NUREG/CR-1394
NOAA Tech. Memo.
ERL ARL-84

Diffusion Near Buildings as Determined from Atmospheric Tracer Experiments

Prepared by J. F. Sagendorf, N. R. Ricks, G. E. Start, C. R. Dickson

National Oceanic and Atmospheric Administration

Prepared for
U.S. Nuclear Regulatory Commission

Available from

GPO Sales Program
Division of Technical Information and Document Control
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

and

National Technical Information Service
Springfield, Virginia 22161

NUREG/CR-1394
NOAA Tech. Memo.
ERL ARL-84
RB, R6

Diffusion Near Buildings as Determined from Atmospheric Tracer Experiments

Manuscript Completed: April 1980
Date Published: September 1980

Prepared by
J. F. Sagendorf, N. R. Ricks, G. E. Start, C. R. Dickson

National Oceanic and Atmospheric Administration
Air Resources Laboratories
Field Research Office
Idaho Falls, ID 83401

Prepared for
Division of Reactor Safety Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN No. B5690
Under Contract No. NRC-03-79-132

CONTENTS

LIST OF FIGURES

DIFFUSION NEAR BUILDINGS AS DETERMINED FROM ATMOSPHERIC TRACER EXPERIMENTS[1]

J. F. Sagendorf, N. R. Ricks,
G. E. Start, C. R. Dickson

ABSTRACT

Data from the innermost arcs and roof top samplers of the Rancho Seco and EOCR field studies were used to examine diffusion close to a building. The minimum length plume paths were determined from each release location to each sampler position at these two test sites. Measured concentrations, normalized by source strength (C/Q), were plotted versus plume path length and an envelope containing 95% of the measured values of C/Q was determined.

The curves from the two sites were similar in shape and implied three zones of diffusion. It is speculated that the three zones represent the rapid diffusion in the building wake; a transition zone where the plume leaves the wake of the building and where the rate of diffusion is reduced; and finally, the region where larger scale atmospheric turbulence again causes more rapid diffusion.

By scaling the plume path length by the minimum cross sectional area of the structure, the curves for Rancho Seco and EOCR showed no significant difference in magnitude for about one scaled distance. Since these studies were conducted at two dissimilar sites, the consistency in measured concentrations suggests that the technique may be useful in predicting maximum expected concentrations near a building.

Comparisons were also made with current NRC methods for predicting maximum expected concentrations close to a building. The NRC model overestimated concentrations in all but one case. The model was generally within an order of magnitude at EOCR, and within two orders of magnitude at Rancho Seco.

I. INTRODUCTION

All facets of wind engineering have been rapidly expanding in the last 15 years. Studies of mean wind and gust loading on structures, diffusion in the building wake, and aerodynamics of bluff body flow continue to be actively investigated. These phenomena are being investigated primarily through the medium of physical modeling in the wind tunnel. Flow characteristics and diffusion in the boundary layer of a building, long recognized to be applicable to recirculation of building exhausts to local intakes, is now receiving increased emphasis. For the nuclear power plant licensing process, there is a need for more realism in the assessment of potential control room and exclusion area radioactivity exposures during postulated design basis accidents and for evaluation of the conservatism of models currently in use. Both wind tunnel modeling and actual field study data are now becoming available for the re-examinations of these near building diffusion questions.

---

1. Research sponsored by U.S. Nuclear Regulatory Commission under Interagency Agreement Nos. NRC-03-79-132 and AT(49-25)-1004.

In December 1977, the Nuclear Regulatory Commission requested that the sets of field measurement data taken during the EOCR and the Rancho Seco diffusion field studies be analyzed with an emphasis on evaluating the licensing formula in use at that time, and to develop a technique to more realistically estimate relative concentrations close to the building. The original field studies to be discussed in this manuscript [Rancho Seco (Start, et al, 1977) and EOCR (Start, et al 1979)] were designed to emphasize the diffusive character of the turbulent wake at many reference lengths downwind (distance divided by some characteristic dimensions of the structure). However, those samplers located on the roof and ground-level at short downwind distances yielded a significant collection of useful data relevant to the near building problem.

II. QUALITATIVE RESULTS

The Rancho Seco field measurements were collected in the fall of 1975 at the Rancho Seco Nuclear Power Station located approximately 25 miles south of Sacremento, California. The EOCR study was conducted in the summers of 1975 and 1976 at the EOCR facility at the Idaho National Engineering Laboratory (INEL) near Idaho Falls, Idaho. The Rancho Seco site consisted of many large structures set in a broad, dry interior valley of central California. Relatively flat valleys and low hills surround the site. The EOCR facility is much smaller, with one main building and a few smaller structures nearby. It lies in the broad, flat upper Snake River Plain of Southeastern Idaho; the terrain in the immediate vicinity of the building is slightly rolling. Figures 1 and 2 show the buildings and sampler layouts for the two sites. At Rancho Seco, tracers were released from the ground surface, the roof of the auxiliary

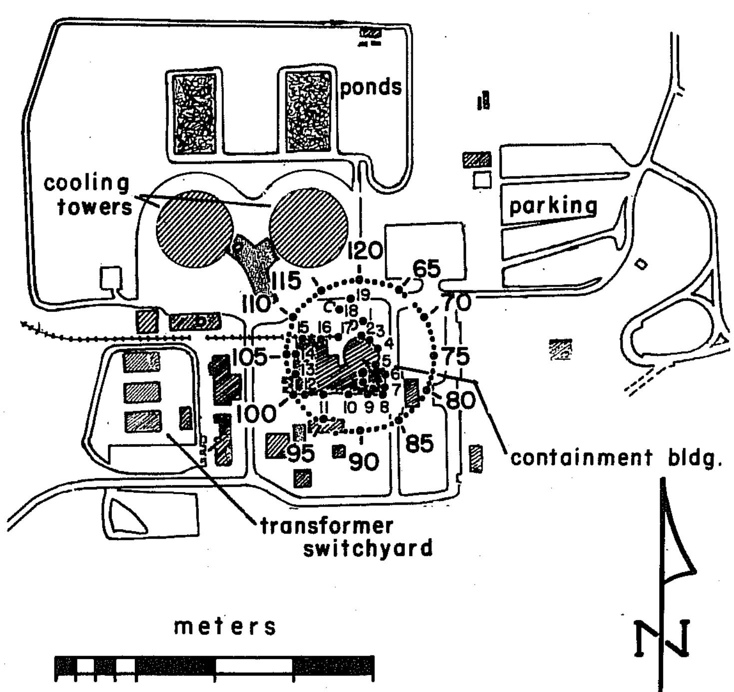

Figure 1. Close-in sampling positions at Rancho Seco.

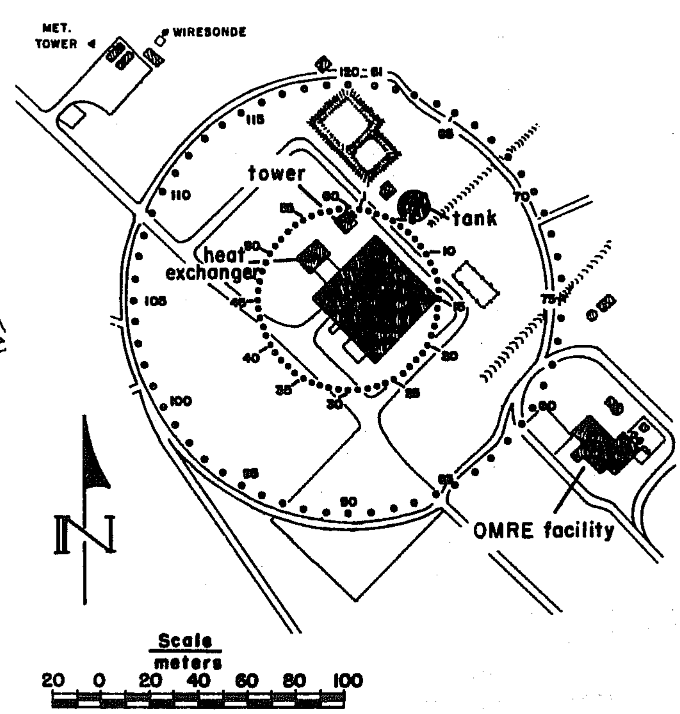

Figure 2. Close-in sampling positions at EOCR.

building, and on top of the containment vessel. Samplers examined for this study include those on the roof of the auxiliary building, the surface samplers adjacent to or near to the auxiliary building and containment vessel, and on the ground-level 100 meter arc. At EOCR, tracers were released from the ground surface, the highest roof of the building and out of the stack. Samplers used in this study were located on the lowest roof and on the ground-level 37.5 m and 87.5 m arcs. The plume travel distance from each release location to each sampler position was determined. If a building was between the release point and the sampler, the shortest possible path length around the building was chosen to be the plume travel distance. Scatter diagrams showing sampled C/Q (concentration normalized by source strength) versus distance for EOCR and Rancho Seco are shown in Figures 3 and 4 respectively. The solid curves on these plots represent the value of C/Q which exceeded 95% of the sampled values at that range of distance. These curves were determined by grouping the points into bands 10 m in width and computing the average distance for the band and the C/Q value at the 95% cumulative frequency level (5% of the values of C/Q exceeded this 95% cumulative frequency). A fourth order curve was fit to the resulting 95% level C/Q values and average distances. The 95% level C/Q values and average distances are contained in Tables 1 and 2 for EOCR and Rancho Seco, respectively.

