination of fractional escape of the developing plume, wind injection by Unit 2, and downflow interception by the turbine building resulted in almost no portion of the release reaching the receptors. For the seepage release, the low-level wind flow pattern in the cavity was altered by the presence of the lee unit and the turbine room to produce a flushing action at D for the Unit 1-WSW release, therby creating larger values in the latter configuration.

The IV releases produced higher K values than did the OV releases, indicating some loss of Q prior to entry of the plume into the cavity in the latter case. Therefore, the OV location is preferable.

The stack produced significantly lower K values. The maximum was 0.7 at D for Unit 2-NNE, compared to 2.6 for the IV release. This is attributable to the larger escape fraction with the higher release point.

Of considerable interest is the lower K values at wall intake B. The test maximum was 1.0 compared to 2.6 at the roof. This is attributable to the lateral inflow of uncontaminated wind along the ground, striking the wall and flowing upward, thereby preventing the contaminated cavity flow at D from descending to B.

The effect of the cooling towers appeared in the NNE orientation, as expected from their upwind placement. Operation of N reduced the maximum K at D from 2.6 to 1.8, with similar reductions for the other vent and the stack. Operation of M reduced K from 2.6 to 0.2. These reductions are attributable to wind disturbances created by the cooling tower plumes. The circulation in a transverse jet plume is a pair of counter-rotating helical vortices, up along the plume centerline and down on each side, and longitudinally downwind. Since N and M straddle Unit 2 in the NNE orientation, each plume produces a downflow at the unit. In addition, N produces a flow toward the east near the ground, while M produces a flow toward the west. The helical circulations alter and displace the Unit 2 cavity so that the receptors are in regions of lower concentration than in an undisturbed NNE wind. The effect is more pronounced when the wind velocity is low, as in the test. The influence of M is stronger than that of N because the M plume is closer to the ground (exit ports at elevation 17.4 m [57 ft]) while the N plume is high (originating as elevation 121.9 m [400 ft]).

CONCLUSIONS

The concentration coefficient technique is generally believed to be quite accurate for predicting full-scale prototype concentrations from scale-model test measurements since such tests are designed to provide exact similarity in the important shape and flow characteristics. It also performs well in providing estimates of K in cases of nonexact similarity, provided that the release can be associated with an isolated, cavity-producing structure for which K isopleths are available.

The method is less accurate when the release point is near the cavity boundary, since small changes in distance from the building surface may create large changes in the fraction of the plume captured by the cavity. It is also less accurate when wind flow aberrations are introduced by nearby portions of the structure or by more distant structures, such as cooling towers, which generate persistent helical circulations for long distances. It seems unlikely that K isopleths for configurations having these variations will be available in the near future.

The alternatives for the designer are to improve one's ability to extrapolate beyond the available data by study of the references, or to be consoled by the observation that in the present tests the maximum increase above the estimated value was 41% (K = 11.8 increasing to 16.6 for the seepage release in the Unit 2-NNE configuration). In dispersion calculations, a factor of ± 2 is considered acceptable.

REFERENCES

1. Halitsky, J. 1963. "Gas diffusion near buildings." New York University, Department of Meteor. and Ocean. GSL Rep. 63-3, Feb. 1963. (Loan copy available from author for duplication.)

2. Halitsky, J.; Golden, J.; Halpern, P.; and Wu, P. 1963. "Wind tunnel tests of gas diffusion from a leak in the shell of a nuclear power reactor and from a nearby stack." New York University, Department of Meteor. and Ocean. GSL Rep. 63-2, April 1963. (Loan copy available from author for duplication.)

3. Wilson, D. J. 1976. "Contamination of building air intakes from nearby vents." University of Alberta, Department of Mechanical Engineering, Rep. 1, May, 1976, Edmonton, Alberta, Canada.

4. Halitsky, J. 1963. "Gas diffusion near buildings." ASHRAE Transactions, Vol. 69, pp. 464-485.

5. Halistky, J. 1968. "Gas diffusion near buildings." Meteorology and Atomic Energy 1968, D. H. Slade, ed., U.S. Atomic Energy Comm. Div. of Tec. Inf., pp. 221-255. (Available as TID-24190 from NTIS, U.S. Dept. of Comm., Springfield, VA 22161.)

6. Wilson, D. J. 1976. "Contamination of air intakes from roof exhaust vents." ASHRAE Transactions, Vol. 82, No. 1, pp 1028-1038.

7. Hosker, R. P., Jr. 1984. "Flow and diffusion near obstacles." Atmospheric Science and Power Production, U.S. Department of Energy, Office of Sci. and Tech. Inf., Chapter 7. (Available as DOE/TIC-27601 from NTIS, U.S. Dept. of Comm., Springfield, VA 22161.)

