ANALYSIS OF THE AP-42, SUPPLEMENT 5 EMISSION MODEL

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

This report examines the performance of the source strength model presented in the U. S. Environmental Protection Agency publication AP-42, Supplement 5 relative to field data gathered during the AIRPOL project and relative to the previous source strength model, AP-42, Supplement 2. The report demonstrates that the Supplement 5 model can be expected to produce "worst case" emission estimates on the order of 1.6 to 2.1 times those of Supplement 2 for typical Virginia applications. Since it appears that Virginia will be required to implement the Supplement 5 model, it is recommended that (1) operation phase input data be accurately determined on a project-by-project basis, (2) "worst case" type analyses be realistically conceived, and (3) the Department request that the FHWA and EPA justify the twofold increase in emission estimates of Supplement 5 over Supplement 2.

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INTRODUCTION

Air quality predictions require two models, a dispersion model and a source strength model. The computer program AIRPOL-4[1,2,3,4] is a combination of a source strength and a dispersion model. The source strength model built into AIRPOL-4 is based on the U. S. Environmental Protection Agency (EPA) publication AP-42, Supplement 2.[5]

On April 16, 1975, the EPA announced that AP-42, Supplement 2 would be replaced by Supplement 5,[6] which would constitute a major revision of the modeling approach used to estimate highway source strengths, and which, according to the EPA, would represent the first of many anticipated revisions. As a result of this indication of a large number of future modifications, AIRPOL-4 was upgraded to AIRPOL-4A,[7] an emissions independent dispersion model; and the computer program EMISSION, a source strength model based on Supplement 5, was developed.

Preliminary experience with EMISSION indicated that the Supplement 5 modeling approach often yielded source strengths significantly greater than those resulting from the Supplement 2 approach, a situation which might prove costly to the Virginia Department of Highways and Transportation. Thus, the Department's Environmental Quality Division requested that the Virginia Highway and Transportation Research Council analyze the behavior of the Supplement 5 model relative to that of the Supplement 2 model.

This report presents the results of the comparative analysis of the predictions generated by the modeling approaches presented in Supplements 2 and 5 to AP-42. The analysis consisted of two parts, a comparison based on field data taken for the validation of AIRPOL-4,[2,4] and a comparison based on the relative behaviors of the two models.

ANALYSIS BASED ON FIELD DATA

The computer program AIRPOL-4 has been shown to be a very reliable and mathematically sound modeling approach to the problem of estimating the air quality (in terms of carbon monoxide (CO) concentrations) in the micro-region of a highway.[1,2] AIRPOL-4A incorporates the same dispersion model as AIRPOL-4;[7] thus, any performance differences between AIRPOL-4 and AIRPOL-4A must be a result of source strength modeling.

Based on the above premise, this section analyzes the predictive performances of AIRPOL-4 (Supplement 2 emissions) and AIRPOL-4A (Supplement 5 emissions) relative to the AIRPOL field data.[4]

Assumptions

The AIRPOL source strength data contain only the test date, the percentage of heavy duty vehicles (called MIX), the mean traffic speed, the total traffic volume, and the observed CO level for each field test. Thus some assumptions are necessary before the Supplement 5 model can be applied to these data to obtain source strengths.[8] Since all data were taken on interstate highways, the percentage of cold starts and the percentage of hot starts were both assumed to be 0%, and, based on Table 1, the vehicle mix by vehicle type was assumed to be

$$\% \text{ GPC} = 0.9 \times (100 - \text{MIX}),$$

$$\% \text{ GLDT} = 0.1 \times (100 - \text{MIX}),$$

$$\% \text{ GHDV} = 0.6 \times \text{MIX},$$

$$\% \text{ DHDV} = 0.4 \times \text{MIX},$$

$$\% \text{ DLDV} = 0.0, \text{ and}$$

$$\% \text{ MC} = 0.0.$$

The ambient temperatures at the time the field data were collected were estimated from meteorological data supplied by the National Atmospheric and Oceanic Administration, see Table 2. The Langley Field data were used to estimate the ambient temperatures at the test sites located in the Tidewater area of Virginia, and the National Airport data were used to estimate the ambient temperatures at the test sites located in the Northern Virginia area.