Figures 5 and 6 are examples of the 10 m bands of C/Q values versus cumulative frequency plotted on log-normal graphs. In these plots a straight line would indicate a normal distribution of C/Q values within the band. In figure 5 it can be seen that the upper part of each curve departs from a normal distribution and turns toward relatively lower values of C/Q. This departure from normality affects a larger fraction of the total values of C/Q within a given band for bands closer to the EOCR structure. For example, the 5-15 meter band is badly distorted from a normal distribution at the higher concentration end of the curve. In figure 6 the same general pattern is seen, although the Rancho Seco bands of C/Q never as closely approached a normal distribution as did the curves for the EOCR data. This greater deviation from normal is likely due to the effects of the much larger complex of buildings at the Rancho Seco facility. It is interesting to note that a normal distribution of C/Q values within each band would give higher extreme values of C/Q than were measured at Rancho Seco or EOCR. Without the presence of buildings it is likely that these distributions would have been more Gaussian. The fourth order equations used to describe the curves seen in figures 3 and 4 are as follows:

$$\mathrm{Log}[C/Q(95\%)]=-1.5482\times10^{-8}X^4+3.6677\times10^{-6}X^3-1.1213\times10^{-4}X^2-2.4971\times10^{-2}X-2.0440 \quad (1)$$

for EOCR, and

$$\mathrm{Log}[C/Q(95\%)]=-7.3268\times10^{-9}X^4+2.6446\times10^{-6}X^3-2.3121\times10^{-4}X^2-1.1795\times10^{-2}X-2.1554 \quad (2)$$

for Rancho Seco, where X is distance in meters.

These curves are plotted in figure 7 with a scatter diagram of the points from Tables 1 and 2. The two curves are similar in appearance and appear to document three types of diffusion. It is suggested that the three diffusion types represent a) the zone of rapid diffusion in the near-building wake, b) a transition zone where the plume leaves the near-wake of the building and the turbulence within the wake is small or comparable to plume size, and finally, c) the "far wake" region where atmospheric turbulence now interacts with the wake to cause the plume to revert to the rate of diffusion expected without the presence of the structure(s). The zones, or types of diffusion are displaced further downwind (for absolute instead of normalized distances) at Rancho Seco

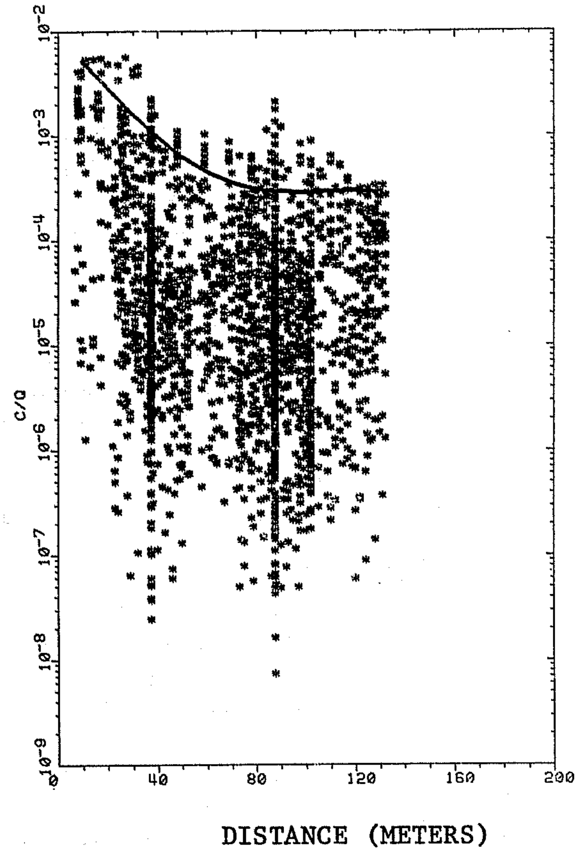

Figure 3. Scatter diagram of normalized concentrations versus distance for EOCR test.

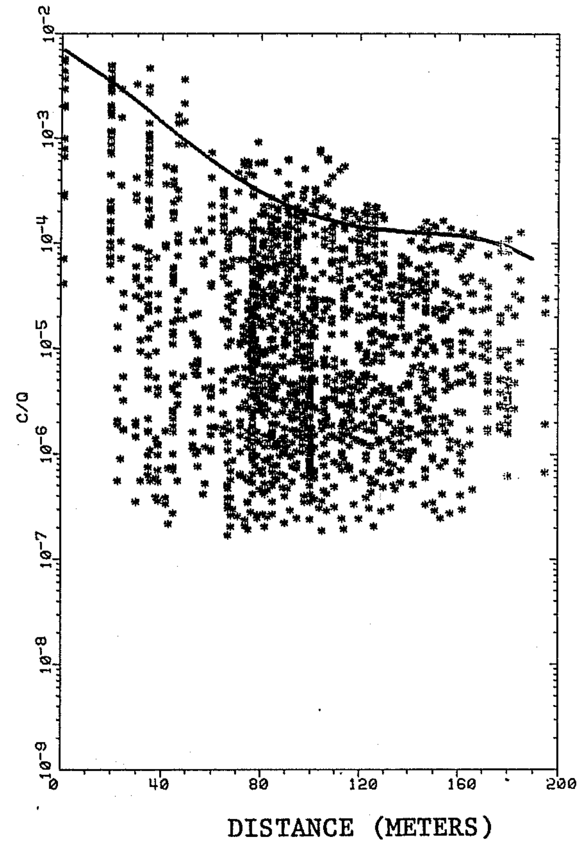

Figure 4. Scatter diagram of normalized concentrations versus distance for Rancho Seco tests.

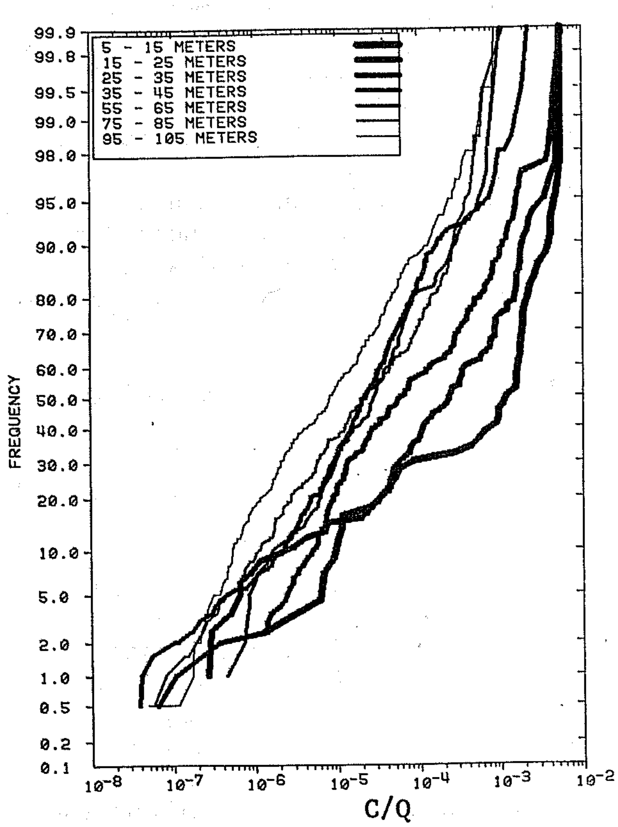

Figure 5. EOCR normalized concentrations versus cumulative frequency.

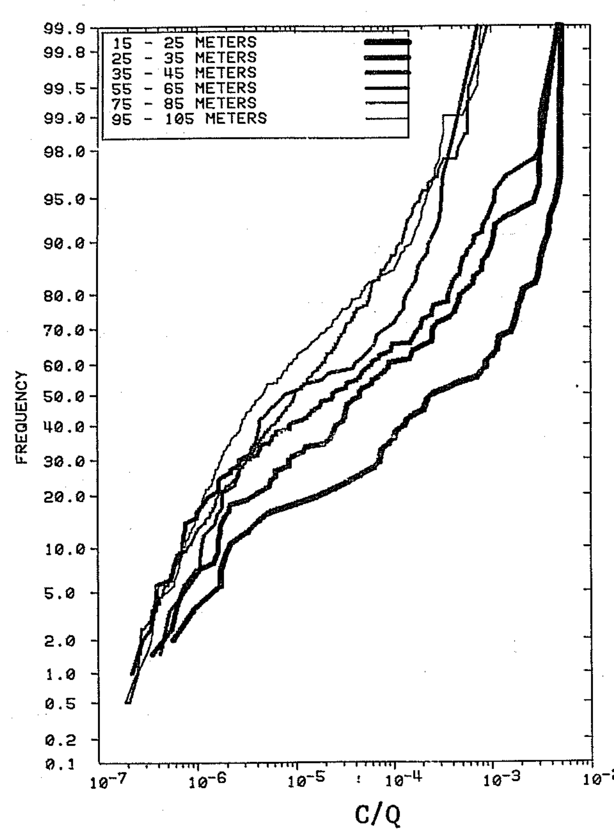

Figure 6. Rancho Seco normalized concentrations versus cumulative frequency.