8. Hosker, R. P., Jr. 1981. "Methods for estimating wake flow and effluent dispersion near simple, block-like buildings." NOAA Env. Res. Labs., Air Resources Labs., Silver Spring, MD, Tech Mem. ERL ARL-108.

9. ASHRAE. 1985. Handbook of fundamentals, Chapter 14. New York: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

10. Halitsky, J. 1966. "A method for estimating concentrations in transverse jet plumes." Air and Wat. Poll. Int. J., Vol. 10, pp. 821-843.

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The sponsor of the case study investigation has made the K estimates and wind tunnel test results available for this presentation in the interest of dissemination of scientific data, but has declined to be identified.

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APPENDIX A
Penetration of a Jet Plume Through a Cavity Boundary

The following discussion is based on jet plume properties presented in detail in Reference 10.

Penetration of a cavity boundary by a jet plume is a much under-investigated subject. Plume rise increases with emission velocity ratio V_e/U and decreases with rate of infusion of cavity air into the exhaust jet. In comparison with free stream conditions, the local cavity wind is slower and more turbulent. The slower velocity creates a higher V_e/U and induces greater plume rise. The higher turbulence and wind shear produce more rapid infusion of cavity air into the jet, producing less rise. The two effects tend to cancel each other. I know of no analytical procedure or experimental data to quantify these trends.

I suggest that the plume rise be calculated as if the cavity were nonexistent and a separate estimate made of the cavity boundary. The plume would then be considered to have escaped the cavity if the calculated plume centerline lies at least σ_z above the cavity boundary, and to have been completely captured if the centerline lies below, at all distances up to the receptor. This is a crude compromise based on the concept that most of the plume will descend into the cavity due to the high cavity turbulence when the centerline lies along the cavity boundary, and most of the plume will escape if the centerline is $2\sigma_z$ above the boundary.

TABLE 1
K Values for IV and OV Releases

			Unit 1-WSW Wall B	Unit 1-WSW Roof D	Unit 2-NNE Wall B	Unit 2-NNE Roof D
Estimated Values of K from EBR-II Figures						
Source	Ref. Fig. No.					
upwind midheight	9		2.5	2.8		
downwind midheight	11				3.8	2.5
opp. side midheight	14				3.0	2.0
Average					3.4	2.3
Wind Tunnel Test Values of K						
	Cooling towers N	Cooling towers M				
Source						
inboard vent IV	on	off	0	0.1	0.3	1.8
inboard vent IV	off	off			1.0	2.6
inboard vent IV	on	on			0.6	0.2
inboard vent IV	off	on			0.5	0.1
outboard vent OV	on	off	0	0.1	0.3	1.3
outboard vent OV	off	off	0	0.1	0.8	2.1
outboard vent OV	on	on				
outboard vent OV	off	on			0.2	0.4
stack	on	off	0	0.1	0	0.2
stack	off	off			0.1	0.7
stack	on	on				
stack	off	on			0	0.1

TABLE 2
K Values for Seepage Releases

			Unit 1-WSW Wall B	Unit 1-WSW Roof D	Unit 2-NNE Wall B	Unit 2-NNE Roof D
Estimated Values of K from EBR-II Figures						
Source	Ref. Fig. No.					
upwind base	8		20	6	7	20
upwind midheight	9		3	3	3	2
top	10		2	5	5	2
downwind midheight	11		3	4	4	2
downwind base	12		19	14	25	17
source side base	13		35	10	15	35
opp. side base	13		4	5	5	4
source side midheight	14		3	3	4	3
opp. side midheight	14		2	3	3	2
Average			10.1	5.9	7.9	9.7
Wind Tunnel Test Values of K						
	Cooling towers N	Cooling towers M				
	on	off	0	16.6	0.1	12.8
	off	off			1.7	11.8
	on	on			2.7	5.9
	off	on			6.5	9.2

