COST-EFFECTIVENESS FRAMEWORK FOR MINIMIZING TOTAL COST OF EPA REGULATIONS

PHASE I REPORT

Prepared for:

U.S. Environmental Protection Agency
Office of Planning and Evaluation

EPA Contract No.
68-02-2672 (Battelle)

January, 1979

Development Planning and Research Associates, Inc.
ICF Incorporated
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1. EXECUTIVE SUMMARY AND INTRODUCTION

The Environmental Protection Agency has been at the forefront of analyzing the economic consequences of regulations on those who must comply with them. As part of its continuing policy of evaluating both the public and private economic effects of its regulations, EPA has recognized the need for a more detailed analysis of the marginal cost-effectiveness (MCE) of alternative pollution control methods and levels of abatement. Much of the previous work evaluating the impact of a proposed regulation has compared the costs of alternative technologies or levels of abatement. However, much of this work has focused on a single technology chosen to represent the "best available" or "economically achieveable" control technology without consideration of its cost-effectiveness compared to other methods of control or levels of abatement (effectiveness).

Recent declarations by EPA that it would analyze the MCE of pollution controls to improve the evaluation of alternative control strategies in order to try to obtain the least costly mix of pollution controls led to the formulation of this study. In this context, the study was designed in two phases:

- Phase I - the development of a methodology and its pilot test in two industries, and
- Phase II - the application of the methodology to selected industries to derive marginal cost-effectiveness relationships for use in policy decisionmaking.

This report presents the results of the work on Phase I, which took place from September 1978 to January 1979. Additional modification and clarification of the methodology described herein will undoubtedly emerge during Phase II. Thus, the methodology should be considered as preliminary at this time. The report is organized as follows:

1. Executive Summary and Introduction
2. Theory of Marginal Cost-Effectiveness
3. Methodology for Marginal Cost-Effectiveness
4. Textile Industry: A Case Study
5. Coal-Fired Power Plants: A Case Study
6. Implementation Concerns

THE POLICY CONTEXT

EPA's primary objective in sponsoring the development of an MCE methodology was to augment its capabilities to analyze the impacts of its regulations.

The Agency recognizes that it is no longer satisfactory to measure only the economic burden that meeting a particular standard for a particular pollutant places on a specific industry; nor does evaluating the cost-effectiveness of moving to a more stringent control level for a single pollutant provide adequate assurance that EPA is acting in a manner consistent with its goal of providing the highest level of environmental protection for the least cost.

The need for more advanced analytic tools is particularly evident, because the Agency is increasingly being subjected to legal challenge on economic-related issues. In adopting more effective regulations, EPA confronts increasingly complex policy decisions. The primary policy issues include determining control strategies:

- for a single pollutant or group of pollutants,
- for an industry or industry segment, and
- to determine emphasis among pollutants.

For each of these primary issues, there are a number of aspects which EPA must determine including which specific industries and pollutants to regulate and the order in which they should be considered, how the regulations might affect particular regions, the date at which the regulations should be implemented, and whether or not interim standards should be used.

In developing the marginal cost-effectiveness analysis methodology, it was apparent that a single analytical scheme could not be applied to respond to all the varied policy questions for which such a tool would be useful. We found that different issues arise (e.g., weighting, timing, aggregation) depending on the specific policy questions being addressed. Consequently, we have developed a basic methodology containing a number of steps from which only those necessary to respond to the particular policy questions at issue could be selected.

THE ANALYTIC CONTEXT

In theory, environmental regulations are designed to maximize the difference between the social benefits derived from the regulation and the social costs (both public and private) of compliance with the regulation. Benefit-cost analysis (BC) is a well-developed theory of analysis designed to aid in identifying socially optimal policies or regulations. Its utility is severely limited, however, by the requirement to quantify both tangible and intangible social costs and benefits. Cost-effectiveness analysis (CE) was developed to analyze problems where benefits could not be quantified in a manner commensurate with the quantification of costs. CE is designed to identify efficient but not necessarily optimal solutions by answering one of the following to questions:

1. What is the least-cost way to achieve a given level of effectiveness?, or

2. How can the greatest effectiveness be achieved for a given level of expenditure?

CE results have a good deal of utility in the decisionmaking process provided that one of the two conditions specified can be met. CE ratios (cost per unit of effectiveness) are often used as a comparative tool for ranking alternative courses of action, but the validity of the comparison suffers when neither cost nor effectiveness are held constant. Furthermore, CE results represent <u>average</u> solutions and are a relatively poor measure of the marginal change in cost with effectiveness at a given level of effectiveness.

Marginal cost-effectiveness (MCE) tends to overcome the problems associated with conventional CE solutions. MCE results can be used for comparisons when neither cost nor effectiveness is held constant and thus is a suitable basis for identifying efficient solutions to a broad array of policy questions regarding pollution control alternatives.

MCE analysis as applied to pollution control issues seeks to establish the relation between successively more stringent degrees of abatement (effectiveness) and the corresponding change in cost of compliance. Theoretically, a continuous functional relationship between cost and effectiveness can be developed at both the macro- and microeconomic levels. In practice, these relationships can rarely be derived analytically, because the abatement technologies generally yield a discrete interval of effectiveness at a discrete increase in cost.

Functional relationships between cost and effectiveness can be approximated statistically through successive incremental analyses. Thus, where a continuous cost-effectiveness function does not exist or cannot be easily derived, the MCE analysis is akin to repeated applications of CE analysis under nearly equal effectiveness conditions, i.e., repeated CE analysis for several closely related effectiveness levels so that the "marginal" costs of the "marginal" removals can be ascertained.

Consequently, MCE analysis as applied in this methodology is the blending of successive incremental changes in cost and effectiveness and technically should be called incremental cost-effectiveness analysis. However, for the purposes of this study, we have adopted the more general term -- marginal cost-effectiveness analysis.

THE DATA CONTEXT

The MCE analysis tool is not a complex one, but it does require extensive cost and effectiveness data in order to establish useful relationships. From the existing EPA policy of requiring economic analyses of regulations, it could readily be inferred that a considerable amount of the appropriate data existed. This was <u>not</u> the case. The orientation of the regulation development process toward selecting a single "best" technology for control of a given pollutant has meant that little or no data has been reported on alternative technological processes which might approach but not reach the "best" level of control. The absence of this data means that relatively few points were available to establish a curve relating marginal costs with marginal effectiveness for any regulation. This presented a reasonably severe handicap in accomplishing one of the objectives of Phase I, which was to develop some useful relationships for the two pilot-test industries.

Because marginal cost-effectiveness analysis is not now an integral part of the standards-setting process, extensive data requirements must be fulfilled in order to undertake this type of analysis. For EPA to analyze the marginal cost-effectiveness of its actions in a comprehensive fashion, it would have to allocate increased resources to broad examination of the effects of proposed policies. At some future time, EPA must decide whether the costs necessary to collect the additional required data are justified by improvements in the cost-effectiveness of its regulations. Because data requirements are an integral part of performing an MCE analysis, we have incorporated into the early steps of the methodology a systematic approach to defining the pollutants and treatment systems for which costs and abatement levels will be needed. In addition, where data limitations exist, we recommend simplifications and data manipulations which will facilitate MCE analysis in these instances.