Table 1. EOCR 10 meter bands

Band (meters)	Average distance (meters)	Number of points	C/Q (sec/m^3)
5-15	9.6	44	$4.736x10^{-3}$
15-25	21.6	84	$3.255x10^{-3}$
25-35	29.3	170	$1.619x10^{-3}$
35-45	38.3	454	$7.295x10^{-4}$
45-55	49.3	156	$5.460x10^{-4}$
55-65	60.8	99	$5.702x10^{-4}$
65-75	71.1	160	$4.411x10^{-4}$
75-85	79.8	229	$3.877x10^{-4}$
85-95	88.6	666	$1.504x10^{-4}$
95-105	99.9	270	$2.541x10^{-4}$
105-115	110.3	90	$4.320x10^{-4}$
115-125	120.7	119	$2.903x10^{-4}$
125-135	128.2	106	$2.693x10^{-4}$

Table 2. Rancho Seco 10 meter bands

Band (meters)	Average distance (meters)	Number of points	C/Q (sec/m^3)
0-10	1.0	16	$5.485x10^{-3}$
15-25	21.3	56	$4.495x10^{-3}$
25-35	33.0	73	$4.273x10^{-3}$
35-45	39.4	114	$1.072x10^{-3}$
45-55	48.3	82	$1.434x10^{-3}$
55-65	60.2	58	$3.151x10^{-4}$
65-75	70.2	119	$4.080x10^{-4}$
75-85	79.7	302	$1.883x10^{-4}$
85-95	90.1	226	$2.075x10^{-4}$
95-105	99.0	244	$2.224x10^{-4}$
105-115	110.0	134	$2.579x10^{-4}$
115-125	120.5	124	$1.908x10^{-4}$
125-135	129.0	120	$1.717x10^{-4}$
135-145	140.0	97	$7.865x10^{-5}$
145-155	149.5	109	$1.273x10^{-4}$
155-165	159.5	66	$9.701x10^{-5}$
165-175	169.0	38	$9.833x10^{-5}$
175-185	179.9	45	$9.685x10^{-5}$
185-195	189.4	9	$8.075x10^{-5}$

due to the influence of larger structures at that site. As can be seen in figure 7 the EOCR curve just reaches the beginning of zone 3.

Samples were collected out to 800 m at Rancho Seco and to 1600 m at EOCR. In a later study the above techniques will be applied to further examine the zone 3 region and determine if the two curves become parallel.

As a first attempt to scale the distance, in order to make the two curves comparable, the height of the structure (42.9 m for Rancho Seco and 22.9 m for EOCR) was used as a scaling length. In figure 8, this scaling by building height is shown. In a second and apparently better approach, the square root of the minimum cross sectional building area was used to scale downwind distance. These cross-sectional areas were 1090 m^2 for EOCR and 2050 m^2 for Rancho Seco. The results are illustrated in figure 9. Both curves fall rather sharply in zone 1, which extends for about one and one half scaled distances. In zone 2 both curves flatten out for about two more scaled distances. The difference in magnitude between the curves in this zone is probably related to the difference in the cross-sectional areas of the structures; the larger structure yields a greater total volumetric type of initial dilution. The curves differ by about a factor of two in this zone and the ratio of cross-sectional areas of the two facilities is essentially of the same magnitude. Zone 3 begins at about four scaled distances downwind where the curves appear to resume a more negative slope.

For much of zone 1 the two curves in figure 9 are not very different. In fact, at the 95% confidence level the curves show no significant difference out to about one scaled distance. This first zone of agreement

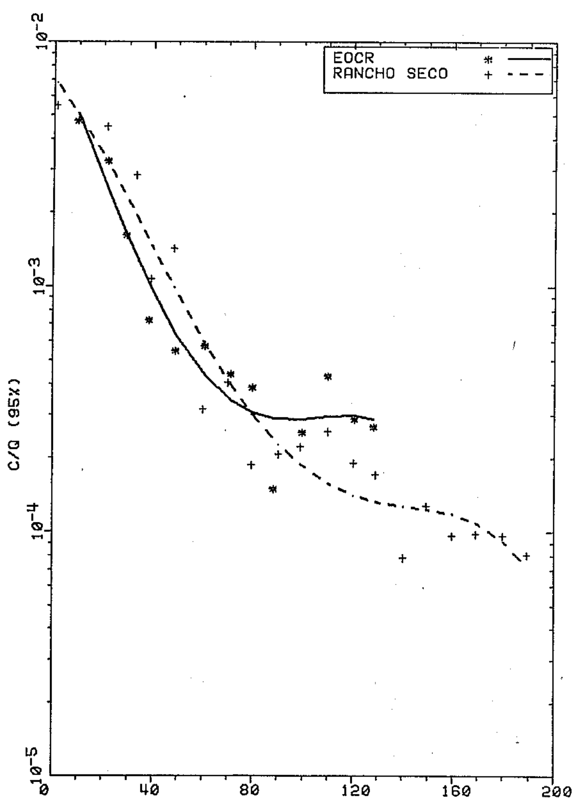

Figure 7. EOCR and Rancho Seco 95% level 4th order curves of normalized concentrations versus distance.

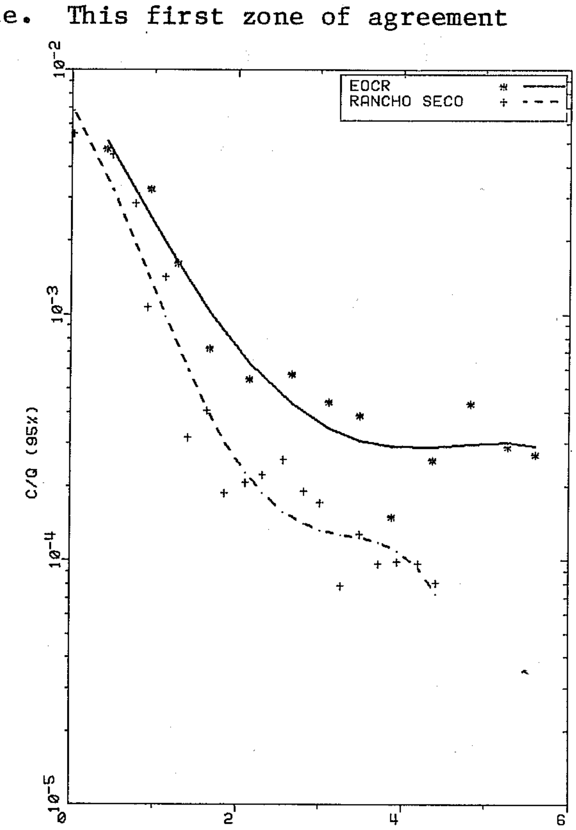

Figure 8. EOCR and Rancho Seco 95% level 4th order curves of normalized concentrations versus building heights.

suggests that close to the building a curve such as those shown in figure 9 would have some general applicability in describing maximum expected concentrations. At the Rancho Seco facility one scaled distance is about 45 m and at EOCR one scaled distance is about 33 m.

III. NRC MODEL COMPARISONS

When activity is assumed to leak from many points on the surface of the containment in conjunction with a single point receptor, NRC (Murphy and Campe, 1974) uses the following equation:

$$C/Q = [U(\sigma_y\sigma_z + a/(k+2))]^{-1} \quad (3)$$

$$k = 3/(s/d)^{1.4}$$

s = distance between containment surface and receptor location

d = diameter of containment

a = projected area of containment building

C/Q = relative concentration at the plume centerline (sec/m^3)

$\sigma_y\sigma_z$ = standard deviations of the gas concentration in the horizontal and vertical crosswind directions, respectively. These are evaluated at the distance from the source to the receptor.

Q = source strength (gm/sec)

U = wind speed (m/sec)

The parameters σ_y,σ_z and U are determined by statistical analysis of site meterological data to determine values that are indicative of the five percentile dispersion at the site. Typically Pasquill "F" conditions with wind speeds of 0.5 to 1.5 m/s are assumed (Murphy and Campe, 1974).

Table 3 includes the stability class for each test [as determined by vertical temperature gradient measurements, (NRC Regulatory Guide 1.23)], the distance from the source to the maximum concentration at the same level (i.e., ground-to-ground or roof-to-roof), the wind speed for the test, the maximum measured relative concentration, the calculated relative concentration [using (3)], and the ratio of calculated to measured concentration [using

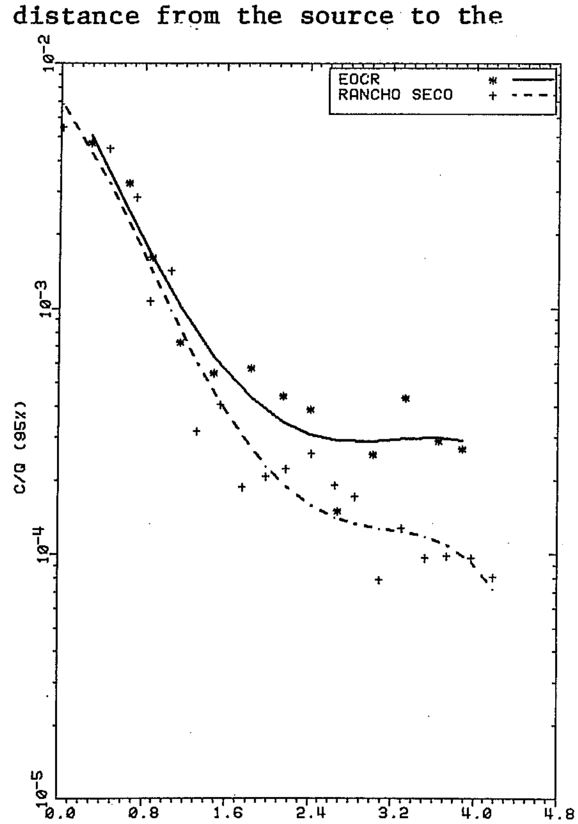

Figure 9. EOCR and Rancho Seco 95% level 4th order curves of normalized frequency versus scaled distance.

