Development of Alternative Sulfur Dioxide Control Strategies for a Metropolitan Area and its Environs, Utilizing a Modified Climatological Dispersion Model

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ABSTRACT.—Alternative control strategies were developed for achieving compliance with ambient air quality standards in Portland, Maine, and its environs, using a modified climatological dispersion model (CDM) and manipulating the sulfur content of the fuel oil consumed in four concentric zones. Strategies were evaluated for their impact on ambient air quality, economics, and fuel oil resources. Based on these evaluations, a control strategy best suited for meeting the needs of the Portland area could be recommended.

IMPLEMENTATION PLANS for meeting ambient air quality standards were prepared by most states in the early 1970s pursuant to requirements of the Clean Air Act of 1970. These plans mandated various measures for controlling pollutant emissions to ensure compliance with the standards. However, implementation of the control strategies met with varying degrees of success.

Prompted by the failures, reevaluations of control strategies in the past year have highlighted a number of questionable approaches in strategy development. For example, a major shortcoming in the development of many strategies was the assumption that all pollutant sources should be controlled by the same percentage amount to achieve improved air quality. This approach to strategy development was commonly called the "rollback" procedure.

The rollback procedure was the basis for establishing in 1972 the control strategy *(Maine Dep. Environ. Protect. 1972)* for sulfur dioxide emissions in the Metropolitan Portland Air Quality Control Region (AQCR). The Portland AQCR encompasses Cumberland, Sagadahoc, and York Counties and a small portion of Oxford County in southern Maine (fig. 1). A substantial body of air quality data has been collected in the region in the past several years by the State Department of Environmental Protection and industrial concerns. All monitoring data indicate that ambient sulfur dioxide concentrations throughout the AQCR are well below the federal EPA standards except in the downtown area of Portland. There, violations of federal and state 24-hour average and annual average standards have been and continue to be recorded. Measured 24-hour average sulfur dioxide concentrations at one location in the downtown Portland peninsula have exceeded the state standard by 100 percent, and measured annual average levels have exceeded the standard by 50 percent.

Recent examinations of air quality data collected in the Portland AQCR since 1972 indicated that the originally developed rollback strategy would be ineffective in solving regional air quality problems. Realizing that there were several alternatives for solving the re-

