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THE CALCULATION OF DOSES RECEIVED WHILE CROSSING A PLUME OF RADIOACTIVE MATERIAL*

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ABSTRACT

A method has been developed for determining the dose received by a person while crossing a plume of radioactive material. The method uses a Gaussian plume model to arrive at a dose rate on the plume centerline at the position of the plume crossing. This dose rate may be due to any external or internal dose pathway. An algebraic formula can then be used to convert the plume centerline dose rate to a total dose integrated over the total time of plume crossing. Correction factors are presented for dose pathways in which the dose rate is not normally distributed about the plume centerline. The method is illustrated by a study done at the Pacific Northwest Laboratory, and results of this study are presented.

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INTRODUCTION

During an accidental release of radioactive material, officials responsible for the health and safety of the affected population must make decisions that minimize the doses resulting from the accident. In order to minimize doses to the general population, strategies such as evacuation, or sheltering and subsequent relocation, would be employed to minimize exposure to the plume. In certain cases, however, it may be necessary for people to move across the plume. Such crossings might be made by emergency medical or security workers, or for tasks such as monitoring the plume. For such circumstances it would be important to have an estimate of the dose received by a person crossing the plume.

In this paper a method is presented for performing these cross-plume dose calculations. The important steps for performing these calculations are described. These steps are illustrated with details of a study performed at the Pacific Northwest Laboratory, and the results of this study are also presented.

METHOD

Important elements for starting the calculation include a release list, a description of the release conditions, and a description of the meteorological conditions existing while the radioactive material is released. In the PNL study, three types of accidents were considered, and the release lists and release conditions were described by the PWR-1, PWR-4, and PWR-8 accident scenarios from WASH-1400 (US75). Each type of accident was calculated for three different meteorological conditions: extremely unstable, neutral, and moderately stable (Pasquill Classes A, D, and F).

This calculation assumes that the conditions governing movement of the plume remain constant during the entire plume crossing. Under these conditions a bivariate Gaussian plume model can be used for the atmospheric dispersion calculation. A set of points should be chosen on the plume centerline for performing the dose calculations. These points should be representative of the range of downwind distances at which plume crossings might be made. The PNL study calculated doses at ten points, ranging from 1 to 40 km from the release point. The computer code, WRAITH (Sc80), was used to perform the atmospheric dispersion calculations. WRAITH uses a bivariate Gaussian plume model with Pasquill standard deviations. A wind speed of 2 m/sec was used for all three atmospheric conditions.

At each of the dose points, calculations should be performed to determine the dose rate on the plume centerline for each dose pathway considered. In the PNL study, three dose pathways were considered: internal due to inhalation of radioactive material in the plume, external due to exposure to the plume, and external due to exposure to radioactive material deposited on the ground. WRAITH was used to calculate dose rates due to the first two pathways, and the computer code FABLM (Na80) was used to calculate external dose rates due to exposure to contaminated ground.

The plume centerline dose rates can be converted to cross plume doses if a few assumptions are made. The person crossing the plume is assumed to travel in a straight line, at a steady speed, at right angles to the plume centerline, traversing the entire plume. These assumptions are probably unrealistic for an actual accident, but they do provide a basis for meaningful estimates. With these assumptions, Equation (1) can be used to calculate the cross-plume dose for any dose pathway (Ma77):

$$D_{cp} = \dot{D}_{CL} \sqrt{\frac{\pi}{2}} \frac{\sigma_y}{v} P S \qquad (1)$$

where
- D_{cp} = cross-plume dose (rem)
- $\dot{D}_{CL}$ = centerline dose rate (rem/s)
- σ_y = standard deviation for atmospheric dispersion in the horizontal crosswind direction (m)
- v = travelling speed (m/s)
- P = a correction factor for a non-normal dose distribution
- S = a shielding factor.