Table 3.

Test[1]	Stability	Distance (Meters)	U (m/x)	C/Q(Meas) (Sec/m^3)	C/Q(calc) (Sec/m^3)	Ratio (Calc/Meas)
1-SMUD	A	17	1.0	8.81×10^{-5}	7.85×10^{-3}	89.1
7-SMUD	A	20	4.6	2.07×10^{-3}	3.23×10^{-3}	1.56
5-EOCR	A	38	7.4	9.42×10^{-4}	6.44×10^{-4}	0.684
10-EOCR	A	61	0.8	1.05×10^{-4}	1.65×10^{-3}	15.7
11-EOCR	A	23	1.5	1.53×10^{-4}	8.95×10^{-3}	58.5
13-EOCR	A	20	1.9	7.68×10^{-4}	7.11×10^{-3}	9.26
6-SMUD	D	6	2.8	5.13×10^{-3}	1.52×10^{-2}	2.96
9-SMUD	D	20	1.5	8.74×10^{-4}	5.86×10^{-2}	67.1
15-SMUD	D	20	0.8	5.00×10^{-3}	5.75×10^{-2}	11.5
22-SMUD	D	20	1.9	7.09×10^{-4}	4.68×10^{-2}	66.0
6-EOCR	D	27	1.8	1.77×10^{-3}	3.32×10^{-3}	1.88
15-EOCR	D	25	2.0	1.79×10^{-3}	3.70×10^{-2}	20.7
16-EOCR	D	8	3.1	2.29×10^{-3}	6.55×10^{-3}	2.86
11-SMUD	E	20	3.7	4.93×10^{-3}	1.02×10^{-2}	2.07
12-SMUD	E	20	1.3	4.97×10^{-3}	5.55×10^{-2}	11.2
13-SMUD	E	6	0.8	1.03×10^{-3}	5.37×10^{-2}	52.1
16-SMUD	E	35	1.0	3.08×10^{-3}	6.53×10^{-2}	21.2
19-SMUD	E	30	1.1	3.32×10^{-3}	7.33×10^{-2}	22.1
4-EOCR	E	26	3.1	1.57×10^{-3}	2.03×10^{-3}	1.29
12-EOCR	E	30	2.3	7.13×10^{-4}	2.45×10^{-2}	34.4
14-EOCR	E	32	1.9	4.02×10^{-4}	3.33×10^{-3}	8.28
22-EOCR	E	8	2.4	9.17×10^{-4}	8.72×10^{-3}	9.51
23-EOCR	E	16	1.9	2.26×10^{-3}	1.94×10^{-2}	8.58
10-SMUD	F	20	2.9	1.82×10^{-3}	1.71×10^{-2}	9.40
18-SMUD	F	20	0.7	3.15×10^{-3}	2.56×10^{-1}	81.3
23-SMUD	F	24	0.8	2.95×10^{-3}	5.86×10^{-2}	19.9
3-EOCR	F	26	0.5	8.14×10^{-4}	1.29×10^{-2}	15.8
8-EOCR	F	27	0.9	5.72×10^{-3}	4.89×10^{-2}	8.55
18-EOCR	F	8	4.1	1.78×10^{-3}	5.23×10^{-3}	2.94
24-EOCR	F	8	1.8	2.02×10^{-3}	1.16×10^{-2}	5.74
4-SMUD	G	35	1.3	4.68×10^{-4}	1.37×10^{-1}	293.
5-SMUD	G	20	0.9	1.85×10^{-3}	2.77×10^{-1}	150.
8-SMUD	G	35	0.9	4.75×10^{-3}	2.09×10^{-1}	44.0
14-SMUD	G	20	0.9	4.39×10^{-3}	2.63×10^{-1}	59.9
17-SMUD	G	49	2.0	3.62×10^{-3}	6.97×10^{-2}	19.3
20-SMUD	G	20	2.1	3.46×10^{-3}	1.16×10^{-1}	33.5
21-SMUD	G	20	2.3	3.84×10^{-3}	1.04×10^{-1}	27.1
7-EOCR	G	11	0.5	4.88×10^{-3}	4.74×10^{-2}	9.71
9-EOCR	G	100	1.9	3.58×10^{-4}	1.58×10^{-3}	4.41
17-EOCR	G	8	1.1	2.17×10^{-3}	1.75×10^{-2}	8.06
19-EOCR	G	8	1.0	2.91×10^{-3}	2.04×10^{-2}	7.01
20-EOCR	G	8	1.5	1.90×10^{-3}	1.44×10^{-2}	7.58
21-EOCR	G	8	1.3	4.18×10^{-3}	1.57×10^{-2}	3.76

1 SMUD refers to Rancho Seco.

(3)], and the ratio of calculated to measured concentrations. Somewhat higher concentrations than those in the table were occasionally measured at distances less that 5 m from the source. These higher values were not listed in the table because of the close proximity of the sampler from the source.

In calculating σ_y and σ_z the following expressions were used:

$$\sigma_y = ax^{.9031}$$

$$\sigma_z = bx^c$$

where a, b and c are functions of stability as indicated in table 4 (Eimutis and Konicek, 1972).

Table 4.

Stability	a	b	c
A	.3658	.192	.936
D	.1471	.079	.881
E	.1046	.063	.871
F	.0722	.053	.814

For stability class G: $\sigma_y(G) = 2/3\sigma_y(F)$ and $\sigma_z(G) = 3/5\sigma_z(F)$

From the values in Table 3 we can see that in only one case did (3) underestimate the measured peak value. This was in test 5 at the EOCR facility under "A" atmospheric stability conditions. The wind speed in this case was 7.4 m/s. Perhaps in this example the use of temperature gradient, by itself, was insufficient to accurately determine the stability class. Eqn. (3) was usually within a factor of 10 at the EOCR facility and within two orders of magnitude at Rancho Seco.

IV. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Since the EOCR and Rancho Seco sites and structures are very different, it is significant to note that the maximum measured relative concentrations from numerous samples were just under 6×10^{-3} sec m^{-3} at both sites. It is postulated that there is enough turbulence generated close to the buildings within a surface boundary or skin layer that values of C/Q much larger than 6×10^{-3} sec m^{-3} will not be measured for sixty minute averaging times. For shorter averaging times, somewhat larger values may be expected (Smith, 1978).

In this paper a consistency in measured tracer concentrations at the two sites was found that enables one to determine a more realistic maximum expected C/Q within about one scaled distance units from the building. This "method" is also simple to use since the only information required is the minimum cross sectional area of the building and the distance from source to receptor.

Further progress in our understanding of diffusion in the near-building environment will hinge on well-planned field measurements which are carefully correlated with wind tunnel studies. R. N. Meroney, Colorado State University, has conducted wind tunnel modeling of the EOCR and Rancho Seco sites in order to make comparisons with the field studies.

Several specific problems need to be resolved:

a) By means of field studies, the effect of building wakes needs to be separated from that of wind meander in time-averaged concentration distributions. Licensing requirements might then consider the magnitudes of these effects for a given site.

b) The impact of changes in basic building shapes probably requires additional wind tunnel and field investigations. The effects of surface roughness, relative wind direction, turbulent intensities, Reynolds numbers, and eddy scale need to be documented. In this way, a useful data base for analytical modeling may be built. The state of the art in wind tunnel modeling could be particularly aided if full scale studies evaluated the nature of flow around buildings with projecting surfaces, circular cross-section, and curved roof surfaces (Cermak, 1975).

c) The nature of air flow along the building skin needs to be studied. Such factors as the steadiness of the approach flow, the wind shear (profile) and the turbulent characteristics of the wind all affect locations of flow separation and reattachment, and should be well-documented. Data defining the relationships between mean surface pressure distributions and flow patterns at various distances from the building surface are not well understood. The majority of flow studies have concerned themselves with the wake side of buildings. Attention needs to be given to measurements on each of the other sides, as well. Remote sensing technologies might be exploited as a cost effective means to obtain some of the data.

d) Little is known about the speed of movement of gases within the near-building environment. Sampling techniques suitable for study of transient (or fluctuating) pollutant fields may be utilized for understanding classes of problems related to short period phenomena.

e) The relative magnitudes and effects due to varying building geometry, atmospheric parameters, topography, and source exit speed need definition. These four variables introduce a wide field of research for both the wind tunnel and full-scale investigations. As measurement programs progress from the simple to the complex, close coordination among the three areas of analytic modeling, full scale field studies, and wind tunnel measurements should be maintained. Judicious exploitation of the advantages of each of the separate methods may best help fill the gaps in understanding.

V. ACKNOWLEDGEMENTS

The Rancho Seco and EOCR tracer test series were supported by the NRC Office of Nuclear Regulatory Research and the DOE Division of Reactor Research and Technology. The analysis of the close-in tracer concentrations which is presented in this report, is partially supported by the NRC Office of Nuclear Reactor Regulation.