Table 1

National Average Interstate Highway Vehicle Mix

Acronym	Vehicle Type	Percentage of National Average Vehicle Mix
GPC	Gasoline Powered Passenger Cars	80.4%
GLDT	Gasoline Powered Light Duty Trucks	11.8%
GHDV	Gasoline Powered Heavy Duty Vehicles	4.6%
DHDV	Diesel Powered Heavy Duty Vehicles	3.2%
DLDV	Diesel Powered Light Duty Vehicles	0.0%
MC	Motorcycles	0.0%

Table 2

Average Monthly Temperatures for the
Tidewater and Northern Virginia Areas
(Based on data from 1941 to 1970
by the National Atmospheric and Oceanic Administration)

Month	Average Monthly Temperatures, Degrees Fahrenheit	
	Langley Field	National Airport
January	40.1	35.6
February	41.3	37.3
March	48.2	45.1
April	57.8	56.4
May	66.9	66.2
June	74.7	74.6
July	78.6	78.7
August	77.3	77.1
September	71.9	70.6
October	61.8	59.8
November	51.4	48.0
December	42.2	37.4

Results of Analysis Based on Field Data

Table 3 presents the performance statistics relative to the AIRPOL field data of the Supplement 5 and Supplement 2 emission models. The reader will note that relative to the measures of average performance (average deviations, etc.) the Supplement 5 based predictions are slightly superior to the Supplement 2 based predictions (an indication that over and under predictions are somewhat more balanced when the Supplement 5 model is used), while relative to the measures of performance variability (average squared deviation, correlation, regression line, deviation range, etc.) the Supplement 2 based predictions are somewhat superior to the Supplement 5 based predictions. None of the differences in performance, however, are significant at the 5% level;[9] although one must keep in mind that the 0% cold starts and 0% hot starts conservatively assumed in this analysis (there are no data to justify any other particular choice) minimize the variability of the Supplement 5 model.

As an aside for those who may question the validity of examining emissions predictions by using AIRPOL, notice that the Supplement 5 model does somewhat over predict the Supplement 2 model, and recall that the models HIWAY[2] and CALAIR[2], the other readily available models, generally over predict pollution levels based on Supplement 2 emissions;[2] therefore, an examination of the Supplement 2 and Supplement 5 emissions models using either HIWAY or CALAIR would have yielded the same general results but would have shown even greater variability of prediction than did the above examination.

Table 3

The Effectiveness of Supplement 5 Emissions
vs.
The Effectiveness of Supplement 2 Emissions

Statistics	AIRPOL-4A (Supplement 5 Emissions)	AIRPOL-4 (Supplement 2 Emissions)
Data Points	254.00	254.00
Average Deviation, ppm	- 0.42	- 0.45
Average Squared Deviation, ppm	1.18	1.16
Probable Error, ppm	0.73	0.72
% Correlation Coefficient	0.48	0.51
A, OB = A × P + B	0.85	0.96
B, OB = A × P + B	0.55	0.49
Minimum Deviation, ppm	- 4.57	- 4.71
Maximum Deviation, ppm	1.62	1.41
Deviation Range, ppm	6.19	6.12
Minimum Observation, ppm	0.00	0.00
Maximum Observation, ppm	6.50	6.50
Observation Range, ppm	6.50	6.50
Sum of Deviations, ppm	-107.74	-115.12
Sum of Squared Deviations, ppm^2	299.47	294.69
Average Observation, ppm	1.25	1.25
Average Prediction, ppm	0.83	0.80
Variance of Deviation, ppm^2	1.00	0.96
Variance of Prediction, ppm^2	0.42	0.38
Variance of Observation, ppm^2	1.30	1.30
Avg. Dev. ÷ Avg. Obs.	- 0.34	- 0.36
Avg. Pred. ÷ Avg. Obs.	0.66	0.64
Min. Dev. ÷ Avg. Obs.	- 3.63	- 3.76
Max. Dev. ÷ Avg. Obs.	1.29	1.13
Range Dev. ÷ Range Obs.	0.95	0.94