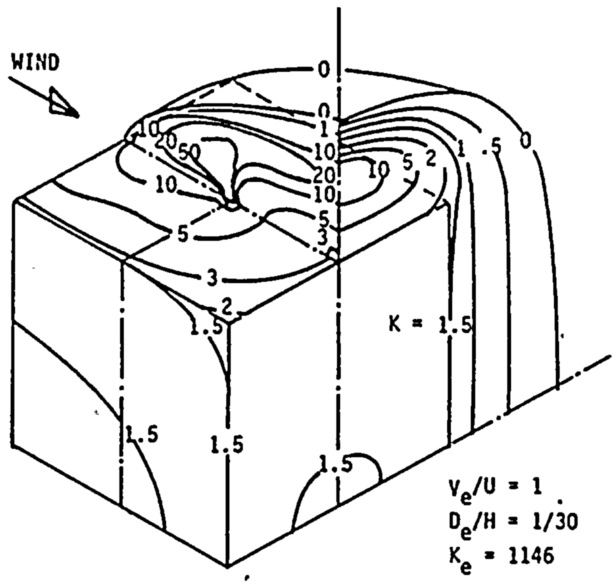

Figure 1. K isopleths for a cube in normal orientation to the wind. (Abridged from Reference 4, Figure 16.)

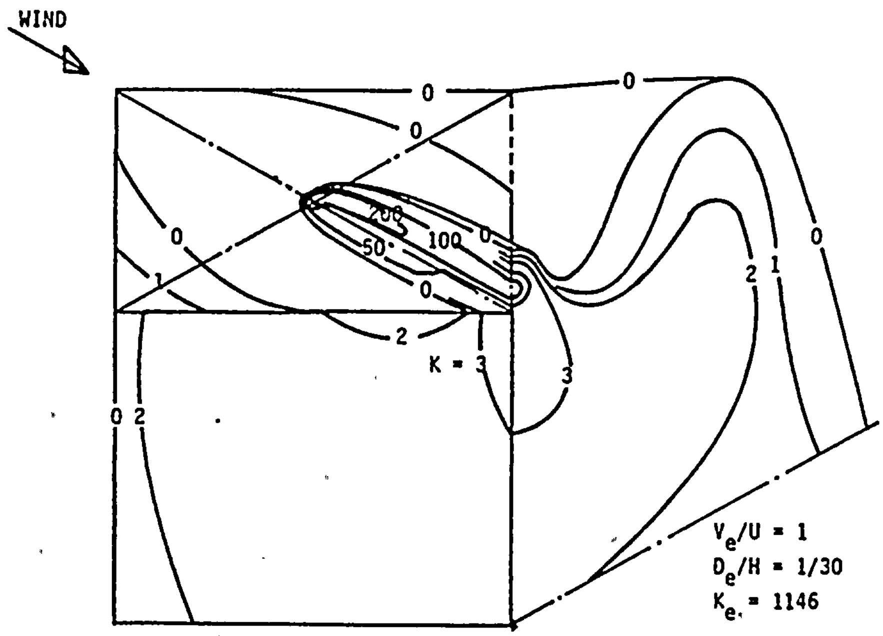

Figure 2. K isopleths for a cube at 45° orientation to the wind. (Abridged from Reference 4, Figure 19.)

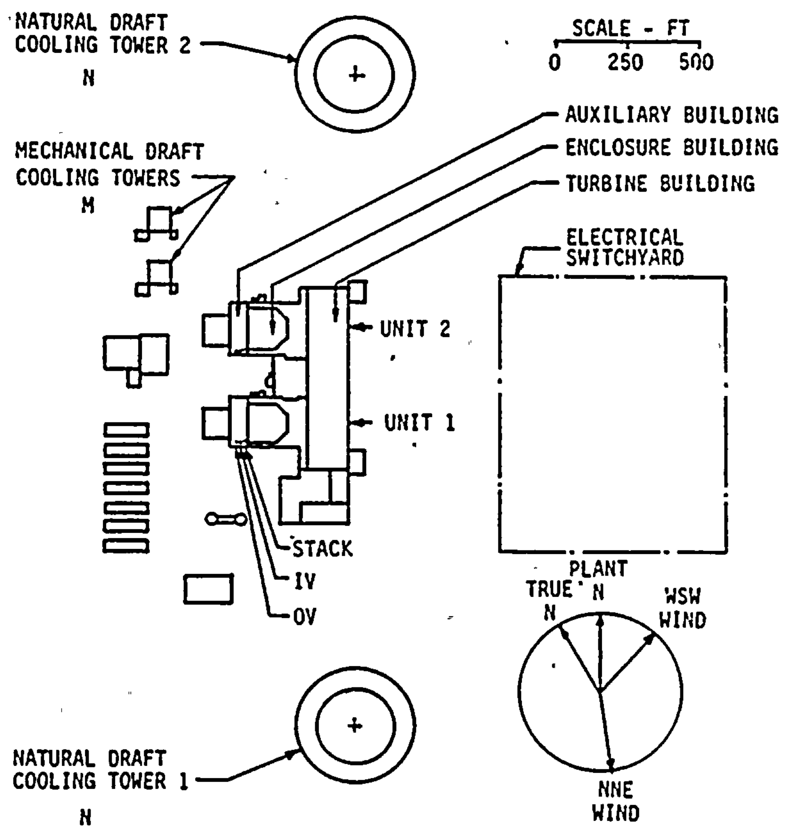

Figure 3. Plan view of building at case study site.