A constant speed at which the person travels across the plume, v, must be chosen. The PNL study used a value for v of 30 mi/hr (13.4 m/sec). The choice of v is somewhat arbitrary, but Equation (1) shows that the cross-plume dose is inversely proportional to v. Therefore the effect of a change in v on the calculated dose can be easily determined.

The correction factor P is used to adjust for the non-normal distribution of the dose rate along a horizontal crosswind line for the two external dose pathways. The derivation of Equation (1) assumes that the dose rate is normally distributed about the plume centerline on a horizontal crosswind line. The Gaussian plume model assumes that the concentration of radionuclides follows this normal distribution, and the internal dose due to inhalation is directly proportional to the radionuclide concentrations at the point of inhalation. Thus, the dose rate for the inhalation pathway is normally distributed, and $P_i = 1$. For the two external dose pathways, the dose to any dose point is due to radionuclide concentrations at a large number of points around the dose point, and the dose rate distribution is consequently not a normal one.

In order to evaluate P_p, the correction factor for external doses due to exposure to the plume, an expression was derived which is a function of the variables, Δ and y_1. The instantaneous distance of a dose point from the plume centerline is represented by Δ and the horizontal crosswind coordinate of a point in the plume irradiating the dose point is y_1 (the vertical coordinate of the source point is z). The expression is

$$P(y_1, \Delta) = 1 - e^{-y_1 \Delta/\sigma_y^2} \qquad (2)$$

P_p can be found by integrating Equation (2) over the appropriate ranges, and including weighting factors to adjust for the relative importance of each variable's contribution to the total dose. The whole equation is normalized by integrating the three weighting factors over the appropriate ranges and dividing by this value. P_p is, therefore, found by:

$$P_p = \frac{\int_0^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P\,(y_1, \Delta)\, W_{y_1}\, W_\Delta\, W_z\, dy_1\, d\Delta\, dz}{\int_0^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} W_{y_1}\, W_\Delta\, W_z\, dy_1\, d\Delta\, dz} \qquad (3)$$

where $$W_{y_1} = \frac{1}{y^2 + z^2}$$

$$W_\Delta = e^{-\Delta^2/2\sigma_y{}^2}$$

and $$W_z = e^{-(\Delta^2 - 2zh_e)/2\sigma_y{}^2}$$

where h_e is the effective release height, including plume rise corrections.

To find the values for P_g, the correction factors for the dose pathway of exposure to contaminated ground, an equation similar to Equation (3) can be used:

$$P_g = \frac{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P_g\,(y_1, \Delta)\, W_{y_1}\, W_\Delta\, dy_1\, d\Delta}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} W_{y_1}\, W_\Delta\, dy_1\, d\Delta} \qquad (4)$$

Equation (4) omits the integration in the z direction, since contamination occurs in only one plane.

In the PNL study, Equations (3) and (4) were evaluated for input values of σ_y and σ_z using a computer code which employed Simpson's integration to evaluate the multiple integrals. The results of these calculations are presented in Table 1.

The shielding factor S in Equation (1) needs to be determined for each dose pathway. In the PNL study, the person crossing the plume was assumed to be in an automobile. No credit was given for the automobile's shielding reducing the dose in any of the three pathways, so S = 1 for all three cases. For exposure to contaminated ground, this is probably overly convervative, and values for S ranging from 0.25 to 0.5 have been suggested (Bu77).

RESULTS

The PNL study showed that the pathway of exposure to the plume made a far smaller contribution to the dose than the other two pathways (Figure 1). Thus, during the presence of the plume, only the dose pathways of inhalation and exposure to the plume are significant. Sample results from the PNL study for these two pathways are given in Figures2, 3, and 4. These figures illustrate the cross-plume doses for a PWR-1 accident with meteorological conditions described by Pasquill A. Values are presented for the two important dose pathways, inhalation and external due to exposure to the plume. The sum of these two pathways is also presented.

REFERENCES

Bu77 Burson Z. G. and Profio A. E., 1977, "Structure Shielding in Reactor Accidents," Health Phys. 33, 287-299.