RELATIVE BEHAVIORS OF THE SUPPLEMENT 2 AND SUPPLEMENT 5 MODELS

The previous section showed that relative to the AIRPOL field data, the Supplement 5 and Supplemental 2 models are not statistically different. This conclusion is, however, restricted to predictions for calendar years 1973 and 1974, since the AIRPOL field data are so restricted, and to the case in which 100% of the vehicles are in the hot-operation phase. The purpose of this section is to provide the reader a basis for directly comparing the Supplement 2 and Supplement 5 models (without, however, the benefit of actual field data as a reference). The Supplement 5 data in this analysis were generated using 40°F and 80°F ambient temperatures, an average route speed of 45 mph, and national average vehicle mix data (shown in Table 1) with 20% of the vehicles being in the cold-operation phase, 53% being in the hot-operation phase, and 27% being in the hot-start phase. (These input parameters were chosen for this analysis since they are the input parameters which the Virginia Department of Highways and Transportation will use in practice until an accurate and reliable method of estimating input parameters is developed either by the Department or by the FHWA.) The Supplement 2 data in this analysis were generated using an 8% heavy duty vehicle mix[1] (the sum of the two heavy-duty classes in Table 1) and an average route speed of 45 mph. (Notice that the ambient temperature and operation phase data are not applicable to Supplement 2.)

Figure 1 contains the prediction results of Supplement 2 and Supplement 5 for the years 1973 to 1989 using the above input parameters. The reader will observe that the Supplement 5 data at 40°F, the temperature at which "worst case" predictions will be made, greatly exceed the Supplement 2 data for all calendar years. Furthermore, the Supplement 5 data at 80°F, the upper limit of daily average temperatures in Virginia, exceeds the Supplement 2 data for all years prior to 1983 and is only nomially exceeded by the Supplement 2 data thereafter.

According to current FHWA guidelines, "worst case" conditions must be employed when making air quality predictions;[8] thus the relationship of the Supplement 5 data at 40°F to the Supplement 2 data is of great interest to the Department. Figure 2 illustrates the extent to which the Supplement 5 predictions at 40°F exceed the Supplement 2 predictions. Examination of Figure 2 will reveal that for a "worst case" air quality analysis, predicted CO levels based on Supplement 5 would be from 1.6 to 2.1 times as great as those based on Supplement 2.