The author's wish to acknowledge the willing and helpful assistance of Dr. Jack E. Cermak, Colorado State University, and of Mr. Robert H. Forde, Union Carbide Corporation, in the preparation of the bibliography found in Appendix A.

REFERENCES

Cermak, J. E., (1975): Applications of Fluid Mechanics to Wind Engineering-A Freeman Scholar Lecture, Journal of Fluids Engineering, Vol. 97, pp 9-38.

Eimutis, E. C., and M. G. Konicek, (1972): Derivation of Continuous Functions for the Lateral and Vertical Dispersion Coefficients, Atmospheric Environment, Vol. 6, pp. 859-863.

Murphy, K. G., and K. M. Campe (1974), Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19, 13th AEC Air Cleaning Conference.

Smith, Douglas, 1978: Personal Communication (unpublished dissertation)

Start, G. E., J. H. Cate, C. R. Dickson, N. R. Ricks, G. R. Ackermann, J. F. Sagendorf (1977): Rancho Seco building wake effects on atmospheric diffusion. NOAA Tech. Memo., ERL ARL-69, Air Resources Laboratories, Idaho Falls, ID. NUREG/CR-0456.*

Start, G. E., N. F. Hukari, J. F. Sagendorf, J. H. Cate, C. R. Dickson, N. R. Ricks, (1979): EOCR building wake effects on atmospheric diffusion. NUREG/CR-1395. (To be published, available from the National Oceanic and Atmospheric Administration)

*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

APPENDIX A

The bibliography which follows represents a compilation of the known research work in close-to-building diffusion. It includes complete listings on known research work dealing directly with diffusion, but lists only a portion of those references which address related topics such as the structure of atmospheric boundary layers and turbulence, or restrictive hardware or theory development. The papers are ordered chronologically by topic. Approximately 3% of the listings were thought to pertain to more than one topic listing. Where this is the case, the reference is enclosed in parenthesis under the secondary topic.

The topic areas used are:

I. Summary Papers

   A. Empirical data summary

II. Theoretical Studies

III. Analytic Development

IV. Wind Tunnel Tests

   A. Area of Flow Separation

   B. Wake Area

   C. Effects of Other Structures

   D. Measured Surface Pressures and their effects on Building Surface Flows

   E. Effects of Meteorological Parameters, Surface Roughness, and Upstream Turbulence

   F. Modeling Problems

   G. Wind Tunnel Hardware Development

   H. Scaling Validation Studies

   I. Studies of Specific Building Complexes

V. Studies for Engineering Diffusion Estimates

VI. Field (Prototype) Studies

VII. Comparison Studies - Model to Prototype

VIII. Related Research Topics

IX. Applicable Engineering Journals

I. SUMMARY PAPERS

B. H. Evans, "Natural Flow Around Buildings," Texas Engineering Experimental Station Research Report 59, College Station, Texas, 1957.

Halitsky, J., "Gas Diffusion Near Buildings," Translations of American Society of Heating, Refrigeration and Air Conditioning Engineers, Vol. 69, 1963, pp 476-477.

Barry, P. J., 1964: Estimation of downwind concentration of airborne effluents discharged in the neighborhood of buildings. Canadian Report AECL-2043, 16 pp.

J. Halitsky, "Gas Diffusion Near Buildings," Meterology and Atomic Energy, U. S. Atomic Energy Commission, TID-24190, 1968, pp. 221-255.

Lawson, T. V. 1968 Architects' Journal Handbook - Building Environment, p. 1283.

W. A. Mair and D. J. Maull, "Bluff Bodies and Vortex Shedding--A Report on Euromech 17, 1971": Journal of Fluid Mechanics, vol. 45, part 2, pp. 209-224.

Abbey, R. F. Jr., "Concentration Measurements Downwind of Buildings: Previous and Current Experiments," 3rd Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, October 19-22, 1976, Raleigh, N.C. pp 247-254.

Cermak, J. E., Aerodynamics of Buildings, Annual Reviews of Fluid Mechanics, Vol. 8, 1976, CEP74-75JEC51.

Cermak, J. E., Nature of Air Flow Around Buildings, ASHRAE Transactions 1976, Vol. 82, Part I, CEP75-76JEC5.

Meroney, R. N., J. A. Peterka, R. V. Hatcher and K. Kothari (1976): Gaseous Dispersion and Turbulence in the Wake of Nuclear Power Plants, 4th International Clean Air Congress, Tokyo, May 16-20, 1977. CEP76-77 RNM-JAP-RVH-KK14. Colorado State Univ., Ft. Collins, CO.

A. EMPIRICAL DATA SUMMARY

Barry, P. J. 1964: Estimation of downwind concentration of airborne effluents discharged in the neighborhood of buildings. Canadian Report AECL-2043, 16pp.

II. THEORETICAL STUDIES

Baines, W. D. 1965, Proc. of Symp. on Wind Effects on Buildings and Structures, London, H.M.S.O.

Gosman, A. D., Pun, W. M., Runchal, A. K., Spalding, D. B. & Wolfshtein, M. W. 1969: Heat and Mass Transfer in Re-Circulating Flows. New York: Academic Press.

Sforza, Pasquale M., A Quasi-Axisymmetric Approximation for Turbulent Three-Dimensional Jets and Wakes, AIAA Journal, Vol. 7, pp. 1380-1383, 1969.

Hunt, J. C. R., Further Aspects and Theory of Wakes Behind Buildings and Comparison of Theory with Experiment, CERL Report RL/L/1665, Central Electric Research Laboratories, 1971.

Hunt, J. C. R. (1971): The Effect of Single Buildings and Structures, Phil. Trans. Roy. Soc. Lond., A., 269, pp 457-467.

Hunt, J. C. R. 1973. A theory of turbulent flow around two-dimensional bluff bodies. J. Fluid Mech. 61:625-706.

Lemberg, R., On the Wakes Behind Bluff Bodies in a Turbulent Boundary Layer, Report BLWT-3-73, University of Western Ontario, London, Canada, 1973.

Saffman, P. G., Structure of Turbulent Line Vortices, The Physics of Fluids, Vol. 16, No. 8, August 1973.

Counihan, J., J. C. R. Hunt and P. S. Jackson (1974): Wakes behind two-dimensional surface obstacles in turbulent boundary layers. J. Fluid Mech. 564, part 3, p 529-563.

Lavery, T. F., Egan, B. A., and Iwanchuk, R. M., "The Numerical Simulation of the Advection and Diffusion of a Plume Under Aerodynamic Downwash Conditions," Reprint Paper No. 74-215, 67th Annual Meeting of the Air Pollution Control Association, Denver, CO, June 1974, 16 pp.

Castro, I. P. and A. G. Robins (1975): The effect of a thick incident boundary layer on the flow around a small surface mounted cube. Central Electricity Generating Board, Marchwood Laboratories Report R/M/N795, Marchwood, England.

III. ANALYTIC DEVELOPMENT

Birkhoff, G. & Zarantello, E. H. 1957: Jet, Wakes and Cavities, New York Academic Press.

Morkovin, M. V. 1964: Flow around circular cylinder. Symposium on Fully Separated Flows, American Soc. Mech. Engrs.

Halitsky, J., 1965: Estimation of stack height required to limit contamination of building air intakes. Amer. Ind. Hygiene J., 26, 106-108.

Lin, J. T. and C. J. Apelt, Stratified Flow over an Obstacle: A Numerical Experiment, Project THEMIS Technical Report No. 7, January 1970, CER69-70JTL-CJA25.

Sadeh, W. Z., S. P. Sutera and P. F. Maeder, Analysis of Vorticity Amlification in the Flow Approaching a Two-Dimensional Stagnation Point, Zeitchr. angew. Math. Phys. -ZAMP, Vol. 21, 5, pp. 699-716, September 1970, CEP69-70WZS23, AD-718-257.

Meroney, R. N. and T. Yamada, Numerical and Wind Tunnel Simulation of Airflow over and Obstacle, Presented at the National Conference on Atmospheric Waves, 11-15 October 1971, Salt Lake City, Utah, CEP70-71RNM-TY94.

Sadeh, W. Z., J. E. Cermak, T. Kawatani, "Flow Over High Roughness Elements," Boundary Layer Meterology (1; 321; 1971).

Hirt, C. W. and J. L. Cook (1972): Calculating Three-Dimensional Flows around Structures and Over Rough Terrain, J. Comput. Phys., 10:324 (1972).

Peterka, J. A., J. E. Cermak, 1975: Wind Pressures on Buildings, Probability Densities. Proc. Am. Soc. Civ. Eng. J. Struct. Div. 101: 1255-67.

Halitsky, J.(1976): Wake and Dispersion Models for the EBR-II Building Complex, paper submitted to Atmospheric Environment, 22, Sept. 1976.

Meroney, R. N., J. A. Peterka, R. V. Hatcher and K. Kothari (1976): Gaseous Dispersion and Turbulence in the Wake of Nuclear Power Plants, May 16-20, 1977., CEP76-77RNM-JAP-RVH-KK14. Colorado State Univ. Ft. Collins, Co.

IV. WIND TUNNEL TESTS

A. AREA OF FLOW SEPARATION

Naumann, A., Morsbach, M. & Kramer, C. 1966: The conditions of separation and vortex formation past cylinders. AGARD Fluid Dynamics Panel, Specialists' Meeting on Separated Flows, Brussels.