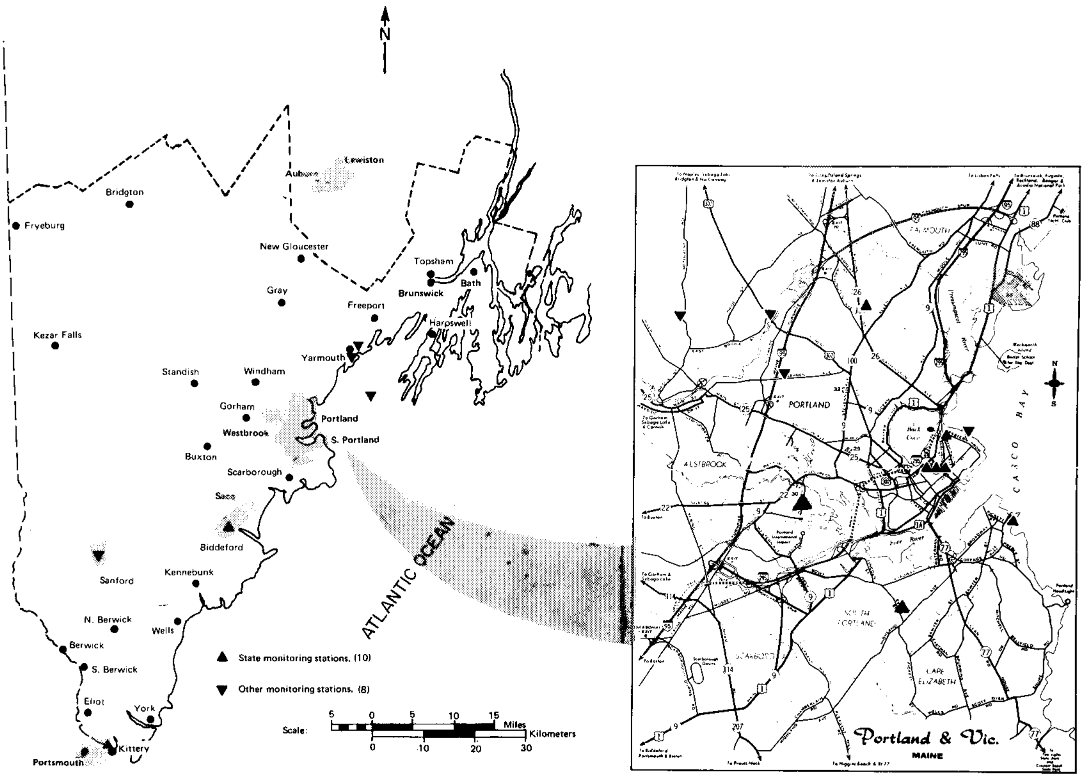


Figure 1.—The Maine Metropolitan Portland Air Quality Control Region.

gional problem, the Maine Board of Environmental Protection heard evidence on alternative control strategies from the Maine Department of Environmental Protection and all other interested individuals. These opinions and suggestions were presented before the Board at a public hearing on 16 April 1975. The thorough reevaluation and development of the Portland sulfur dioxide control strategy, which is described in this paper, was presented at that time.

REGIONAL AIR QUALITY MODEL AND MODEL VALIDATION

The Climatological Dispersion Model (CDM) developed by the federal Environmental Protection Agency *(Calder 1973, Busse and Zimmerman 1973)* was the principal tool used to evaluate both the regional air quality problem and, subsequently, alternative solutions. The CDM is a computer code that uses input data on pollutant concentrations based on generally accepted principles.

CDM's emission inventory input capability was expanded to accommodate different categories of fuel use for both point and area sources and for different geographical areas. The purpose of this modification was to permit testing of the effect on ambient air quality of variation in the sulfur level in fuel oil both as a function of fuel type (No. 6, No. 4, and No. 2) and as a function of geographical area (downtown and suburbs).

To use CDM in the Portland AQCR, the model had to be validated for application to both 24-hour and annual time periods. This important first step was accomplished by assembling an extensive data base comprised of ambient sulfur dioxide concentration measurements, meteorological observations, and a sulfur dioxide emission inventory.

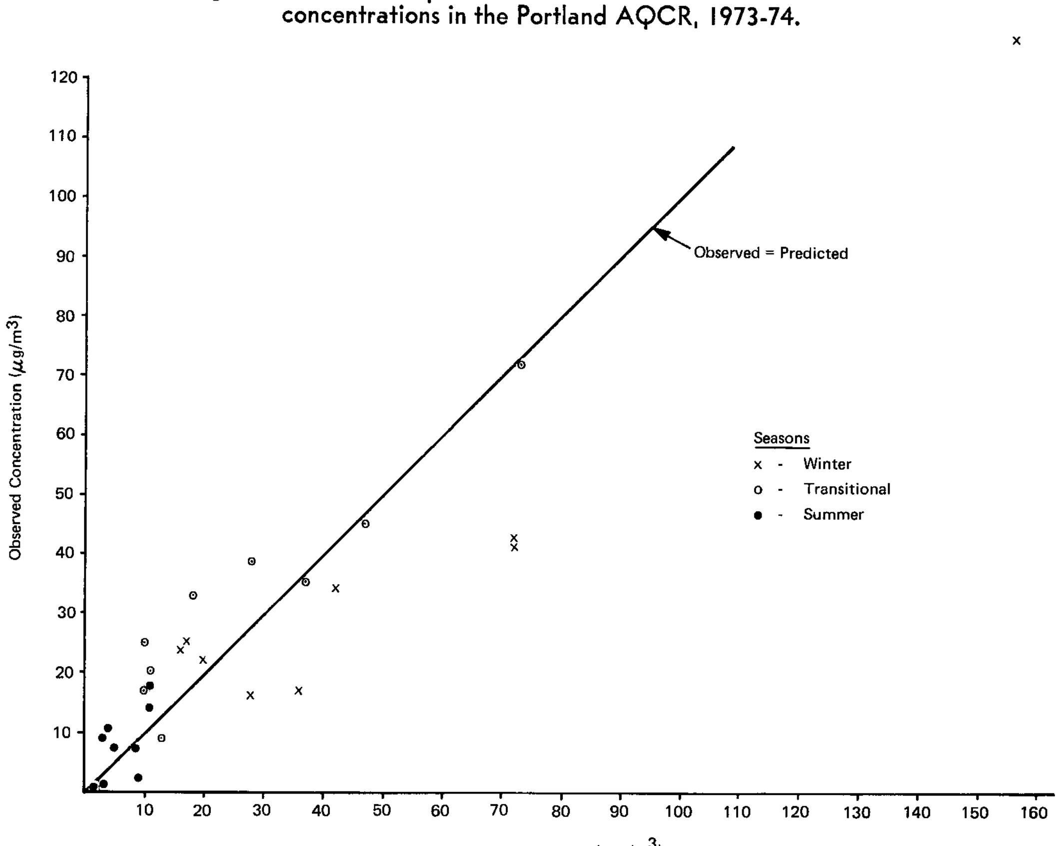
The year October 1973 through September 1974 was selected for validating CDM over an annual period because the most comprehensive set of sulfur dioxide measurements were available for this period. This data set included continuous measurements at two downtown sites and two suburban sites and measurements on an every-sixth-day schedule at seven additional sites in the AQCR. Meteorological data were assembled from the National Weather Service station at the Portland International Jetport.