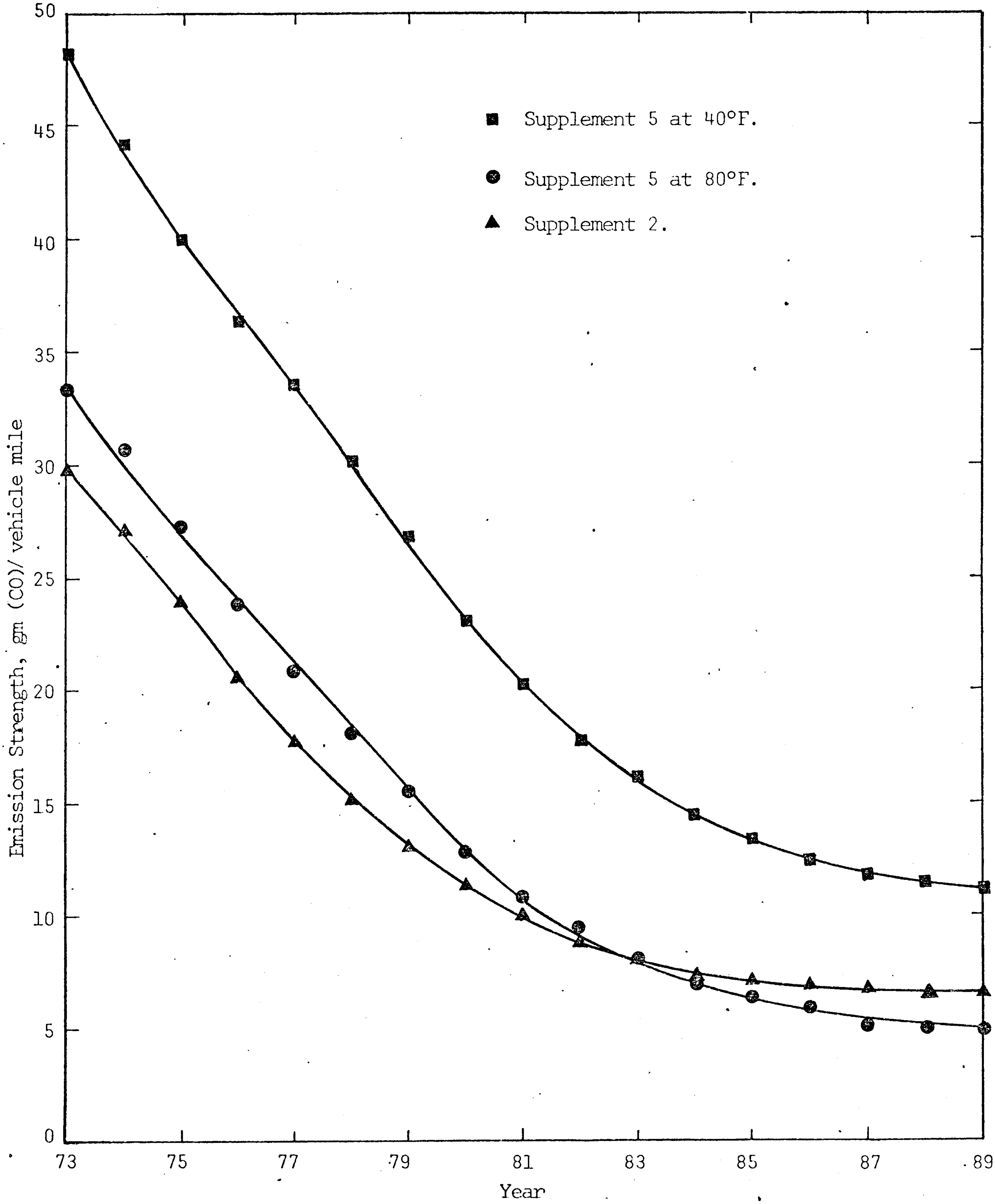

Figure 1. Typical predictions of the Supplement 2 and Supplement 5 models.