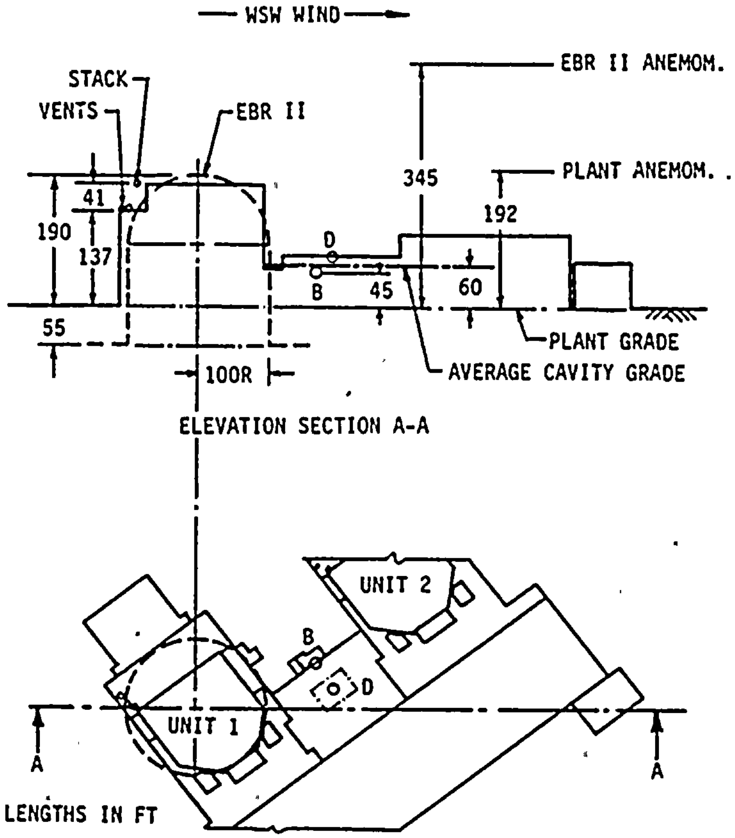

Figure 4. Local configuration for releases from Unit 1 in a WSW wind.

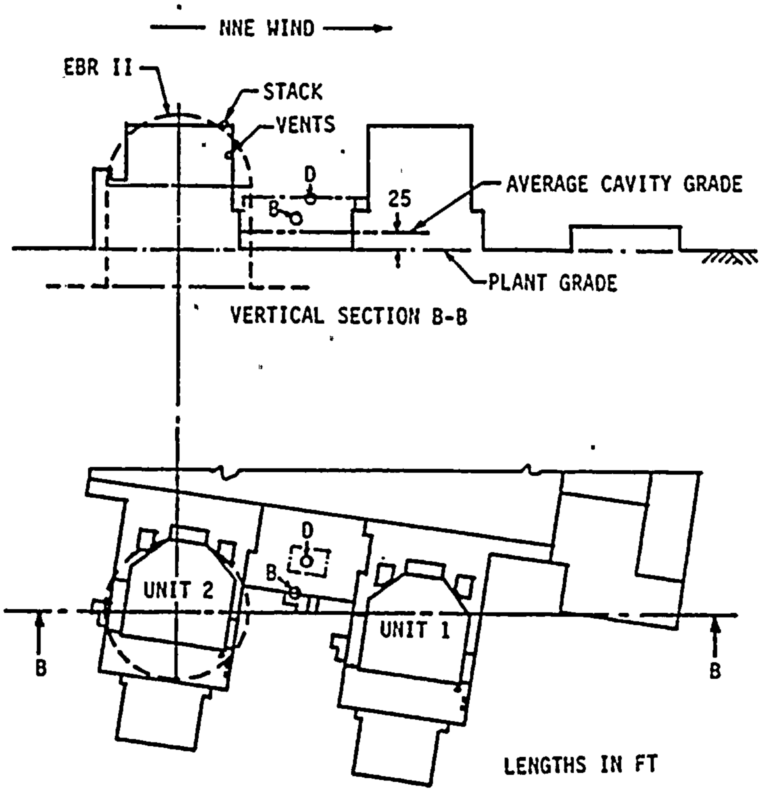

Figure 5. Local configuration for releases from Unit 2 in a NNE wind.