We must also emphasize that MCE is only one analytical tool among many (e.g., average cost-effectiveness analysis, least-cost solutions, and total-cost analysis), and for some specific policy questions, it may be inappropriate. Recognizing the possible limitations of performing MCE analysis, the methodology has been designed so that it can also be applied to other relevant economic analysis. In effect, we have expanded the scope of the original workplan and have attempted to provide EPA with a systematic approach to defining the basic inputs (cost and effectiveness data for alternative pollution control strategies) necessary to enhancing its ability to do economic analysis leading to more efficient regulatory strategies.

SUMMARY OF RESULTS

This section presents a summary description of the methodology that was developed during Phase I and briefly reviews the results of the two pilot tests.

Summary Description of the Methodology

The methodology devised for computing marginal cost-effectiveness ratios is comprised of seven steps:

1. Perform Population Analysis
2. Perform Entity Analysis
3. Identify Elements of Data Base
4. Compute Treatment System Cost and Abatement Table
5. Compute MCE Ratios
6. Analyze MCE Ratios
7. Aggregate Entities

Each of this steps is discussed below.

Population Analysis. Population analysis identifies the universe of industries or processes relevant to the policy issues being examined. For example, if the policy question were: "What is the MCE of controlling pollution from the steel industry?" then the relevant population would be all the processes in the steel industry. If the policy issue were "Compare the MCE of controlling BOD in two different industries," the population would be those processes in each industry involved in BOD production and control. Similarly, if the policy issue were "Compare the MCE of controlling air pollution from boilers," the relevant processes using boilers must be culled from all industries. In short, population analysis involves two substeps:

1. Define policy issues study is to address in broadest possible terms, and

2. Identify industries and processes relevant to policy issues.

Entity Analysis. For most policy decisions, the ultimate objective is to analyze MCE ratios for an entire population (e.g., the steel industry, all boilers). But populations frequently will consist of diverse components. For example, the steel industry includes three different types of furnaces and a total of twenty-nine processes. For the purposes of performing MCE analysis, we propose that populations be divided into components with similar characteristics. We refer to these subsets of a population in this analysis as "entities." An entity may be a model plant, a particular engineering process or a mobile source. In defining entities, several characteristics should be considered including age, size, and engineering process.

Identify Elements of Data Base. This step of the methodology specifies the required data. In this step, we identify: the pollutants to be included in the analysis (Step 3.1) and the unit processes to control each of these pollutants (Step 3.2).

Ideally, all pollutants affecting a given entity would be included, but this may make the analysis unwieldy. No set rules can be articulated for deciding which pollutants are to be included in the data base. In part, the specific pollutants included will be determined by the entity being analyzed and the policy issues being addressed.

A unit process is a piece of equipment, an engineering process, or a raw material which achieves a level of abatement of a pollutant. It is necessary to identify each plausible unit process capable of abating a particular pollutant. Where a unit process affects only one pollutant, this task will be straightforward. Where a unit process affects two or more pollutants, a method must be employed to apportion the costs of operating the process among the affected pollutants.

Create Treatment Systems Cost and Abatement Table. The Treatment Systems Cost and Abatement Table brings together the entire set of key pollutants, the applicable (unit processes) and the abatement levels they achieve, and their costs of pollution control. The design of the Table (4.1), how to determine the possible number of combinations (4.2), the relevant cost factors (4.3) and the effectiveness of the combinations (4.4) are the substeps involved.

The Treatment Systems Cost and Abatement Table is designed to serve as the fundamental data base for evaluating any MCE-related policy questions and must be as comprehensive as possible. It must present the costs of control, broken down into detailed estimates assignable to specific pollutants. It must present all the levels of effectiveness attainable by each unit process. Most importantly, it must examine the costs and effectiveness of each plausible combination of pollutants and controls. For each pollutant, the required data include:

(1) technology or unit process employed;

(2) the cost of that process;

(3) the amount of pollutant removed by the process; and

(4) the amount of pollutant still emitted.

Calculating control costs for each pollutant is one of the more complex tasks in the MCE methodology particularly for those pollutants and unit processes which affect more than one pollutant. Where possible, based on engineering judgment, these joint costs should be allocated among the affected pollutants on the basis of their relative contribution to the total costs of control. In most cases where joint costs occur, this will be impossible, and a method for allocating costs among affected pollutants is required (see Step 5).

Quantifying effectiveness results in measures of the level of abatement and of the level of emissions from the entity when the unit process combination is applied. For each key pollutant, an appropriate measure should be devised. We recommend kilograms removed and kilograms emitted per year whenever appropriate. For certain pollutants, other standardized measures will be necessary (heat, degrees; pH, pH level).

<u>Compute MCE Ratios</u>. The exact data drawn from the data base will depend on the particular policy question being addressed. The policy issue is then used to identify the relevant data which directly affect it. For example, if the policy question involved the MCE of changing the standard for a particular pollutant, then only those data which accomplish this while holding all other pollutants constant (or by allocating costs to those affected pollutants where costs are nonseparable) must be analyzed.

Having identified the data relevant to the specified policy issue, we now have a measure of costs and abatement for each pollutant. Before using this data to compute the desired MCE ratios, a final manipulation may be required. To determine <u>marginal costs</u> where nonseparable costs exists, some allocation scheme must be employed. Several ways to assign nonseparable costs exist and selecting the one to employ will depend in part on the availability of data and the particular policy question being addressed. These include:

- target pollutant - all costs are assigned to one pollutant,
- ratio of separable costs - costs are assigned in proportion to the ratio of separable costs,
- allocation on effectiveness weighting - costs are assigned in proportion to the ratio of damage averted by the unit process,

- ratio of costs of separate facilities - costs are assigned in proportion to the ratio of the costs of building separate treatment chains for each pollutant, and

- equal allocation of costs - costs are assigned in equal proportion to all affected pollutants -- the last resort.

Analyze MCE Ratios. The next step in the methodology requires the analyst to evaluate the MCE ratios before drawing conclusions. This step is critical because the derived ratios are subject to misinterpretation; they must not be mechanically applied in the decisionmaking process. Situations where misinterpretation is likely include: (a) where thresholds are used to determine acceptable MCE ratios, (b) where major polluters are permitted to continue at the expense of minor polluters; (c) where the percentage of removal varies (e.g., one firm moves from 10 to 50% abatement, another moves from 80-90% abatement); (d) where interim standards are phased in over a period of time; and (e) where the timing of implementation of a standard remains at issue.

Of particular concern are policy questions requiring the consideration of timing. For example, EPA may choose to adopt a less stringent interim level of required abatement in an effort to lessen the burden its regulations impose on industry, followed at some later date by a more stringent target standard. The use of interim standards affects two aspects of the MCE methodology. We can reasonably assume a firm will select the least-cost treatment chain to meet each of the proposed standards. Where the use of interim standards is being considered, examining only the least-cost treatment chain to comply with the alternative standards imposed at different points in time could be misleading. With the likelihood of shifting over time from a given standard to a more stringent one, it may be less costly for a firm to select a unit process which actually costs more than another at the initial period. Thus, from a marginal cost standpoint, in situations where two or more time periods are being considered, it is essential to examine the full range of possible unit processes to comply with each standard.