A total of 8 days in 1973 were selected for validating CDM for application to 24-hour periods. The days selected include 5 on which the sulfur dioxide concentration measured in downtown Portland was the highest recorded at street level in the Portland AQCR.

CDM was successfully validated for both 24-hour and annual periods for the Portland AQCR based on comparisons of calculated and observed concentrations. The correlation coefficient for calculated and observed concentrations at the monitor location of maximum concentration, the Masonic Building in downtown Portland, was 0.78 for 24-hour periods. The correlation for all monitoring locations in the AQCR was 0.67 for 24-hour periods.

The correlation coefficient for all calculated and observed annual average concentrations in the AQCR was 0.96. These annual averages were calculated by taking the mean of three seasonal averages (fig. 2). Seasonal averages were

Figure 2.—Seasonal predicted versus observed sulfur dioxide concentrations in the Portland AQCR, 1973-74.



calculated because of the large variability, typically an order of magnitude, in ambient sulfur dioxide levels from winter to summer. Generally, CDM-predicted concentrations were higher than observed concentrations for both 24-hour and annual periods.

AIR QUALITY PROJECTIONS

Numerous violations of the 24-hour standard and several violations of the annual ambient air quality standard for sulfur dioxide have been recorded in downtown Portland. If no controls are placed on sulfur dioxide emissions, it is reasonable to assume that such violations will recur. These recurrences will probably increase in severity and frequency because of the additional sulfur dioxide emissions that accompany population growth. Hence, any plan designed to resolve the existing problem must also account for worsening of the problem due to such growth. Furthermore, the federal EPA requires that control strategies account for projected growth in an AQCR over the next decade.

Growth is not the only factor that must be considered in designing a control strategy. Meteorological conditions vary from day to day and from year to year. Because the Maine standards allow for no 24-hour average or annual average concentration of sulfur dioxide above the standard, it is only prudent to account for the most adverse meteorological conditions that might be expected over a 24-hour and annual period during the coming decade.

Projections to the data base were made to account for both increased sulfur dioxide emissions due to population growth and the most adverse meteorological conditions. Projected growth in the AQCR was accounted for through 1985 by proportionally increasing the area source emission inventory. Additionally, all emissions were increased to account for increased heating requirements due to very cold weather. Finally, the most adverse meteorological conditions that might be expected over the next 10-year period were projected. The projected emission inventory and meteorological conditions were then combined in CDM to calculate the worst probable air quality levels through the year 1985.

The projected maximum sulfur dioxide concentrations for 24-hour and annual periods consistently fell below the standards except in the downtown Portland peninsula. There, maximum levels projected by CDM exceeded the standards by larger margins than had recorded maximum levels. The projected peak 24-hour average sulfur dioxide concentration is 550 micrograms per cubic meter at the Masonic Building, with projected peak levels above the standard of 230 micrograms per cubic meter over most of the downtown Portland peninsula (fig. 3 and 4). The projected peak annual average is 97 micrograms per cubic meter, again at the Masonic Building, with projected peak levels above the standard of 57 micrograms per cubic meter in the center of the peninsula (table 1).