Ma77 Martin J. A. Jr., 1977, "Doses While Traveling Under Well Established Plumes," Health Phys. 32, 305-307.

Na80 Napier B. A., Kennedy W. E. Jr. and Soldat J. K., 1980, PABLM - A Computer Program to Calculate Accumulated Radiation Doses from Radionuclides in the Environment, Pacific Northwest Laboratory, 1980.

Sc80 Scherpelz R. I., Borst F. J. and Hoenes G. R., 1980, WRAITH - A Computer Code for Calculating Internal and External Doses Resulting from an Atmospheric Release of Radioactive Material, Pacific Northwest Laboratory, NUREG/CR-1690, PNL-3382.

US75 U.S. Nuclear Regulatory Commission, 1975, "Calculation of Reactor Accident Consequences," Appendix VI of Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, NUREG-175-104, WASH-1400.

TABLE 1. Calculated Deviation Factors for External Dose

Pasquill Class	σ_y(m)	σ_z(m)	P Values PWR-1 h_e = 143 m	P Values PWR-4 h_e = 33.7 m	P Values PWR-8 h_e = 10 m	P_g Values
A	200	670	-1.075	-1.068	-1.066	-0.013
	370	2000	-0.636	-0.636	-0.636	-0.007
	830	2000	-0.298	-0.298	-0.298	-0.003
	1190	2000	-0.210	-0.210	-0.210	-0.002
	1550	2000	-0.162	-0.162	-0.162	-0.002
	2200	2000	-0.115	-0.115	-0.115	-0.001
	2800	2000	-0.090	-0.090	-0.090	-0.001
	3400	2000	-0.075	-0.075	-0.074	-0.001
	3950	2000	-0.064	-0.064	-0.064	-0.001
	5070	2000	-0.050	-0.050	-0.050	-0.001
D	72	33	-2.467	-1.219	-0.923	-0.035
	132	52	-1.818	-0.936	-0.780	-0.019
	310	95	-0.840	-0.604	-0.556	-0.008
	445	119	-0.585	-0.467	-0.442	-0.006
	570	140	-0.455	-0.384	-0.369	-0.004
	710	170	-0.362	-0.322	-0.314	-0.004
	980	195	-0.263	-0.240	-0.235	-0.003
	1250	220	-0.206	-0.192	-0.188	-0.002
	1480	242	-0.174	-0.164	-0.162	-0.002
	1900	283	-0.135	-0.129	-0.128	-0.001
F	36	13	-2.516	-1.942	-0.954	-0.070
	66	21	-2.353	-1.293	-0.739	-0.038
	153	35	-1.433	-0.731	-0.503	-0.017
	222	42	-1.059	-0.566	-0.412	-0.011
	280	47	-0.862	-0.483	-0.363	-0.009
	400	55	-0.621	-0.377	-0.295	-0.006
	505	59	-0.498	-0.315	-0.252	-0.005
	610	64	-0.415	-0.274	-0.223	-0.004
	715	68	-0.356	-0.243	-0.201	-0.004
	920	74	-0.278	-0.199	-0.168	-0.003

FIGURE 1

CONTRIBUTIONS OF ALL PATHWAYS TO CROSS-PLUME DOSES

(PWR-1, PASQUILL CLASS A)