Although timing is straightforward as it relates to costs, it severely complicates attempts to measure effectiveness. This problem arises when the MCE methodology is used to compare a proposed standard which is to take effect immediately to one to take effect at some future date. Comparing costs in this situation is relatively easy. Although there may be some debate about the appropriate discount rate when applied to the estimated future costs, these costs can be directly compared to present investments. But no such clear-cut manipulation exists for comparing the effectiveness of the same standards imposed at different times. If we were to ignore this problem, the MCE of a standard imposed today would be exactly the same as that of the same standard if its implementation were delayed for a period of time. The problem is handled by allocating the amount of pollutant removed over a time horizon appropriate to the policy question at issue.

Aggregate Entities. Marginal cost-effectiveness, although most applicable at the entity level, can be conceptually extended to apply to industry segments or across industries, and to geographic regions or nationwide. For many of the policy issues capable of being addressed by MCE analysis, some level of aggregation will be necessary. Examples of these issues include the following:

- What is the marginal cost-effectiveness of cleaning up one pollutant to the same degree in different industries?
- What is the marginal cost-effectiveness curve for cleaning up one pollutant in all industries?
- What is the marginal cost-effectiveness of cleaning up all pollutants in one region of the country?
- What is the marginal cost-effectiveness curve for cleaning up one pollutant across all industries in one region?

To respond to these policy questions requires that model plant data be aggregated along any of three dimensions:

- pollutant
- industry
- geography

Aggregation is the equivalent to summing the applicable entity-level MCE curves over a constant range of marginal costs. Before summing the curves, however, it is necessary to weight each by the proportional number of equivalent model entities in the relevant population. Secondly, in order to obtain a constant range necessary to sum the MCE curves, they may need to be extrapolated to a common marginal cost range. Finally, if different pollutants are being aggregated, they must be weighted (or assumed to be equal).

Coal-Fired Power Plants: A Case Study

This case study shows how the methodology would evaluate alternative new source performance standards currently being proposed for coal-fired power plants. The population must be defined to include those coal-fired power plants likely to be built if specific environmental regulations are adopted.

Defining the entity to be analyzed is relatively straightforward in this case study. Because we are dealing with a new source performance standard, neither age of the plant nor varying engineering processes are relevant considerations. We will assume that all new facilities employ the same boiler processes. For the purposes of this case study, we have defined the entity to be a 500-megawatt power plant.

The Development Documents for coal-fired electric utilities and the numerous studies supporting the development documents have identified over 50 pollutants which are emitted by electric utilities. These fifty pollutants include conventional, non-conventional and priority water pollutants plus criteria and hazardous air pollutants. Sludge is also created in substantial quantities. Of these fifty, the most serious are:

Air:

SO_2
Flyash (TSP)
NO^x

Water:

Suspended and Dissolved solids
Heat
ph
Chlorine
O&G
Trace Metals

Sludge

Several unit processes are available for controlling SO_2 emissions, two unit processes control particulates, and one unit process is available for NO_x. Sludge is chemically treated and land-filled. Because the data were insuffi- cient, water pollution unit processes were not analyzed.

The most well-known unit process to control SO_2 is a flue-gas desulfurizer (FGD), also known as a scrubber. Another unit process to control SO_2 emissions is physical coal cleaning (PCC) and the use of low-sulfur coal (LSC). For particulates, two unit processes have been identified. The most common is an electrostatic precipitator (ESP). The second unit process is a fabric filter. The only unit process available to control NO_x is two-stage combustion.

Several unit processes exist to dispose of sludge, but their current costs reduce the practical options to ponding and chemical treatment and landfill.

Because data were totally inadequate, as compared to the partial inadequacy of air and sludge data, we were unable to incorporate water unit processes into this analysis.

Summary. After identifying the relationships among the unit processes and completing the Treatment Systems Cost and Abatement Table, we were able to illustrate the application of the methodology to specific policy questions. It is important to note that the limited and unreliable quality of air and sludge cost data and the lack of any water treatment data severely compromise the ability to use these trial results as anything more than an example of an application of the methodology. The policy questions addressed were:

- What is the MCE of alternative, more stringent sulfur dioxide standards?

- What is the MCE of trading-off particulate control for sulfur dioxide control?

In applying the methodology to these issues, it was apparent that, when used to address a specific policy question, some manipulation of the basic methodology is required. This is particularly true when only limited data is available. At the same time, the methodology proved to be flexible enough to provide the basic framework for analyzing a diversity of policy issues.

Textile Industry: A Case Study

The relevant population of textile mills was defined as existing direct dischargers. The population is composed of about 220 mills which are subject to best available technology economically achievable. This population can be represented by 26 entities composed of different processes and mill sizes.

The data base used was from recent Effluent Guidelines Document on the textile industry. Although a number of pollutants are present, seven key pollutants and pollutant parameters were reported including:

Conventional	BOD, COD, TSS, O & G
Nonconventional[1]	Phenols, Chromium, Sulfide

The Textile Industry case study demonstrated that marginal cost-effectiveness can be developed but only after significant analytical effort not normally included in the industry engineering studies. Model plant information can be aggregated to industry or regional totals provided that the study includes geographic as well as size/type of plant parameters.

These positive results are offset by the following factors. The results actually generated are useful only as an example application of the methodology and cannot be used for policy decisions. Moreover, the additional analysis required is substantial and requires a degree of sophistication not normally needed in engineering studies -- the methodology relies on data that may be available during the engineering analysis but not generally required to achieve study objectives. Finally, MCE results of the type possible exclude such salient considerations as economic impacts and are therefore only one tool of several required for sound policy decisions.

Because of the data limitations the MCE analysis was confined to one of the 26 segments: "complex plus desizing" mills of the woven fabric finishing segment. Also, the analysis was confined to one of conventional pollutants. This stemmed from the lack of technical background information for detailed cost assignment.

Within a relevant range of the available data, we found a marginal cost curve for conventional pollutants for woven fabric finishing composed of 17 small and 10 large plants. This components of this curve are:

Marginal Cost	ABATEMENT Amount (kkg/y)	Percent
1.00	2415	25
1.50	3875	40
2.00	4950	52
2.50	5810	61
3.00	6450	67
3.50	6955	73
4.00	7325	76

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[1]The inclusion of chromium was done as a matter of convention and ease of presentation of the analysis.

At a marginal cost of $1.50, the small mills could reach a 32 percent abatement level and medium mills could remove 46 percent of the conventionals. This illustrates the different amounts of abatement among a subsegment for a given marginal cost.

The overall finding of this analysis was that, even though the source document used for data points is one of the better ones we have reviewed, a large amount of additional background information is required for carrying out the detailed analysis as represented by MCE analysis.