DEVELOPMENT AND EVALUATION OF ALTERNATIVE CONTROL STRATEGIES

The air quality projections essentially defined the extent and magnitude of the sulfur dioxide air quality problem in the AQCR through 1985. Using CDM as a tool, alternative strategies for solving the problem were developed and evaluated. In addition, an assessment of the impact of these strategies on fuel costs was included in the evaluation.

Following the approach to the problem of the rollback strategy, an average fuel sulfur content limit required throughout the AQCR to meet state standards could be determined using CDM. However, in this study, the approach taken was to examine the problem and develop solutions specifically tailored to the problem.

Violations of the 24-hour and annual

Figure 3.—Predicted peak 24-hour concentrations, northwest wind. (Concentration in $\mu g/m^3$.)

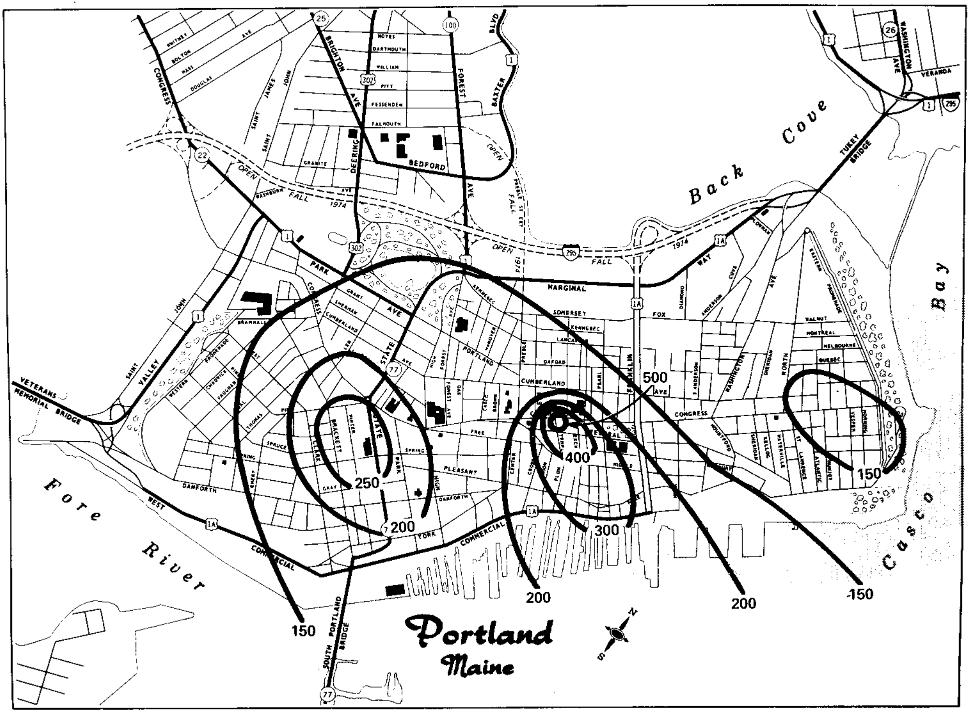


Figure 4.—Predicted peak 24-hour concentrations, southwest wind. (Concentration in $\mu g/m^3$.)