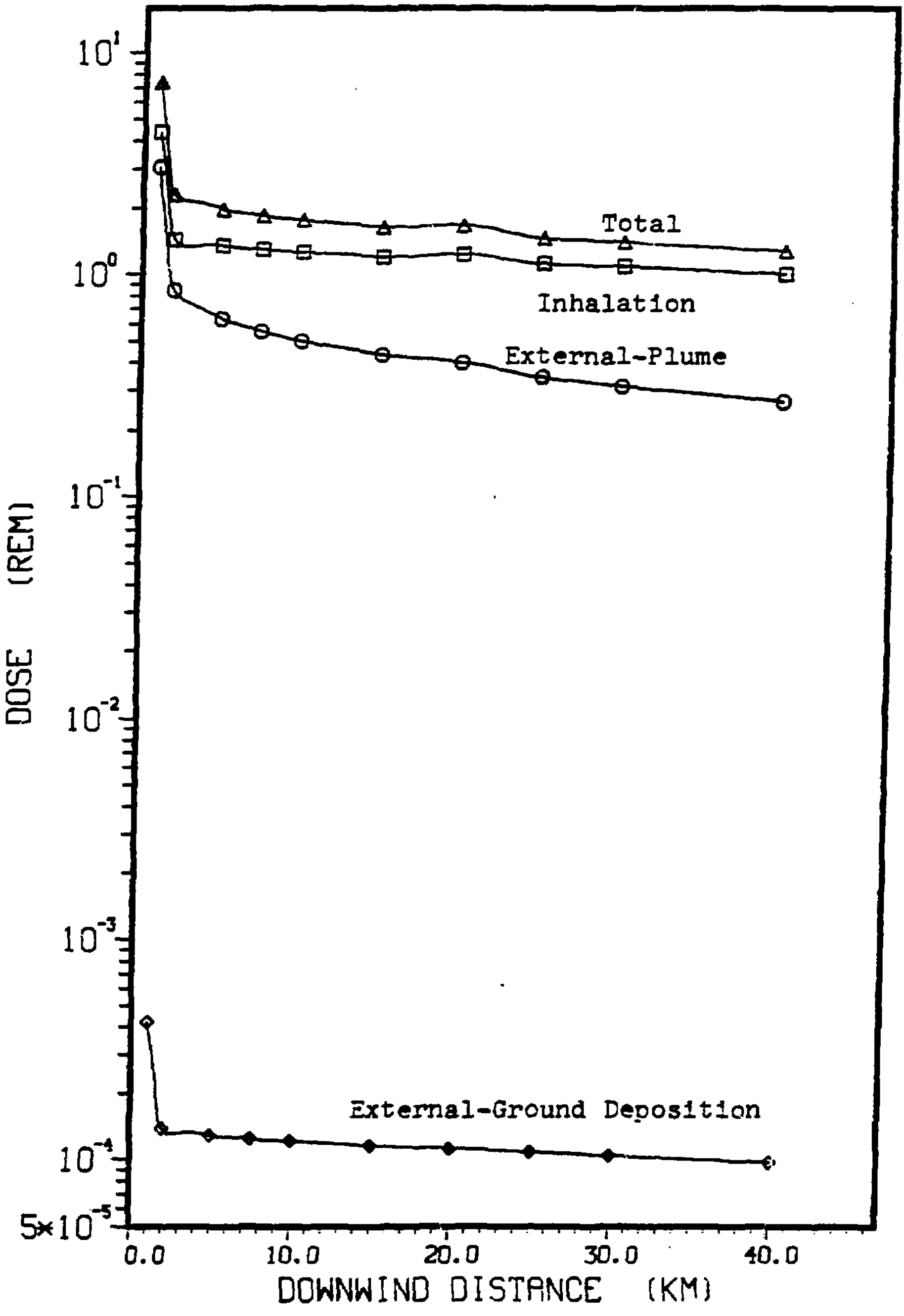


FIGURE 2

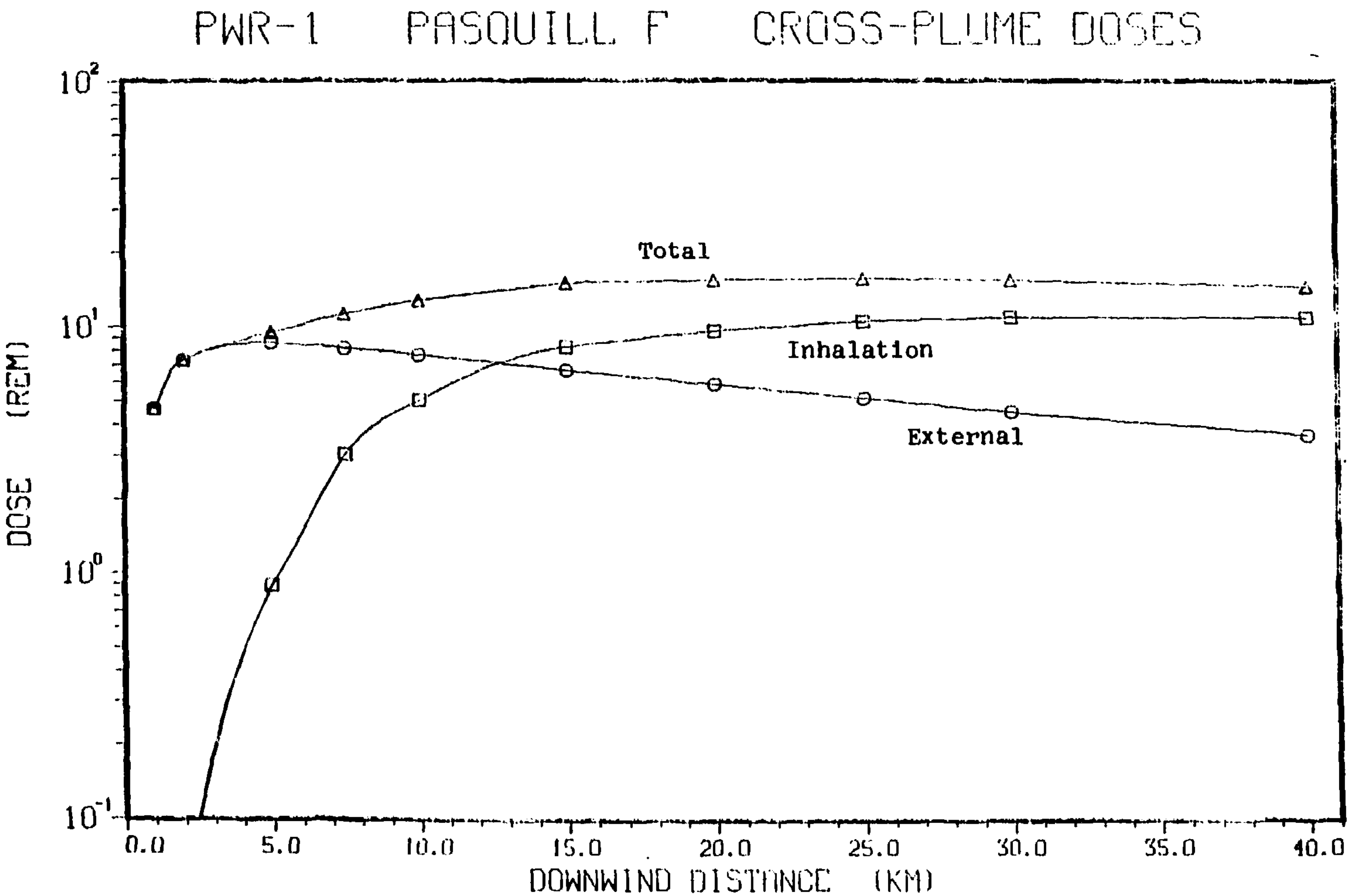

PWR-1 PASQUILL F CROSS-PLUME DOSES
Total
Inhalation
External
DOSE (REM)
10^2
10^1
10^0
10^{-1}
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
DOWNWIND DISTANCE (KM)