Vickery, B. J. 1966: J. Fluid Mech. 25, 481.

Ostrowski, J. S., R. D. Marshall and J. E. Cermak, Vortex Formation and Pressure Fluctuations on Buildings, presented at Research Seminar on Wind Effects on Buildings and Structures, Ottawa, Canada, Sept. 1967, CEP67-68JSO-RDM-JEC80.

Sandborn, V. A., Characteristics of Boundary Layers at Separation and Reattachment, Technical Report, ONR Contract No. N00014-68-A-0493-0001, Research Memo No. 14, February 1969, CEM68-69VAS14.

Meroney, R. N. and Yang, B. T., "Gaseous Plume Diffusion About Isolated Structures of Simple Geometry," 2nd International Air Pollution Conference, December 6-11, 1970, Washington, D. C., 31 p.

McLaren, F. G. 1970: Ph.D. dissertation, Univ. of Nottingham.

Halitsky, J. (1972): Separated Flow Around Buildings and Other Man-Made Obstructions, Univ. of Mass., Amhurst, 16 Nov. 1972.

Robertson, J. M., J. B. Wedding, J. A . Peterka and J. E. Cermak, Wall Pressures of Separation-Reattachment Flow on a Square Prism in Uniform Flow, Submitted to Journal of Industrial Aerodynamics, March 1976, CEP75-76JMR-JBW-JAP-JEC24.

B. WAKE AREA

Smith, E. G., 1951: The feasibility of using models for predetermining natural ventilation. Research Report, Texas Engineering Experimental Station, Texas A & M College.

Roshko, A. 1961, J. Fluid Mech. 10, 345-356.

Halitsky, J., J. Golden, P. Halpern, and P. Wu, 1963: Wind Tunnel Tests of Gas Diffusion from a Leak in the Shell of a Nuclear Power Reactor and from a Nearby Stack. N. Y. University, Dept. of Meteor. and Ocean., Geophysical Sciences Lab., Report No. 63.2.

Gerrard, J. H. 1966 J. Fluid Mech. 25, 143-164.

Hinds, W. T., 1968: On the variation of concentration in plumes and building wakes. Proceedings of the USAEC Meteor. Inf. Meeting, edited by C. A. Mawson, Rept. No AECL-2787, 105-131.

Gaster, M., 1969, J. Fluid Mech. 38, 565-576.

Maull, D. J. 1969, The wake characteristics of a bluff body in a shear flow. Paper 16, AGARD Conference Proceedings no. 48.

Etzold, F. (1970): Diffusion of Matter in the Near Wake of Cylindrical Bodies Protruding into a Cross-flow, European Mechanics Colloquium 17, Cambridge, 3 Jul. 1970.

Meroney, R. N., and B. T. Yang, "Gaseous Plume Diffusion About Isolated Structures of Simple Geometry," 2nd International Air Pollution Conference, December 6-11, 1970, Washington, D. C., 31 pp.

Yang, B. T. and R. N. Meroney, "Gaseous Dispersion into Stratified Building Wakes," Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, CO., Tech. Rept. CER70-71BTY-RNM8, 1970, 103 p.

Meroney, R. N. and C. R. Symes, Entrainment of Stack Gases by Building of Rounded Geometry, Proceedings of Conference on Air Pollution Meterology, 5-8 April 1971, Raleigh, NC, CEP70-71RNM-CRS49.

Meroney, R. N., Gaseous Plume Diffusion about Isolated Structures of Simple Geometry, AEC Report No. COO-2053-7, CER71-72RNM19.

Meroney, R. N., and E. T. Yang, 1971: Wind-tunnel study of gaseous mixing due to various stack heights and injection rates about an isolated structure. Fluid Dynamics & Diffusion Lab., Rept. No. CER71-72RNM-BTY16, Colorado State Univ., Fort Collins, CO.

Lemberg, R., On the Wakes Behind Bluff Bodies in a Turbulent Boundary Layer, Report BLWT-3-73, University of Western Ontario, London, Canada, 1973.

Hansen, A. C., J. A. Peterka and J. E. Cermak, Windtunnel Measurements in the Wake of a Simple Structure in a Simulated Atmospheric Flow, for George C. Marshall Flight Center, NASA, June 1974, CER73-74ACH-JAP-JEC43(a), NASA CR-2540.

Hansen, A. C. and J. E. Cermak, Vortex-Containing Wakes of Surface Obstacles, Project Themis Technical Report No. 29, December 1975, CER75-76ACH-JEC16, ADA19785.

Hansen, A. C., J. E. Cermak and J. A. Peterka, Vortex Wakes Behind Bluff Bodies Submerged in a Turbulent Boundary Layer, Proceedings Second U. S. National Conference on Wind Engineering Research, 22-25 June 1975, Fort Collins, CO.

Peterka, J. A. and J. E. Cermak, "Turbulence in Building Wakes," Proceedings of the Fourth International Conference on Wind Effects on Buildings and Structures, London, England, 1975.

Robins, A. G., "Plume Dispersion in the Vicinity of a Surface Mounted Cube," Central Electricity Generating Board, Report Number R/M220, Marchwood Engineering Laboratories, England, 1975.

Huber, A. H. and Snyder, W. H., "Building Wake Effects on Short Stack Effluents," 3rd Symposium on Atmospheric Turbulence, Diffusion and Air Quality, October 19-22, 1976, Raleigh, N. C., pp 235-242.

C. EFFECTS OF OTHER STRUCTURES

Bailey, A., Vincent, N. D. G. 1943: Wind pressures on buildings including the effects of adjacent buildings. J. Inst. Civ. Eng. 20: 243-75.

Kalinske, A. A., R. A. Jensen and C. F. Schadt, 1945: Wind Tunnel Studies of Gas Diffusion in a Typical Japanese Urban District OSRD, NDRC. Div. 10. Informal Rep. N. 10.3A-48, available from Library of Congress, Washington, D. C.

Baines, W. D. 1965, Proc. of Symp. on Wind Effects on Buildings and Structures, London:H.M.S.O.

Maul, D. J. 1966: Nature, Lond. 211, no. 5053, 1073-1074.

Mair, W. A. & Maull, D. J. 1971: Aerodynamic behaviour of bodies in the wakes of other bodies. Phil Trans. Roy. Soc. A.

Wise, A. F. E., "Effects Due to Groups of Buildings," Phil. Trans. of the Royal Society of London, Series A, Vol. 269, No. 1199, 1971, pp 469-485.

D. MEASURED SURFACE PRESSURES AND THEIR EFFECTS ON BUILDING SURFACE FLOWS

Bailey, A. 1933. Wind pressures on buildings. Inst. Civil Eng. Selected Eng. Pap. No. 189.

Chien, N., Y. Feng, H. Wang, and T. Siao, 1951: ; Wind Tunnel Studies of Pressure Distribution on Elementary Building Forms. Iowa Institute of Hydraulic Research, State Univ. of Iowa, Iowa City.

Holdredge, E. S. and B. H. Reed, 1956: Pressure Distribution on Buildings. Summary Report to U. S. Army, Camp Detrick, Md., by Texas Eng. Exp. Sta., College Sta., Texas.

Ostrowski, J. S., R. D. Marshall and J. E. Cermak, Vortex Formation and Pressure Fluctuations on Buildings, Presented at Research Seminar on Wind Effects on Buildings and Structures, Ottawa, Canada, Sept. 1967, CEP67-68JSO-RDM-JEC80.

Kung, R. J., S. SethuRaman and J. E. Cermak, Wind Pressures on Standard Oil Company (Indiana) Building, Report for Edward Durell Stone and Associates and the Perkins & Will Corp., Sept. 1979, CER70-71RJK-SS-JEC15.

Dalgliesh, W. A., "Cladding Pressures on Commerce Court Tower," Paper presented at Symposium on Full-Scale Measurement of Wind Effects on Tall Buildings and Other Structures, The University of Western Ontario, London, Ontario, 1974, pp. 1-14.

Aikens, R. E., J. A. Peterka and J. E. Cermak, Pressure Distributions on Buildings in Atmospheric Shear Flows, Proceedings Second U. S. National Conference on Wind Engineering Research, 22-25 June 1975, Fort Collins, CO.

K. J. Eaton and J. R. Mayne, "The Measurement of Wind Pressures on Two-Story Houses at Aylesburg," Journal of Industrial Aerodynamics, vol. 1, no. 1, 1975, pp 67-110.

E. EFFECTS OF METEROLOGICAL PARAMETERS, SURFACE ROUGHNESS AND UPSTREAM TURBULENCE

van Einern, J., et al., Windbreaks and Shelterbelts, World Meteorlogical Organization, Technical Report No., 59, 1964.

Baines, W. D. 1965. Effects of velocity distribution on wind loads and flow patterns on buildings. Proc. Conf. Wind Effects Buildings Structures. Teddington, England, 198-225.

Armitt, J. 1968. The effect of surface roughness and free-stream turbulence on the flow around a model cooling tower at critical Renolds numbers. Proc. Symp. Wind Effects Buildings Structures, Loughborough Univ. Technol. England, 6.1-6.13.

Hunt, J. C. R. 1970, C.E.R.L. Rep. RD/L/R1665.

Maull, D. J. 1966 Nature, Lond. 211, no. 5053, 1073-1074.