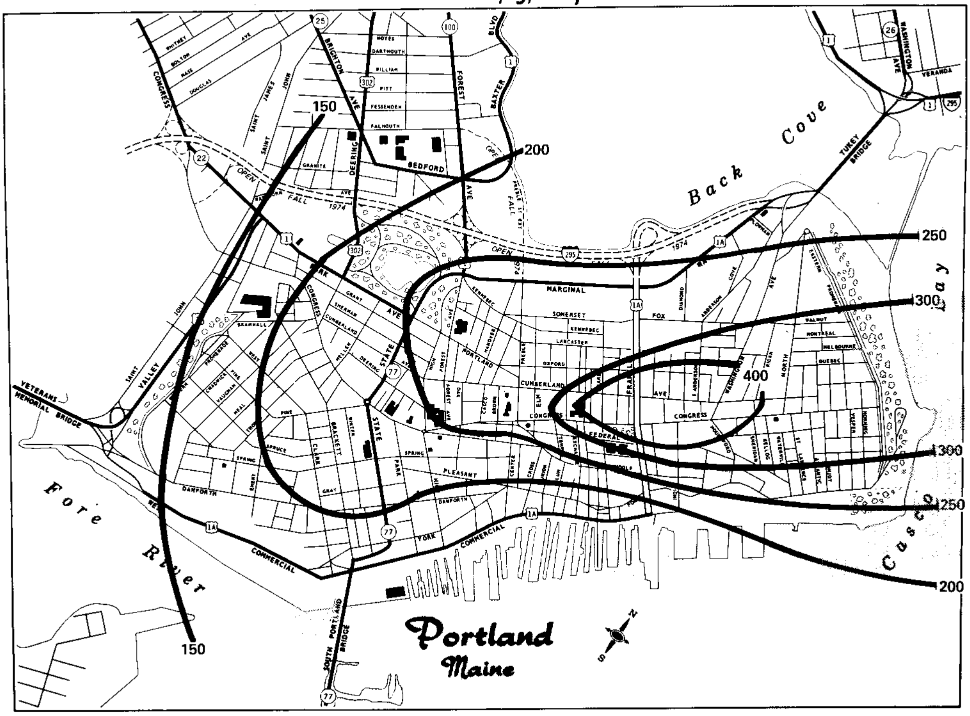


Table 1.—Average fuel sulfur contents required to achieve compliance with state standards for each alternative control strategy

Alternative control strategy	Area of fuel sulfur content control	Average sulfur content		
		No. 6 fuel	No. 4 fuel	No. 2 fuel
24-hour compliance:		*Pct.*	*Pct.*	*Pct.*
A	Downtown Portland Peninsula	0.7	0.7	0.25
B	Portland and South Portland	.8	.8	.25
C	Portland SMSA	.9	.9	.25
D	Entire Portland AQCR	.9	.9	.25
Annual compliance:				
A	Downtown Portland Peninsula	.9	.9	.25
B	Portland and South Portland	1.0	1.0	.25
C	Portland SMSA	1.1	1.1	.25
D	Entire Portland AQCR	1.1	1.1	.25

sulfur dioxide standards were projected in the downtown Portland peninsula only. The highest 24-hour average levels were projected for areas along Congress Street in the center of the downtown peninsula. The major contributors to this problem were identified by the CDM as the users of residual oil in the downtown peninsula. Because the problem was geographically isolated, control strategies for fuel oil sulfur content were developed with a major focus on geography.

Four alternative strategies to bring sulfur dioxide levels in the downtown area into compliance with air quality standards were formulated. These strategies consisted of controlling sulfur dioxide emissions only within specific geographical areas by selectively reducing the average sulfur contents of heavy fuels within these areas alone.

The four alternative strategies differed only in respect to the geographical area within which the controls were exerted. The four geographical areas within which fuel sulfur level controls were exerted are listed below:

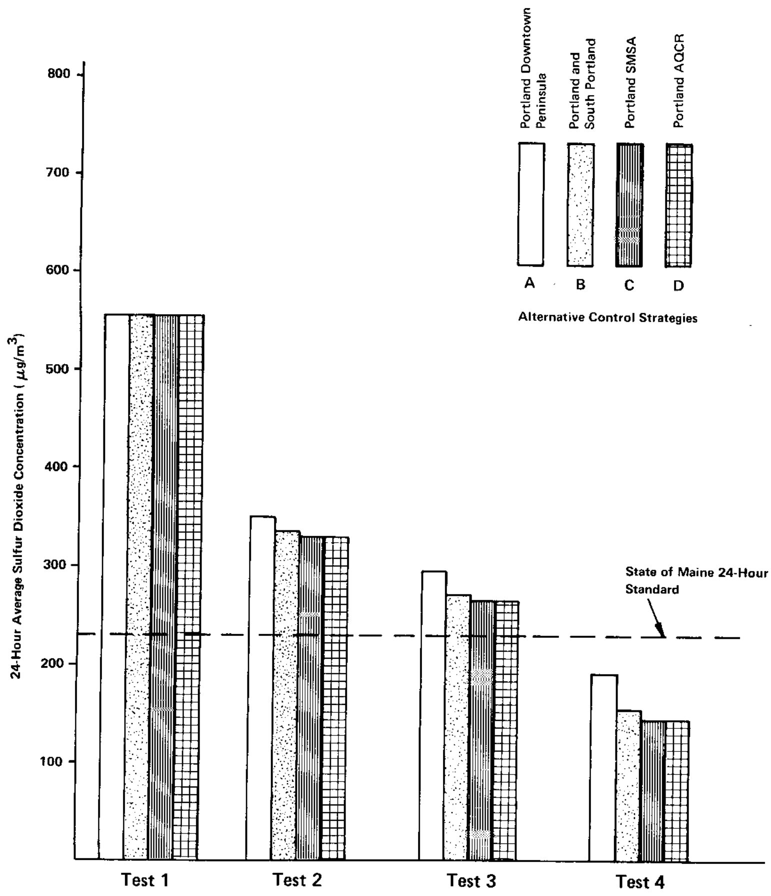
1. Alternative A—Controls on fuel sulfur content within the downtown peninsula only of the city of Portland (the dividing line between the mainland and the peninsula was taken as Interstate 295).
2. Alternative B—Controls on fuel sulfur content within the cities of Portland and South Portland only.
3. Alternative C—Controls on fuel sulfur content within the metropolitan Portland area only (defined as the U. S. Census Bureau's Portland Standard Metropolitan Statistical Area, which includes Portland, South Portland, Cape Elizabeth, Scarborough, Westbrook, Gorham, Cumberland, Falmouth, and Yarmouth).
4. Alternative D—Controls on fuel sulfur content within the entire Portland AQCR.

The CDM predictions showed convincingly that the current average sulfur contents of heavy fuels must be reduced to meet ambient air quality standards. To determine the average sulfur contents of heavy fuels required to meet the standards for each alternative strategy, a series of CDM tests were run. Progressively lower average sulfur contents of No. 6 and 4 fuel were used in each successive test, as defined below, with No. 2 fuel at an average sulfur content of 0.25 percent in all cases.

Test 1—Existing average sulfur contents of heavy fuel oils, with No. 6 at an average of 2.3 percent and No. 4 at an average of 1.27 percent.

Test 2—No. 6 fuel average sulfur content reduced to that of No. 4 fuel, with both No. 6 and No. 4 at an average of 1.27 percent.

Figure 5.—The 24-hour test sequence for the locus of maximum predicted concentration at the Masonic Building monitor.



Test 3—No. 6 and 4 fuel average sulfur content reduced, with both No. 6 and No. 4 at an average of 1.0 percent.

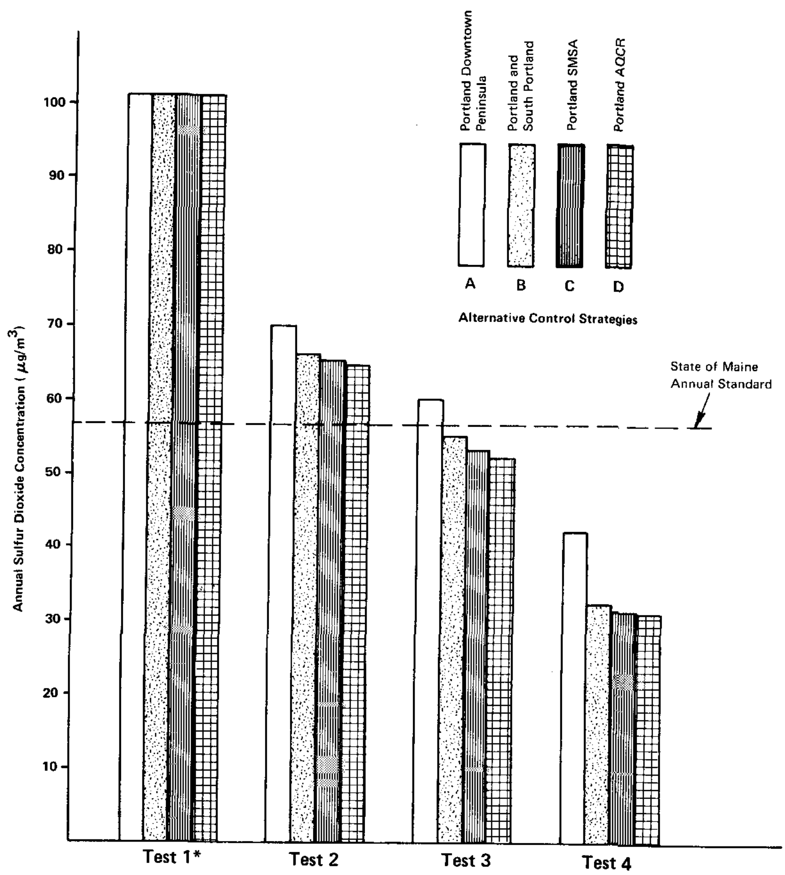
Test 4—No. 6 and 4 fuel average sulfur content further reduced with both No. 6 and No. 4 at an average of 0.5 percent.