Implementation Concerns

The development and testing of methods for measuring the marginal cost effectiveness of EPA regulations was much more complex and difficult than originally thought. A number of factors affect the complexity of the analyses, and, in turn, raise theoretical issues which impact on the rigor of results obtainable. The specific issues which introduce complexities into the implementation of the methodology include: the types of data required and theoretical complexities. The specific issues in each area are:

- Types of Data Issues
  1. Number of Entities
  2. Number of Unit Processes
  3. Interdependency Among Pollutants
- MCE Theoretical Issues
  1. Well Ordered Treatment Chains - unit processes must be combined in such a manner that total systems cost increases and that the amount of each pollutant removed does not decrease.
  2. Number of ICE (MCE) Data Points - to aggregate to industry, region, or national totals requires a reasonable number of data points covering a reasonable range of MCE values. Each data point requires a properly constructed treatment chain and data points are required over an extensive effectiveness range.
  3. ICE (MCE) Interval - the data available for the case studies was not sufficient to develop a statistical approximation to the underlying cost effectiveness function. Instead MCE results were approximated by ICE analysis.

The above issues introduce complexities into implementation not so much because they cannot be resolved but because of the scope and detail of the tasks required. We believe that significant gaps exist in the data available but that these gaps can be closed by more complete and effective systems analysis at the entity level. Moreover, it seems probable that the quality of data available in completed engineering studies can be improved by interaction with selected labs or contractors.

Information gaps include:

1. Raw Influent, BPT Effluent and BAT Effluent Characteristics - No information on raw influent was available and only aggregated characteristic data for BPT and treatment chain effluent. Knowledge of the effluent characteristics for each unit process in each treatment chain is essential for cost assignment.

2. Treatment Chain Logic - The reasons for selecting particular unit processes and the sequence in which they are applied should be fully explained.

3. Complete Cost Analysis - Both investment and operating cost estimates should be prepared for each unit process in each treatment chain tested. This is essential when cost assignment is required.

4. Cost Effectiveness Analysis - A cost effectiveness study, not a mere reporting of cost and effectiveness is required. Each treatment chain presented should be the least cost method for achieving the desired level of effectiveness.

5. Cross-Media Consideration - It is important to include impacts on other media.

The above data gaps were generalized from the Textile Industry case study. The Coal-Fired Power Plan Case Study revealed similar problems. More specifically, information on the interrelationships among pollutants and unit processes was sketchy, cost and effectiveness points were limited even when a continuous function was available and data was lacking on at least several feasible combinations of unit processes.

The data and analysis problems cited above can be solved but at some cost in both money and time. The problems suggest that our Phase II effort be concentrated on a few key industries so that truly useful results can be obtained. It does not appear that a broad-brush study of a large number of industries based on available data will produce results much more applicable than the two case studies completed in this Phase.

The Phase II study will, of course, clarify the issues raised here. It seems ikely, however, that a comprehensive application of MCE methods will require ncreased resources for more detailed analyses of abatement option. EPA must therefore assess the cost effectiveness of MCE at some future time when better estimates of resources are available.

FINAL COMMENT

Marginal cost-effectiveness analysis, when properly performed, can be a powerful and useful tool for policy analysis. However it should be recognized that it requires extensive data. Also it should be considered as only one tool to be used in policy analysis. It does not replace conventional economic impact analysis aimed at plant closure, production and employment impacts. Both types of analyses should be performed in setting pollution control standards.

2. THEORY OF MARGINAL COST-EFFECTIVENESS

Marginal cost-effectiveness (MCE) analysis of pollution abatement seeks to estabish the relationship between successive increments of pollution abatement (effectiveness) and corresponding incremental costs of abatement. Theoretically, continuous functional relationships exist between cost and effectiveness at both microeconomic and macroeconomic levels, but in practice such theoretical MCE functions can only be statistically estimated through successive incremental analyses. This arises because most abatement technologies require discrete components having discrete costs for a given level of pollutant removal. Thus, the marginal costs of pollution abatement and the marginal effectiveness are not normally precisely related, although they may be concurrently analyzed and an MCE relationship may be approximated.

BACKGROUND

As a point of reference, marginal cost-effectiveness analysis is contrasted with that of cost-effectiveness analysis which involves one of two criteria:

- holding effectiveness constant and determining the least cost alternative for meeting the specified effectiveness, or
- holding total cost constant and determining the alternative which maximizes effectiveness for the specified cost.

MCE analyis is most like performing repeated applications of the first criterion, i.e., repeat the cost-effectiveness analysis for several closely-related effectiveness levels so that the "marginal" cost (also least cost for each effectiveness level) of the "marginal" removals can be ascertained. Next, MCE analysis may require that an MCE curve be fitted to successive "marginal" values.

Such an approach to MCE poses analytical subtleties and may present burdensome data requirements even for a single pollutant, because the methods of achieving improved pollutant removal usually involve new or modified treatment systems (rather than changes in operating procedures of a given treatment system). The necessary data may not be readily accessible.

Most pollutant abatement issues deal with multiple pollutants that are interrelated within treatment systems. In this situation, two fundamental questions arise -- both of which may require solutions for many policy problems to be answered:

a) What is the cost of each pollutant's incremental removal, i.e., how are the treatment system's joint costs to be allocated (assigned) to individual pollutants?, or,

b) What is a common measure of <u>effectiveness</u>, i.e., how are the multiple pollutants to be separately weighted to produce an overall index of abatement?

This multipollutant case and the questions it raises are complex and have been the core of this research effort. Although there appears to be no single, best answer to either of the questions posed, the research has developed some alternative approaches to each which are presented below.

In addition to the multipollutant issue, other difficulties were encountered that significantly affect the applicability and value of MCE analysis. Two of these issues are of major consequence -- aggregation and time phasing. Their theoretical and methodological implications are discussed separately below, as are those for other remaining concerns.

CONCEPTUAL DEVELOPMENT

Marginal cost-effectiveness analysis is foremost a microeconomic procedure, although with proper aggregation it provides macroeconomic results. The potential usefulness of MCE analysis in making environmental management decisions can best be described by considering a simplified macroeconomic case in which the economic concepts of public policy are embedded.

Economic Concepts of Public Policy

The generally accepted criterion for selecting among public-policy alternatives (such as those regarding pollution abatement) is to choose those which maximize social welfare, the sum of both public and private net benefits. Such a criterion theoretically requires perfect knowledge of all components of the social costs and social benefits of all feasible alternatives.[1] Thus in these terms the question "What degree of pollution abatement should be achieved to maximize social welfare?" can be posed. The question is extremely complex, but the conceptual basis for answering this question can be illustrated in a simplied case. For example, assume that only one pollutant exists in a static environmental setting and that we know both the total costs and the total benefits associated with all levels of abatement, i.e., costs and benefit functions from 0 to 100 percent abatement. Based on these functions, the associated marginal cost and marginal benefit functions can be derived. These relationships are illustrated in Exhibit 1.

With these relationships, it can be shown that maximum social welfare will be achieved at abatement level A where marginal social costs equal marginal social benefits. In relation to the total functions in Exhibit 1, this optimum point (A) also corresponds to the maximum distance between the total benefit and the total cost functions.