Verma, S. G. and J. E. Cermak, Mass Transfer from Rough Surface, Technical Report, OWRR, Project No. B-015, COLO, May 1971, CER70-71SBV-JEC59.

F. MODELING PROBLEMS

Jensen, M. 1958: The model law for phenomena in natural wind. Ingenioeren 2:121-28.

Golden, J. (1961), "Scale Model Techniques," M. A. Thesis, Dept. of Meteorology and Oceanography, New York University.

Jensen, M., N. Franck 1965: Model-Scale Tests in Turbulent Wind. Pt. II, Copenhagen: Danish Technical Press. 170 pp.

Cermak, J. E., V. A. Sandborn, E. J. Plate, R. N. Meroney, G. J. Binder, H. Chuang and S. Ito, Simulation of Atmospheric Motion by Wind Tunnel Flows, Technical Report, Grant DA-AMC-28-043-65-G20, May 1966.

Cermak, J. E. and S. P. S. Arya, "Problems of Atmospheric Shear Flows and Their Laboratory Simulation," Boundary-Layer Meterology, vol. 1, 1970, pp 40-60.

Cermak, J. E., "Laboratory Simulation of the Atmospheric Boundary Layer," AJAA Journal, vol. 9, 1971, pp 1746-1754.

Peterka, J. A., Cermak, J. E. 1974a. Simulation of atmospheric flows in short wind tunnel test sections. Tech. Rep. CER73-74 J AP-JEC32. Fluid Dyn. Diffusion Lab., Co. State Univ., Fort Collins, CO, 52 pp.

G. WIND TUNNEL HARDWARE DEVELOPMENT

Cermak, J. E., "Wind Tunnel for the Study of Turbulence in the Atmospheric Surface Layer," Fluid Dynamics and Diffusion Laboratory Colorado State University, Fort Collins, CO, Tech. Rept. CER58JEC42, 1958, 31 pp.

Plate, E. J. and J. E. Cermak, "Micro-Meteorological Wind-Tunnel Facility," Fluid Dynamic and Diffusion Laboratory, Colorado State University, Fort Collins, CO, Tech. Rept. CER63EJP-JEC9, 1963, 65 pp.

H. SCALING VALIDATION STUDIES

Jensen, M., and N. Frank, 1963: Model-scale tests in turbulent wind Part I: phenomena dependent on the wind speed, shelter at houses--dispersal of smoke. The Danish Technical Press, Copenhagen, Denmark.

Halitsky, "Validation of Scaling Procedures for Wind-Tunnel Testing of Diffusion Near Buildings," Geophysical Sciences Laboratory, Report No. TR-69-8, New York University, N. Y., 1969, 195 pp.

Ludwig, G. R. and T. R. Sundaram, "On the Laboratory Simulation of Small Scale Atmospheric Turbulence" CAL No. VC2740-S-1, 1969.

I. STUDIES OF SPECIFIC BUILDING COMPLEXES

Halitsky, J. and H. Jones, 1962: Wind Tunnel Tests of Exhaust Recirculation at the NIH Clinical Center. Am. Ind. Hyg. Conf., Washington, D. C. unpublished.

Meroney, R. N., J. E. Cermak and F. H. Chaudhry, Wind Tunnel Model Study of Shoreham Nuclear Power Station Unit I, Long Island Lighting Co., Prepared under contract to Stone and Webster Engineering Corp., Part 1, July 1968, CER68-69RNM-JEC-FHC1.

Chaudhrey, F. H. & J. E. Cermak (1971): Study of Wind Pressures and Air Quality around Children's Hospital, National Medical Center, CER70-71FHC-JEC55, Colorado State Univ. Ft. Collins, CO, 72 pp.

Cermak, J. E., Chaudhry, F. H., A. C. Hansen, J. A. Garrison, 1972. Wind and air-pollution control study of Yerba Buena Center, San Francisco Tech. Rep. CER71-72JEC-FHC-ACH-JAG15. Fluid Dyn.

Cermak, J. E. and S. K. Nayak, Wind-Tunnel Model Study of Downwash from Stacks at Maui Electric Company Power Plant, Kahului, Hawaii, Stearns-Roger, Inc., March 1973, CER72-73JEC-SKN28.

Meroney, R. N., J. E. Cermak, J. R. Connell and J. A. Garrison, Wind Engineering Study of Atmospheric Dispersion of Airborne Materials Released from a Floating Nuclear Power Plant, Tech. Rept. for Offshore Power Systems, Inc., Aug. 1974, CER74-75RNM-JEC-JRC-JAG4.

V. STUDIES FOR ENGINEERING DIFFUSION ESTIMATES

Lighthill, M. J. 1956, J. Fluid Mech. 1, 31.

Halitsky, "Vent to Intake Short Circuit," Air Conditioning Heating and Ventilating, p. 81, July 1961.

Halitsky, J., 1962: Diffusion of Vented Gas around Buildings. Journal APCA 12, 74-80.

McCormick, R. A. 1971. Air Pollution in the Locality of Buildings. Philos. Trans. R. Soc. London Ser. A 269:515-26.

Cermak, J. E., F. H. Chaudhry and J. A. Bagala, Urban and Architectural Planning for Air Pollution Control, Presented at the 65th Annual Meeting of APCA, Miami Beach, Florida, 18-22 June 1972, CEP71-72JEC-FHC54.

Murphy, K. C., and K. M. Campe, 1975: Nuclear power plant control room ventilation system design for meeting General Criterion 19. Proceedings of the 13th AEC Air Cleaning Conference, edited by M. W. First, Aug. 12-15, 1974, San Francisco, CA CONF-740807, 401-428.

Wilson, D. J., "Contamination of Air Intakes from Nearby Vents," Univ. of Alberta, Dept. of Mechanical Eng. Rept. No. 1, May 1976 (also as final contract report ASHRAE, RP-136, De. 1975).

Wilson, D. J. and d. D. J. Netterville, "Effluent Plume Impingement on Downwind Buildings," Proc. Second U. S. National Conference on Wind Engineering Research, Colorado State Univ., Fort Collins, June 1975.

Wilson, D. J., "Contamination of Air Intakes from Roof Exhaust Vents," ASHRAE Transactions 82, Part I, 1976.

Wilson, D. J. (1978): Dilution of Exhaust Gases from Building Surface Vents, Dept. of Mech. Engin., U. of Alberta, Edmonton, Alberta, Canada.

VI. FIELD (PROTOTYPE) STUDIES

Islitzer, N. F., 1965: Aerodynamic effects of large reactor complexes upon atmospheric turbulence and diffusion, USAEC, Idaho Op. Off. Rept. No. IDO-12041.

Munn, R. E., A. F. W. Cole, "Turbulence and Diffusion in the Wake of the Building," Atmospheric Environment, Vol. 1, pp. 34-43, (1967).

Dickson, C. R., G. E. Start, and E. H. Markee, 1969: Aerodynamic effects of the EBR-II reactor complex on effluent concentration, Nuc. Safety, 10, 228-242.

Hinds, W. T., "Peak-to-Mean Concentration ratios from ground-level sources in building wakes," Atmosphere Environment, Vol. 3, 1969, pp 145-156.

Colmer, J. J. 1970 R.A.E. Tech. Rep. 70202.

Metropolitan Edison Company, 1972: Atmospheric diffusion experiment with SF6 tracer gas at Three Mile Island Nuclear Station under low wind speed inversion conditions. Three Mile Island Unit FSAR Amendment 24, USAEC Docket No. 50-289.

Smith, D. G., "Influence of Meterological Factors Upon Effluent Concentrations on and near Buildings with Short Stacks," 68th APCA Annual Meeting, June, 1975.

Start, G. E., J. H. Cate, C. R. Dickson, N. R. Ricks, G. R. Ackermann, J. F. Sagendorf (1978): Rancho Seco Building Wake Effects on Atmospheric Diffusion, NUREG/CR-0456.

VII. COMPARISON STUDIES - MODEL TO PROTOTYPE

Kalinske, A. A., R. A. Jensen, and Schadt, C. F., 1945: Correlation of Wind Tunnel Studies with Field Measurements of Gas Diffusion, OSRD NDRC, Div. 10 Informal Rep. No. 10.3A-48a available from Library of Congress, Washington, D. C.

Davies, P.O.A.L., and D. J. Moore, 1964: Experiments on the behavior of effluent emitted from stacks at or near the roof level of tall reactor buildings. Int. J. Air & Water Poll. 8, 515-533.

Martin, J. E., 1965: The correlation of wind tunnel and field measurements of gas diffusion using krypton-85 as a tracer. Univ. of Michigan Rept. No. MMPP272, Ann Arbor, Michigan.

Standen, N. M., W. A. Dalgliesh, R. J. Templin, 1971: A wind tunnel and full-scale study of turbulent wind pressures on a tall building. Proc. Int. Conf. Wind Effects Buildings Structures, 3rd, Tokyo, 199-209.

Robins, A. G., "Plume Dispersion in the Vicinity of a Surface Mounted Cube," Central Electricity Generating Board, Report Number R/M/220, Marchwood Engineering Laboratories, England, 1975.

Smith, D. G., "Influence of Meteorological Factors Upon Effluent Concentrations on and near Buildings with Short Stacks," 68th APCA Annual Meeting, June, 1975.

VIII. RELATED RESEARCH TOPICS

Cooper, R. D., and M. Lutzky (1955): Exploratory investigation of turbulent wakes behind bluff bodies, U. S. Navy Dept. David Taylor Model Basin Rep. No. DTMB-963.