Test 1, of course, represents worst-case projections without controls. Projected ground-level concentrations at the location of maximum concentration in the Portland AQCR, which is at the Masonic Building monitor, were shown for the 24-hour period and for the annual period. These concentrations represent the magnitude of peak sulfur dioxide concentrations under projected worst-case meteorological and emission-rate conditions. Both projections show that ambient concentrations would exceed state standards by a considerable margin.

In test 2, the average sulfur content of No. 6 fuel was reduced from 2.3 to 1.27 percent, the same average sulfur content as No. 4 fuel. The predicted ground-level concentrations for test 2 still exceeded state standards for both the 24-hour (fig. 5) and annual (fig. 6) time frames for all alternative strategies.

Predicted concentrations for the 24-hour case of test 3 continue to exceed the state standards for all alternative strategies. However, for the annual case the standard is exceeded only with al-

Figure 6.—Predicted annual sulfur dioxide concentration for alternative control strategies, Masonic Building monitor.



ternative A. The remaining alternative strategies bring levels below the standard and are acceptable strategies for assuring compliance with the state sulfur dioxide annual standards.

As anticipated, achieving compliance with the 24-hour standard requires a more restrictive fuel sulfur content than required to achieve compliance with the annual standard. Although compliance with the annual standard may be possible at the test 3 sulfur content level with alternative A, the same sulfur combination in fuel oils will not meet the 24-hour state standard (see comparisons, *figures 5 and 6*).

The average fuel sulfur contents that would assure compliance with the 24-hour standard and the annual standard were derived by interpolation between test 3 and test 4 (table 2). The average fuel sulfur contents for the 24-hour compliance case are more restrictive than for the annual case. To assure compliance with both 24-hour and annual standards, a set of alternatives that establishes compliance with the 24-hour standard must be selected.

In order to place into perspective the cost of implementing each strategy, a brief economic analysis was prepared. Generally, the economic impact of implementing a given control strategy will depend on the number of affected fuel oil users, the affected volume of oil consumption, and the reduction in fuel sulfur content required. The economic analysis prepared here accounts only

Table 2.—Predicted peak annual concentrations at monitoring sites

Site	Annual concentration
	$\mu g/m^3$
Jack Junior High School	46
Lyseth School	12
Portland Jetport	15
South Portland High School	25
South Maine Vocational Training Institute	35
Portland High School	72
Masonic Building	97
Mobile Van (Downtown Location)	66
Stroudwater (S.D. Warren)	22
Warren Avenue (S.D. Warren)	13

for the differential cost between fuel of the current and required sulfur contents.

This economic analysis does not account for the expenses that might be incurred if changes to the present boiler configurations are required. Nor does it include any of the other expenses that might be required as a result of implementing the proposed alternative control strategies. The analysis also assumes that sufficient oil of the required sulfur content will be available for fulfilling the needs of the selected strategy.