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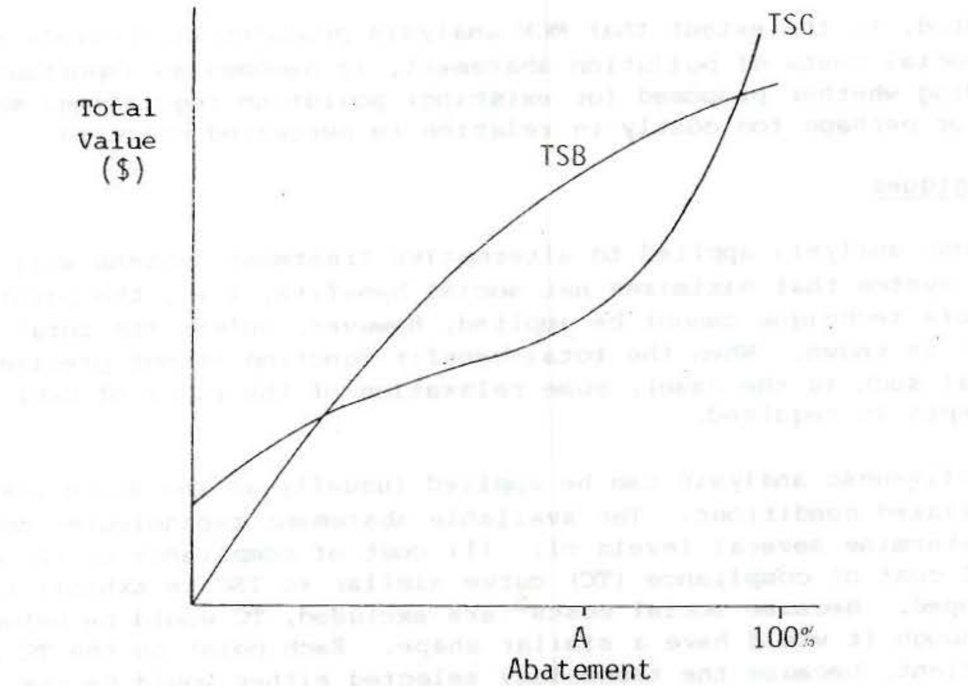
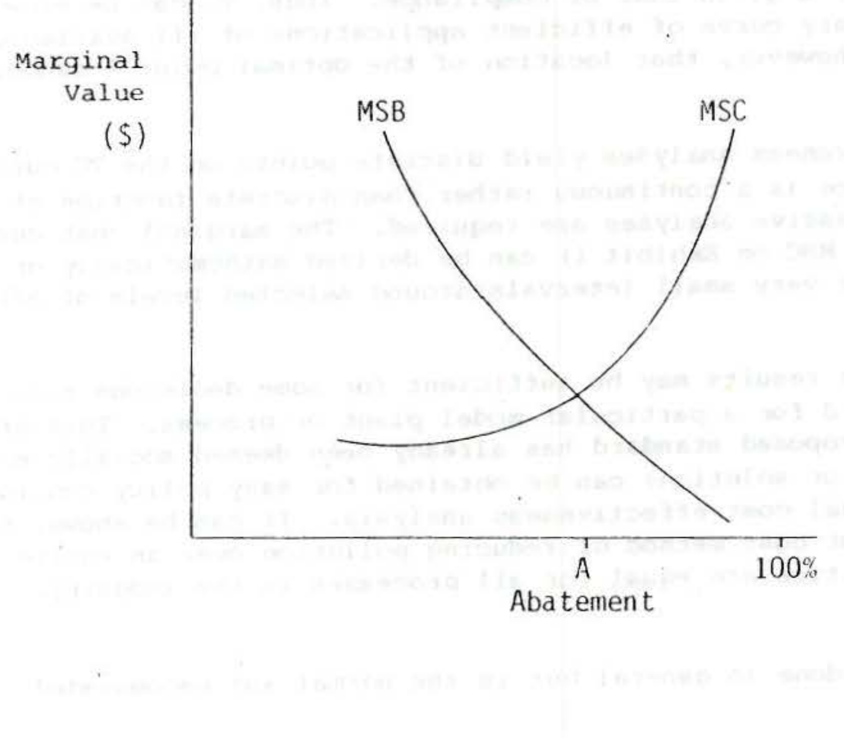
[1]This objective involves both issues of efficiency and equity, although these issues will not be pursued here.

EXHIBIT 1

PUBLIC POLICY ECONOMIC CONCEPTS:
TOTAL AND MARGINAL SOCIAL BENEFIT AND SOCIAL COST FUNCTIONS





In the single pollutant case, MCE analysis is equivalent to estimating the marginal social cost function of Exhibit 1. Estimating the marginal social benefits is extremely difficult and must be approached using a proxy based on effectiveness. Thus, the optimum level of abatement, i.e., (A), will not be known. Presumably, some independently derived criterion in terms of the cost level associated with A may be specified to indicate the desired marginal cost level that will approximate the optimum abatement level.

As suggested, to the extent that MCE analysis produces an accurate estimate of marginal social costs of pollution abatement, it becomes an important component in deciding whether proposed (or existing) pollution regulations may be "reasonable" or perhaps too costly in relation to perceived criteria.

Analysis Techniques

Benefit-cost analysis applied to alternative treatment systems will identify the treatment system that maximizes net social benefits, i.e., the point A on Exhibit 1. This technique cannot be applied, however, unless the total benefit function (TSB) is known. When the total benefit function is not precisely known (and in general such is the case), some relaxation of the rigor of public-policy economic concepts is required.

Cost-effectiveness analysis can be applied (usually at the micro level) under these relaxed conditions. The available abatement technologies could be examined to determine several levels of: (1) cost of compliance or (2) abatement. A total cost of compliance (TC) curve similar to TSC in Exhibit 1, can thus be developed. Because social costs[2] are excluded, TC would be below the TSC curve although it would have a similar shape. Each point on the TC curve would be efficient, because the technology selected either would be the least cost method of providing the desired level of abatement, or would yield the greatest abatement for a given cost of compliance. Thus, TC can be viewed as the envelope or boundary curve of efficient applications of all available technologies. Note, however, that location of the optimal point A cannot be identified.

Most cost-effectiveness analyses yield discrete points on the TC curve (unless cost of compliance is a continuous rather than discrete function of effectiveness); thus, successive analyses are required. The marginal cost curve (similar to but below MSC on Exhibit 1) can be derived mathematically or through successive analyses at very small intervals around selected levels of effectiveness.

Cost-effectiveness results may be sufficient for some decisions such as establishing a standard for a particular model plant or process. This presumes, of course, that the proposed standard has already been deemed socially efficient and equitable. Superior solutions can be obtained for many policy considerations by use of marginal cost-effectiveness analysis. It can be shown, for example, that the least cost method of reducing pollution over an entire industry occurs when MCE ratios are equal for all processes in the industry.

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[2]This need not be done in general but is the normal and recommended procedure.

This being so, determining the best estimator of the true marginal cost function is desirable. The precision of the techniques discussed above can be illustrated in the following example. Assume that cost (C) is a non-decreasing function of abatement or effectiveness (E) and further that the abatement has a finite limit. One such function can be written:

$$C = \frac{aE}{b-E}$$

where a is a scaling constant and b is the limit of effectiveness.