FIGURE 3

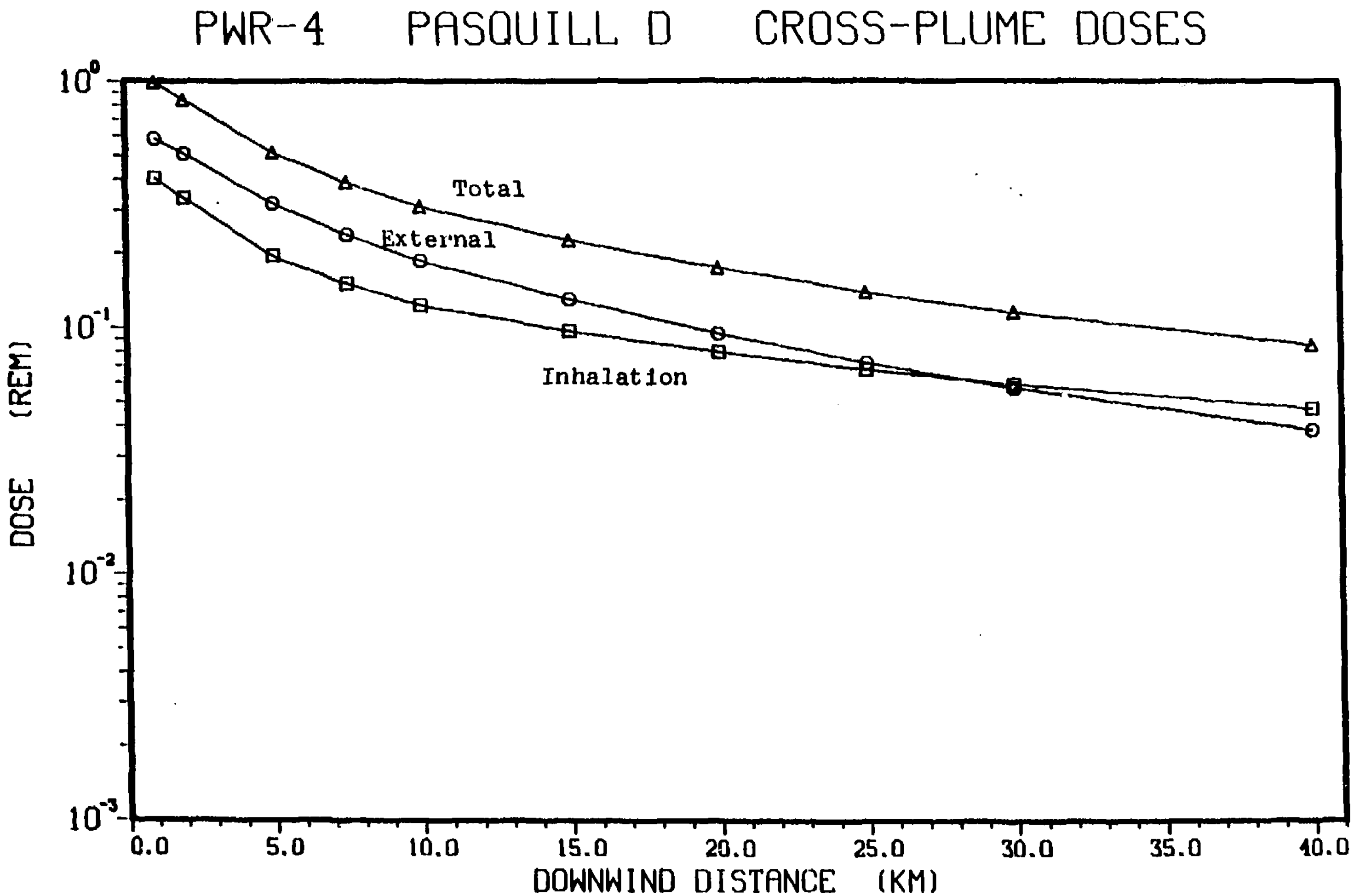
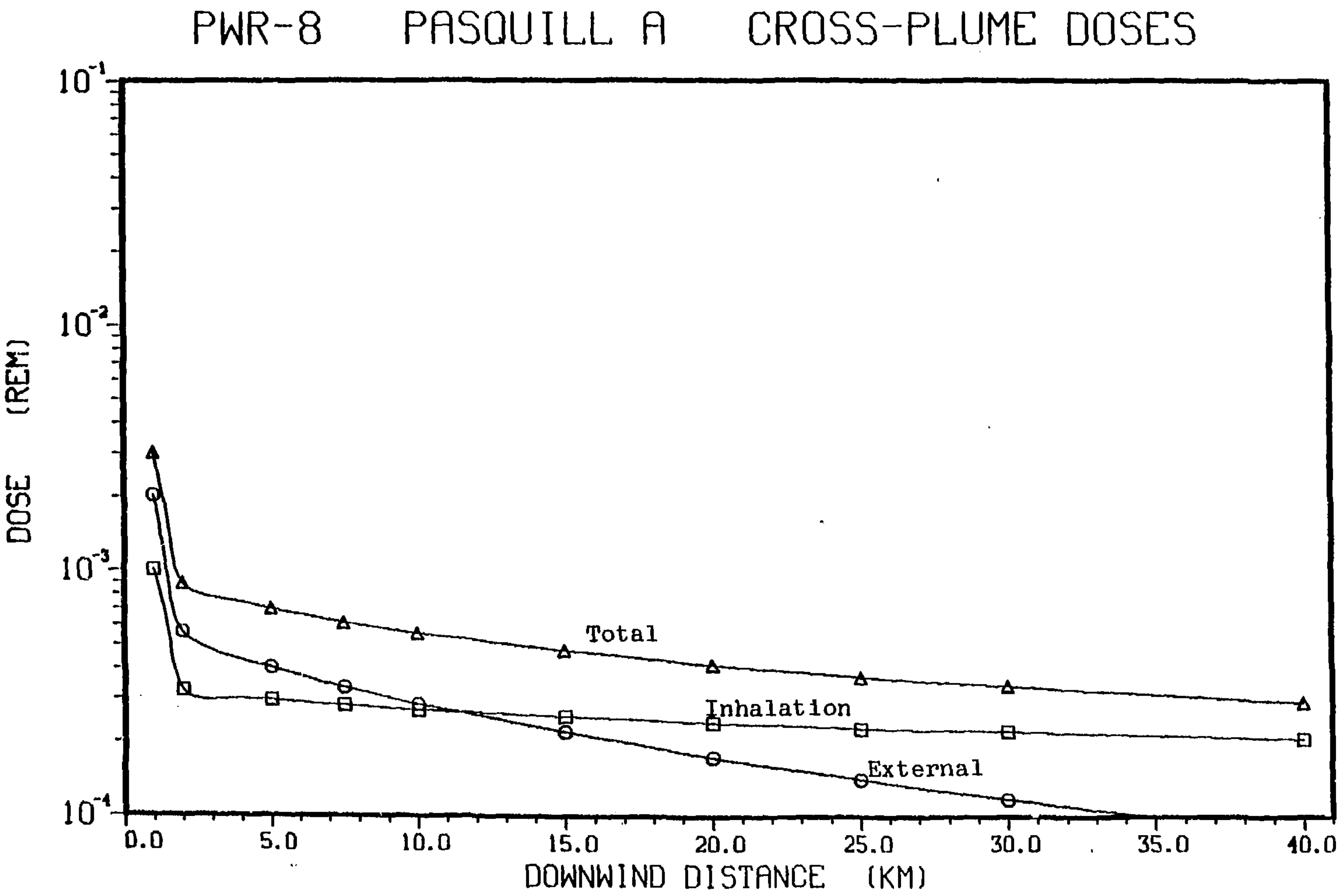

PWR-4 PASQUILL D CROSS-PLUME DOSES
DOSE (REM)
10^0
10^{-1}
10^{-2}
10^{-3}
Total
External
Inhalation
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
DOWNWIND DISTANCE (KM)

FIGURE 4


PWR-8 PASQUILL A CROSS-PLUME DOSES
DOSE (REM)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Total
Inhalation
External
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
DOWNWIND DISTANCE (KM)