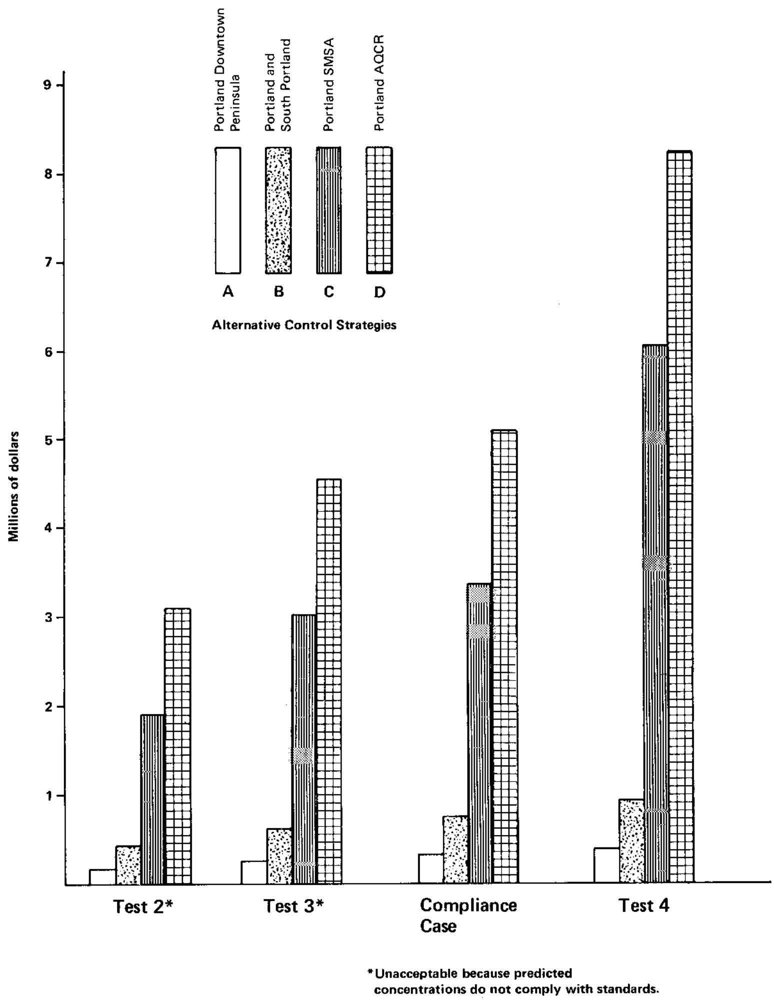
The 24-hour test case was shown to be the limiting case in terms of compliance with state standards. The economic analysis was therefore established for the average sulfur content of fuel oil specified by the 24-hour case. The annual case was not considered because less stringent reductions in fuel sulfur content were required for assuring compliance with state standards.

The results of the economic analysis per test case and alternative strategy show that costs increase dramatically as fuel sulfur level decreases and the area of control or volume of fuel affected increases (fig. 7). Test 1 is not included because it represents the status quo and no expenditures would be required. Tests 2 and 3 show costs increasing as fuel users in the Portland AQCR are subjected to increasingly stringent controls on fuel sulfur content. However, these tests are unacceptable in terms of meeting state sulfur dioxide standards. Test 4 was shown to be overrestrictive in regulating the fuel sulfur content in meeting ambient-air quality standards.

The compliance case, intermediate to tests 3 and 4, restricts fuel sulfur content only to the degree required to achieve compliance with the state standard. A comparison of the incremental costs for implementing each of the four alternatives in the compliance case shows that alternative A is the least expensive. The total incremental annual cost for implementing this strategy would be an estimated $330,000.

The results of this study and their analyses were presented at a hearing before the Maine Board of Environmental Protection. Subsequent to the hearing, the Board promulgated a new strategy for meeting sulfur dioxide ambient air quality standards in the Portland AQCR. The Board established a subregion within the original Metropolitan Portland AQCR, denoted as the Portland Peninsula Air Quality Control Region. Included in this subregion are all monitoring locations where violations had occurred. The fuel used in the subregion after 1 November 1975 was restricted to a maximum sulfur content of 1.5 percent, and the remainder of the Metropolitan Portland AQCR was per-

Figure 7.—Incremental annual costs associated with 24-hour test sequences for alternative control strategies.



mitted to use fuel with a sulfur content not exceeding 2.5 percent. The action of the Board indicates a consideration of several alternative strategies, and the final selection was based on economics and fuel supplies as well as assuring compliance with standards.

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