The marginal cost-effectiveness (MCE) function can be derived mathematically and is

$$MCE = \frac{ab}{(b-E)^2}$$

and the MCE ratio at any point x is

$$MCE_x = \frac{ab}{(b-E_x)^2}$$

Now, as discussed above, the MCE ratio can be approximated by repeated analyses of small intervals around an effectivness level of x. This procedure, applied to an interval of x, that is moving from x - x to x yields an incremental cost effectiveness (ICE) ratio of

$$ICE_x = \frac{ab}{(b-x)(b-x+\Delta x)}$$

This shows that ICE is a good estimator of MCE when x is small and further that the mathematic definition of MCE

$$MCE = \lim_{E \to o} \frac{\Delta C}{\Delta E}$$

holds. Note, however, that ICE is not a good estimator of MCE if x is larger and that, for a given x, the error of the estimate increases as the point x moves farther along the effectiveness axis.

A cost effectiveness (CE) ratio is a poor estimator of MCE. The ratio is obtained by dividing total cost at abatement point x by the abatement, i.e., x. Assuming the same functional relationship

$$CE_x = \frac{ab}{b-E_x}$$

and

$$\frac{CE_x}{MCE_x} = (b-E_x)$$

so that for

$(b-x) < 1$, CE $>$ MCE

$(b-x) = 1$, CE = MCE

$(b-x) > 1$, CE $<$ MCE

The relationship between MCE, ICE and CE have implications for the application of the theoretical approach to practical situations. Considerable care will be required to develop reasonable estimators of MCE when the cost effectiveness function cannot be derived.

Basic Aggregation Concepts

The previous example as illustrated in Exhibit 1 could have represented either a single polluter or many polluters each with its own marginal cost functions. If more than one polluter were involved, the "horizontal sum of the marginal cost curves" of all sources is required. The abatement levels must be specified in absolute terms in order to weight each source in the summation properly; percentages are inadequate.

This aggregation concept is illustrated in Exhibit 2 for a hypothetical two-source case in the same environmental control region. Only the marginal cost functions are shown, though implicitly the total abatement cost curves exist.

The example illustrates that the amount of the pollutant abated by each source is to be summed for each marginal cost level. A new total abatement axis must be specified to represent the aggregate pollution levels in the control region. Important characteristics of the summation process are to use only the rising marginal cost portion of the marginal cost functions and to be sure that all marginal cost functions span the cost-range being aggregated.

By aggregating in this manner, the sum of the sources marginal cost functions yields the same aggregate marginal social cost function as portrayed in Exhibit 1. Furthermore, it can be shown that the most efficient pollution abatement procedure would be to establish the marginal cost level associated with point A (in the aggregate) and then require that all sources (two in Exhibit 2) "spend" that marginal cost level, i.e., $MC_A = MC_1 = MC_2$ for sources 1 and 2. This is the least-cost (and most efficient) manner to achieve the abatement level A in this hypothetical case.

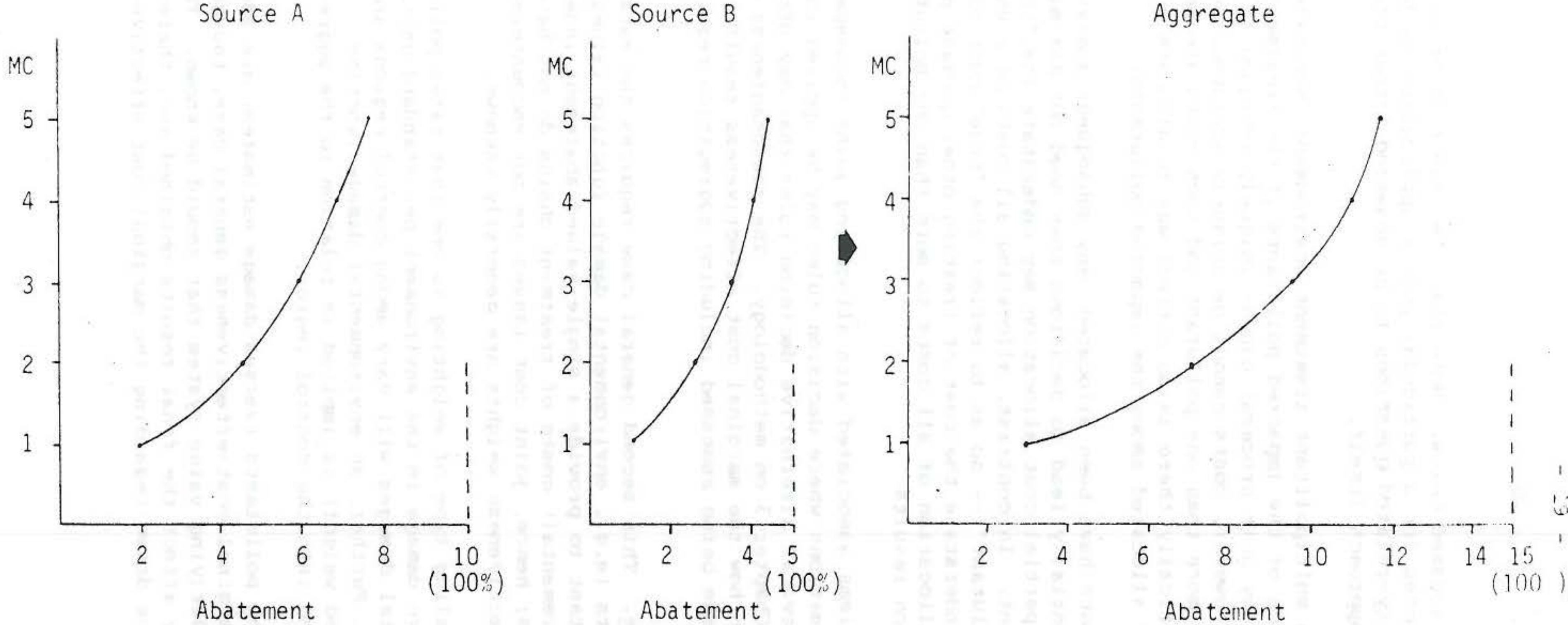
Other aggregation procedures, though perhaps useful, will not possess the properties described here. The main concern is to maintain comparability across sources in the aggregate.

Marginal Cost-Effectiveness Concepts

The preceding discussion was based upon the single-pollutant case for which theoretical constructs are readily determined. However, in fact, multiple pollutants are often involved in treatment systems, and this complicates the conceptual basis (and the analytical requirements) of MCE analysis. Three general cases exist for assessing the multipollutant problem. First, one might allocate all treatment costs among the impacted pollutants and consequently complete separate MCE analyses for each pollutant, i.e., cost allocation approach. Secondly, one might develop effectiveness weights for each pollutant in order to define a single-valued abatement index, i.e., effectiveness weighting approach. Thirdly, one might combine the cost allocation and the effectiveness weighting approaches for specified classes of pollutants with consequent separate MCE analyses for each class of pollutants. Each of these general cases has underlying

EXHIBIT 2

BASIC MCE AGGREGATION CONCEPTS



Source A

MC	A
1	2.0
2	4.5
3	6.0
4	7.0
5	7.5

Source B

MC	A
1	1.0
2	2.5
3	3.5
4	4.0
5	4.2

Aggregate

MC	A
1	3.0
2	7.0
3	9.5
4	11.0
5	11.7

theoretical complications as discussed below. Note that the selection of one (or more) of the general approaches for a particular policy application is dependent primarily upon the policy-related questions to be answered rather than on the inherent nature of the approach itself.