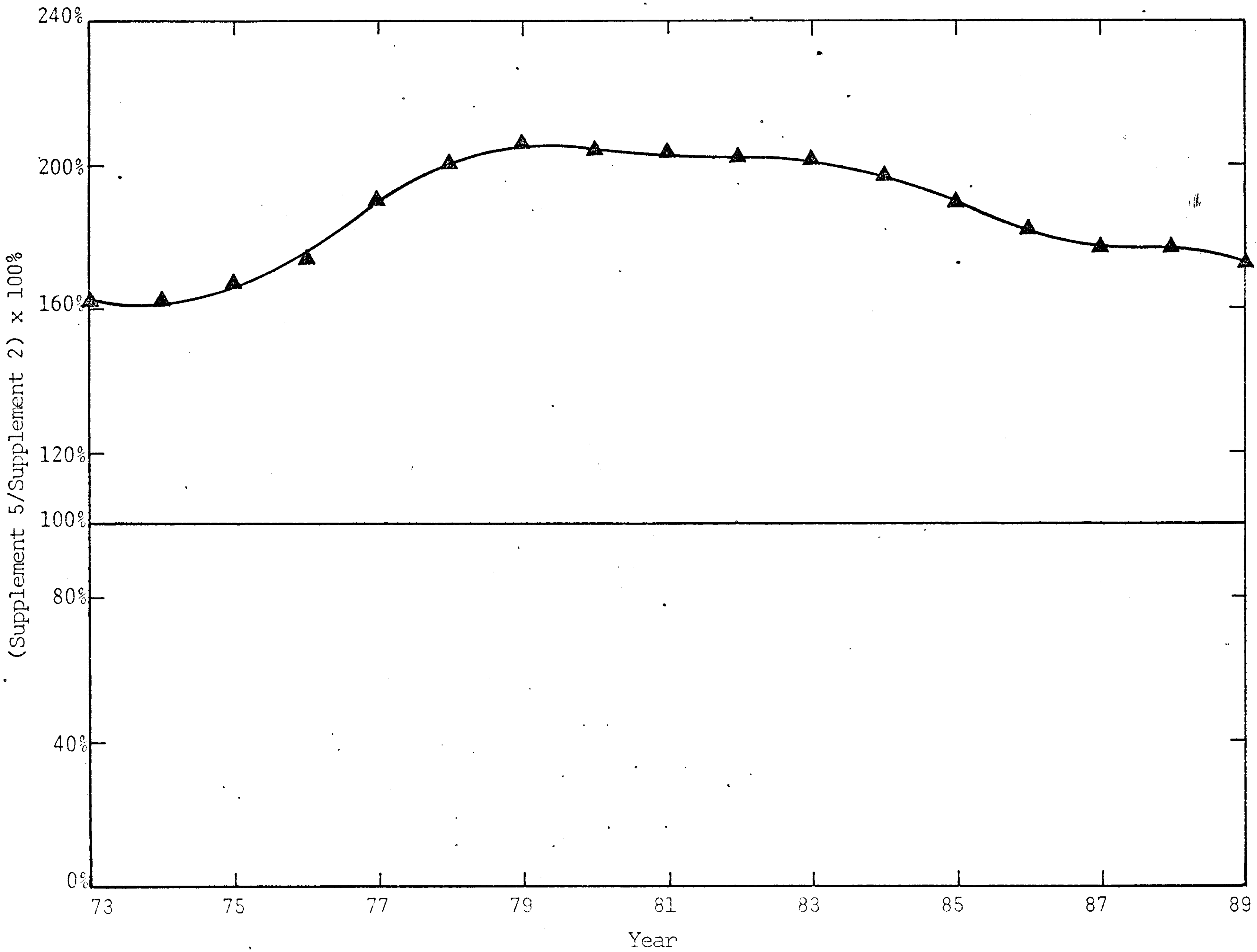

Figure 2. Extent to which Supplement 5 predictions at 40°F exceed Supplement 2 predictions.

CONCLUSIONS AND RECOMMENDATIONS

This study has shown that although the Supplement 2 and Supplement 5 models are not statistically different relative to the 1973-1974 AIRPOL data (where it was assumed that 100% of the vehicles were in the hot-operation phase) when predictions are made using the vehicle operation phase data inputs currently employed by the Department, the Supplement 5 model predicts "worst case" emissions which are from 1.6 to 2.1 times those predicted by the Supplement 2 model.

In the opinion of the author, these findings indicate that the hot-start, cold-start, hot-operation mix of 27%, 20%, and 53% scheduled to be employed by the Department is not appropriate to the general population of vehicles on Virginia's interstate highways. In particular, recall that the 0%, 0%, 100% mix used in the first section of this study produced CO predictions in good agreement with field results. Thus, the author recommends that the Environmental Quality Division employ surveys and traffic modeling techniques to estimate operation phase mixes on a project-by-project basis.

The author also cautions against using a "worst case" analysis which is impossible to observe in the real world. It would be unwise to base predictions on a traffic volume applicable to the late spring, an ambient temperature applicable to the middle of winter, a wind speed and wind direction characteristic of the early fall, and a stability class applicable to midsummer. Unrealistic choices for "worst case" parameters will yield unrealistically high estimates of highway generated pollution levels.

As a final recommendation, the author suggests that the Department request the FHWA and the EPA to demonstrate that the high emission rates predicted by the Supplement 5 model are justified. Virginia and other states could be unjustly hampered and economically injured by a prediction model which overestimates highway emissions.

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