Fail, R., J. A. Lawford and R. C. W. Eyre (1957): Low speed experiments on the wake characteristics of flat plates normal to an air stream. Aer. Res. Council R and M 3120. London.

Gifford, F. A. Jr. 1960: Atmospheric dispersion calculations using the generalized Guassian plume model. Nuc. Safety. 2. 47-51, 67-68.

Gifford, F. A. Jr., 1961: Use of routine meteorological observations for estimating atmospheric dispersion, Nuc. Safety, 2, 47-51.

Bearman, P. W. 1967: The effects of base bleed on the flow behind a two-dimensional model with a blunt trailing edge. Aero. Quart. 8, 207-224.

Gifford, F. A. Jr., 1968: An outline of the theories of diffusion in the lower layers of the atmosphere. In Meterology and Atomic Energy-1968, edited by D. H. Slade, USAEC Rept. No. TID 24190. 65-116.

Ludwig, G. R. and T. R. Sundaram, "On the Laboratory Simulation of Small Scale Atmospheric Turbulence" CAL No. VC2740-S-1, 1969.

Cermak, J. E., Separation-Induced Pressure Fluctuations on Buildings, Paper presented at the U.S.-Japan Research Seminar "Wind Loads on Structures," 19-24 October 1970, East-West Center, University of Hawaii, Honolulu, Hawaii, CEP70-71JEC19.

Turner, D. B., 1970: Workbook of atmospheric dispersion estimates. Office at Air Program Pub. No. AP-26, Environmental Protection Agency, Research Triangle Park, N.C.

Chang, P. C., P. N. Wang, A. Lin, "Turbulent Diffusion in a City Street." Proc. of the Symposium on Air Pollution, Turbulence and Diffusion, 1971.

Kawatani, T. and W. Z. Sadeh, An Investigation of Flow Over High Roughness, Project THEMIS Technical Report No. 11, ECOM No. C-0423-10, August 1971, CER71-72TK-WZS3, AD-734-326.

Lighthill, J. J., and A. Silverleaf, (eds.), "A Discussion on Architectural Aerodynamics," Phil. Trans. of the Royal Society of London, Series A, Vol. 269, No. 1199, 1971, pp 321-554.

Meroney, R. N. and B. T. Yang, Wind Tunnel Study on Gaseous Mixing due to Various Stack Heights and Injection Rates Above an Isolated Structure, Prepared for U. S. Atomic Energy Commission Contract AT(11-1)-2053, Fallout Studies Branch, Division of Biology and Medicine, AEC, Nov. 1971, CER71-72RNM-BTY16.

Hoydish, W. G., R. A. Griffiths, and Y. Ogawa, "A Scale Model Study of the Dispersion of Pollution in Street Canyons," Preprint paper No. 74-157, 67th Annual Meeting of the Air Pollution Control Association, Denver, CO, June 1974, 24 pp.

Briggs, G. A., "Diffusion Estimation for Small Emissions," Atmospheric Turbulence and Diffusion Laboratory, NOAA, Oak Ridge, ATDL No. 75/15.

IX. APPLICABLE ENGINEERING JOURNALS

Journal of Industrial Aerodynamics, RI Harris (Ed), Elsevier Scientific Publishing Co., P. O. Box 211, Amsterdam, The Netherlands.

Wind Engineering, E. Mowforth, Ed., MultiScience Publishing Co., Ltd, The Old Mill, Dorset Place, London E15 1DJ, England.

APPENDIX B

AMERICAN SOCIET: OF HEATING, REFRIGERATION AND AIR CONDITIONING ENGINEERS

TASK GROUP - AIR FLOW AROUND BUILDINGS

MEMBERSHIP LIST

CHAIRMAN: Prof. Swiki A. Anderson
Dept of Mechanical Engineering
College of Engineering
Texas A&M University
College Station, Texas 77843

VICE CHAIRMAN: Mr. Frederick H. Kohloss
(Chairman TC 8.6 Cooling Towers and Evaporative Condensers)
345 Queen Street, Suite 401
Honolulu, Hawaii 96813

SECRETARY: Mr. Robert H. Forde
Nuclear Division
Union Carbide Corporation
ORNL Building 1000
Oak Ridge, Tennessee 37830
(615) 483-8611, Ext. 3-1851

PAST CHAIRMAN: Mr. John H. Clarke
Retired
4253 S. River Road
St. Clair, MI. 48079
(3213) 329-4808

Prof. Jack E. Cermak
Dept. of Civil Engineering
Colorado State University
Ft. Collins, Colorado 80523

Mr. Kenneth L. Credle
(TC 9.8 Large Bldg. A.C. Applications)
Division of Energy, Bldg. Tech. & Stds.
Dept. of Housing and Urban Development
451 7th Street, SW
Washington, D.C. 20410
(202) 755-5574

Mr. Loren Crow
Certified Consulting Meteorologist
2422 S. Downing Street
Denver, Colorado 84210

Mr. Bayliss J. Erdelyi
(TC 5.6, Control Fire & Smoke)
Chief Operations Engineer
Seattle First National Bank Bldg.
1001 Fourth Avenue
Seattle, Washington 98104

Mr. Norman Goldberg
(TC 9.1 Large Building Air Conditioning Systems)
Economides and Goldberg
110 East 30th Street
New York, NY 10016

Prof. R. L. Gorton
(TC 9.2, Ind. Air Cond. - will appoint a representative)
Dept. of Mechanical Engineering
Seaton Hall, Kansas State Univ.
Manhattan, Kansas 66506

Dr. Walter G. Hoydysh
Engineering Consultant
150 East 73rd Street
New York, New York 10021
(212) 628-3062

Mr. George Jepson, Sr.
The Upjohn Company
Kalamazoo, Michigan 49001
(616) 382-4000, Ext. 2766

Mr. Ross G. Luce
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Mr. Russell McFarlan
(TG on Energy Conservation)
Day & Zimmerman, Inc.
1700 Sansom Street
Philadelphia, PA 19103
(215) 864-3342

MEMBERSHIP LIST (Continued)

Dr. Stanley A. Mumma
College of Architecture
Arizona State University
Tempe, Arizona 85281

Mr. Oscar E. Richard, Chief
Engineering Meteorological Section
USAF Environmental Technical
Applications Center
Scott AFB, Illinois 62225

Mr. G. T. Tamura
(Chairman TC 4.3, Ventilation
Requirements and Infiltration)
Division of Building Research
National Research Council
Montreal Road
Ottawa, Ontario, Canada K1A CR6

Prof. David J. Wilson
Dept. of Mechanical Engineering
University of Alberta
Edmonton, Alberta, Canada T6G-2G8

CHAIRMAN - R&T COMMITTEE
Donald G. Rich
Carrier Corporation
Carrier Parkway
Syracuse, New York 13201

R&T COMMITTEE SECTION HEAD
Wilbert F. Stoecker
Dept. of Mechanical Engineering
University of Illinois
Urbana, Illinois 61801

PROGRAM COMMITTEE LIASON
Dr. Ralph F. Goldman
U.S. Army Research
Institute of Environmental Medicine
Kansas Street
Natick, Massachusetts 01760
(617) 653-1000, Ext. 2831

ASHRAE STAFF
Mr. Joseph F. Cuba, Director of Research (212) 644-7853

Mr. Carl W. MacPhee, Editor-Handbook

Mr. Craig Standbury, Manager
R&T Administration
(212) 644-7852

ASHRAE - United Engineering Center
345 East 47th Street
New York, New York 10017

NRC FORM 335 (7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR-1394
NOAA Tech. Memo. ERL ARL-84

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
Diffusion Near Buildings as Determined from Atmospheric Tracer Experiments

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
J. F. Sagendorf and others

5. DATE REPORT COMPLETED
MONTH April YEAR 1980

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
National Oceanic & Atmospheric Administration
Air Resources Laboratory - Field Research Office
550 Second Street
Idaho Falls, Idaho 83401

DATE REPORT ISSUED
MONTH September YEAR 1980

6. *(Leave blank)*

8. *(Leave blank)*

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Site Safety Research Branch
Division of Reactor Safety Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.
FIN No. B5690
NRC-03-79-132

13. TYPE OF REPORT
Technical

PERIOD COVERED *(Inclusive dates)*

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*

Data from the innermost arcs and roof top samplers of the Rancho Seco and EOCR field studies were used to examine diffusion close to a building. The minimum length plume paths were determined from each release location to each sampler position at these two test sites. Measured concentrations, normalized by source strength (C/Q), were plotted versus plume path length and an envelope containing 95% of the measured values of C/Q was determined.

The curves from the two sites were similar in shape and implied three zones of diffusion. Comparisons were also made with current NRC methods for predicting maximum expected concentrations close to a building. The NRC model overestimated concentrations in all but one case. The model was generally within an order of magnitude at EOCR, and within two orders of magnitude at Rancho Seco.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*
Unclassified

21. NO. OF PAGES

20. SECURITY CLASS *(This page)*
Unclassified

22. PRICE
S

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
U.S. NUCLEAR REGULATORY
COMMISSION

U.S. MAIL

NUREG/CR-1394

DIFFUSION NEAR BUILDINGS AS DETERMINED FROM
ATMOSPHERIC TRACER EXPERIMENTS

SEPTEMBER 1980