Cost-Allocation Case. In a multipolltant treatment environment, separate MCE analyses may be made for each of the impacted pollutants if the treatment system's component costs (e.g., by unit process) can be uniquely assigned to individual pollutants. Often, however, costs cannot be uniquely assigned, because some unit processes abate more than one pollutant and such costs are nonseparable, i.e., joint. Theoretically there is no correct way to allocate joint costs; they must be arbitrarily allocated among the impacted pollutants.

Conceptually, when joint costs have been allocated, any subsequent analysis of a single pollutant will potentially lead to decisions that need not maximize public and private welfare. A partial cost allocation may understate the "true" cost of abating a given pollutant. In contrast, allocating all costs of a unit process to a single "target pollutant" -- so as to reflect the "true" cost of abatement -- will necessarily understate the cost of treating other germane pollutants. Also, the potential allocation of all costs to more than one pollutant may lead to erroneous aggregation results.

Despite the conceptual problems associated with allocating joint (nonseparable) costs, there are many situations where decision rules may be applied to allocate costs "reasonably". Several alternative decision rules that may often be applicable are described in Chapter 3 on methodology. The reasonableness of each is principally dependent on how the marginal cost effectiveness results are to be used, i.e., the policy issue being assessed including aggregation requirements.

Effectiveness-Weighting Case. This second general case requires the establishment of effectiveness weights (e.g., environmental damage function values) that are assigned to each pollutant to provide a single-valued abatement index. In this case, the marginal (incremental) costs of treatment chains do not have to be allocated among pollutants; hence, joint cost issues are not encountered. On the other hand, suitable effectiveness weights are generally unknown.

Conceptually, the most appealing type of weighting is one that rates pollutants according to their relative damage in the environment per standard units of pollutants. Such environmental damages will vary among control regions and subregions within such regions. Further, an environmental damage function weighting (versus a single-valued weight) is implied in relation to the aggregate levels of pollutants emitted into the control region.

Simple relative weights among pollutants (versus damage estimates) are adequate for aggregating in this marginal cost-effectiveness general case, though they too must be based on an underlying value system that should be known. The weights used will instrumentally affect the final results obtained and, therefore, the conclusions that can be drawn regarding the marginal cost effectiveness of the pollutants abated.

Cost-Allocation and Effectiveness-Weighting Case. A combination of the first two cases can be utilized, perhaps most suitably, for most policy questions. This general case involves both partial cost allocation among classes of pollutants and partial effectiveness weighting. For instance, a common distinction is made among conventional, nonconventional and priority pollutants, and this may be an acceptable distinction for certain analyses. In this situation, costs could be allocated among the three classes (thereby reducing joint cost allocation problems) and effectiveness weights would only be required within classes (perhaps equal) for purposes of the marginal cost-effectiveness computations. This procedure would help reduce the scope of the problem yet allow a needed separation of results for each class of pollutant analyzed including the ex post assignment of effectiveness weights as deemed appropriate for each case studied.

The combination case has advantage of overcoming some of the joint cost allocation issues, but, also, the disadvantage of introducing subjective (often unknown) effectiveness weights within each class of pollutants. Information is lost concerning the marginal cost effectiveness of individual pollutants, though certain of the individual-pollutant results would be theoretically suspect because of joint cost allocation problems. At best, one should carefully consider the issue to be analyzed, the availability and quality of data input, and the degree of confidence in using needed effectiveness weights in deciding to use a combination cost allocation and effectiveness weighting approach.

Types of Data Required[3]

Basically, only four types of data are required to conduct MCE analysis at the entity, e.g., model plant, level. (Aggregation requires further data regarding the "population" being analyzed as described separately below.)

These four types of data are:

a) Treatment Options
b) Treatment Chain Costs
c) Treatment Chain Abatements
d) Effectiveness Weights

The latter effectiveness weights are not needed for the cost allocation approach, whereas much of the detailed treatment chain costs (by pollutant) are not needed where the effectiveness weighting is applicable.

Each of these types of data are briefly described here, to emphasize the data that are conceptually required for MCE analysis. Oftentimes available data does not approach the "ideal", though the data to be used can be accepted as representing such an ideal. Further descriptions of these types of data, including common limitations, are presented in Chapter 3.

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[3] In addition to the data needs specified here, MCE analysis ultimately requires, also, a criteria or a "threshold" MC level that approximates the optimum level if it is to be employed by all sources. Such a level corresponds conceptually to the MSC level associated with abatement level A in Exhibit 1, above, where MSC = MSB.

Treatment Options. An ordered set of treatment options -- theoretically the least-cost set[4] -- are required, each of which successively achieves increasing levels of abatement for one or more of the specificed pollutants for which the treatment system is designed. The abatement level of no pollutant should decline throughout the specified treatment sequence.

Unless a cost-effectiveness analysis is performed to assure for each effectiveness level the chosen treatment option is least cost, then the MCE analysis performed may not be optimal. Hence, decisions based on the analysis may not maximize achievement of public-policy objectives.

Discrete, increased levels of abatement, for one or more pollutants, will occur as a result of the ordered, sequencing process. Still, though, each pollutant may have varied increments of abatement and all pollutants may not have the same number of applicable incremental abatements, i.e., no change in abatement is valid for some pollutants (but not all) affected by the designated treatment system.

Ideally, the abatement (effectiveness) increments for each pollutant will be small throughout the sequence of treatment options. The smaller the increments, the more nearly the assessment will represent a "marginal" analysis, and, hence, a true MCE analysis. However, the discrete nature of known technological pollution removal alternatives may limit the available options.

Treatment Chain Costs. The cost allocation approach is highly demanding of treatment-system engineering and economic data to perform the requisite cost allocations among multiple pollutants. Generally, treatment systems are comprised of unit processes that are designed to attack specific pollutants. Therefore, data pertaining to these building blocks are essential, e.g., pollutant influent and effluent levels, investment and operating costs, and engineering design parameters. In contrast, if only the effectiveness weighting approach is to be applied, then only total treatment costs for each option are required. These data requirements are fully described below in Chapter 3.

Two types of costs are generally applicable when the cost allocation approach is required: separable and nonseparable. Nonseparable costs may be further divided as either semi-separable or unseparable. Separable costs are those which are clearly applicable to a given pollutant, e.g., a specific unit process attacks only one pollutant. Semi-separable costs are those that can be shown to apply to only a subset of the pollutants; any subsequent cost allocations will also apply to this subset. Finally, unseparable costs pertain to those cost items which cannot be clearly allocated to any specific pollutants.

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[3]In practice, alternative ordered sets of treatment options may not be "least-cost" over the entire range of effectiveness. Furthermore, many there exist technological constraints to shifting from one set of treatment options to another set. Theoretically, however, in the static case, one can consider the "envelope curve" of least-cost options.

Conceptually, the nonseparable costs present the greatest burden of analysis in the cost allocation approach. At best, only arbitrary cost allocation decision rules can be applied to obtain the desired data for individual pollutant MCE analysis. Various, potentially applicable decision rules are described in Chapter 3.

Treatment Chain Abatement. A full disclosure of the treatment chain's abatement performance is needed for each treatment option. Furthermore, a breakdown of influent-effluent characteristics for each unit process within each treatment option is needed in order to determine those pollutants affected (and the degree of abatement) as a partial basis of the preceding cost allocation decisions. Such detailed unit process abatement data are not required for effectiveness weighting; instead, only abatements for each treatment option are needed.

Obviously, the cost allocation approach requires additional detailed data pertaining to abatements as well as more detailed cost data. However, unless the joint cost allocation requirements are realistically approached, the results of MCE assessment will be highly suspect. Theoretically, there is no correct way, because joint costs cannot be separated.

Effectiveness Weights. Effectiveness weights are required for MCE analysis when either the effectiveness weighting or the combination (cost allocation and effectiveness weighting) approaches are used. In the first case, at least relative, differential weights are required for each pollutant in the analysis. In the combination case, at least relative weights are necessary within classes of pollutants so that abatement levels of each may be appropriately aggregated.

Conceptually, in the most general case, the effectiveness weights for all pollutants would be based upon their relative environmental damages. However, such damages will be functionally related to the aggregate levels of each pollutant, and others, in the environment. Hence, it follows that environmental damage function weights are the most suitable. Even more complex functions exist when dynamic versus static relationships are considered and/or synergistic interpollutant environmental reactions are embedded in the functions posited.

As is evident, effectiveness weights are not based on any of the calculations or data that are germane to MCE analysis, per se. That is, such weights are to be determined exogenously for use in certain MCE analyses as the basis for aggregating pollutant abatements into a common effectiveness index.

Although effectiveness weights are theoretically definable, such weights seldom exist and are necessarily subjective when they do exist. This state-of-the-art limitation handicaps the potential application of MCE analysis in many cases where at least partial effectiveness weighting is required to answer some policy questions.

Whenever effectiveness weights are used in MCE analysis, their effects should be easily identifiable from the analysis. Ideally, a sensitivity analysis can also be made using alternative weights so that decisionmakers can carefully assess the effectiveness weighting effects of their decisions.

3. MARGINAL COST-EFFECTIVENESS METHODOLOGY

This chapter presents the analytical scheme devised for computing marginal cost-effectiveness (MCE) ratios. The methodology is comprised of seven steps:

1. Perform Population Analysis
2. Perform Entity Analysis
3. Identify Elements of Data Base
4. Create Treatment Systems Cost and Abatement Table
5. Compute Marginal Cost-Effectiveness Ratios
6. Analyze Marginal Cost-Effectiveness Ratios
7. Aggregate Entities

The methodology is organized first to define the universe being studied (population analysis), then to disaggregate the universe into homogenous segments (Step 2) to facilitate marginal cost-effectiveness analysis. Steps 3 and 4 define the data requirments to compute marginal cost-effectiveness and compile the information in a systematic manner. Steps 5 and 6 describe alternative procedures for computing and analyzing MCE ratios. The last step discusses how to manipulate the entity-level analysis to make policy decisions relating to either segments of or the entire population.

As suggested in the introduction MCE analysis can be a useful analytical tool to address a variety of relevant policy issues. Therefore, we have aimed at developing a comprehensive, yet flexible mechanism that can be incorporated into EPA's standards-setting process. The diverse nature of the policy questions that may be posed preclude the mechanical application of the methodology to a particular policy issue. Depending on the policy question being addressed, some substeps (such as weighting), may not be required. For other substeps, we have presented several acceptable alternative methodologies and suggest guidelines to aid the analyst in deciding which of the approaches is most applicable to a particular policy issue.

A second major consideration in applying the methodology is assembling the required data. As constructed, the methodology requires information on the costs and abatement levels for all relevant combinations of pollutants and control processes. We believe that this level of detail is critical to doing a useful, credible, and defensible MCE analysis. We also recognize that the additional costs associated with these requirements in some cases may not be justified. In the methodology (especially Steps 3 and 4), we address what data ideally would either be available or developed for the purpose of this analysis. We then discuss what modifications must be made where data limitations exist.

STEP 1: POPULATION ANALYSIS

Population analysis is the first step in undertaking an MCE study. This step identifies the universe of industries and/or processes relevant to such a study. The objective in defining the universe is to establish the parameters that the policy analysis is to address; to accomplish this, it is necessary to articulate fully the policy issues themselves. We emphasize that, at least in the early stages, these issues should be defined as broadly as possible. By definind these issues broadly, it will then in subsequent steps of the methodology, be possible to address a variety of specific policy issues contained within the initial framework.

For some policy questions, the population would be all the relevant pollution-related processes in a specific industry, e.g., the steel industry. But for more complex policy questions, comparisons are required across industries and even across pollutants.

If the policy issue were, "Compare the MCE of controlling BOD in two different industries," the population would be those processes in each industry involved in BOD production and control. Similarly, if the policy issue were, "Compare the MCE of controlling air pollution from boilers," all processes using boilers in all industries would be examined.

Thus, population analysis involves two substeps:

1.1 Define policy issues to be analyzed in broadest possible terms.

1.2 Identify industries and processes relevant to policy issues.

STEP 2: ENTITY ANALYSIS

For most policy decisions, the ultimate objective is to analyze MCE ratios for an entire population (e.g., the steel industry, all boilers). But populations frequently consist of diverse components with different pollution characteristics, control processes, etc. For example, the steel industry includes three different types of furnaces and more than twenty processes. To compute the MCE of a proposed government action on such a diverse population is extremely complex; it is most workable to divide the population into relatively homogeneous segments. Such subsets of a population in this analysis are referred to as "entities". In most existing EPA development documents, the model plant defined for each industry segment is the equivalent of an "entity". Frequently, this same model plant can be adopted as the entity for the purposes of MCE analysis. But for some policy issues, an entity may be a particular engineering process (e.g. boiler units, auto engines). To avoid this confusion, we have elected to use the term "entity" for the purposes of this study.

In defining entities for a given population, the key characteristic which determines whether distinct entities are required is the extent to which different abatement strategies (i.e., unit processes and costs) are used within the population. Other characteristics of the population that should be examined include:

Age - Older plants may have markedly different pollution and abatement characteristics than new facilities. This may be true even where the same processes are employed in new and old facilities. If a known relationship exists between the old and new segments of the population, some computed "factor" can be used to estimate the MCE of one segment based on computations of the MCE for the other. In most instances, this relationship will be unknown and therefore, will necessitate the definition of two or more independent entities and MCE analysis for each. This analysis would then be followed by aggregation based on the proportional weighting of each entity as determined by its representation in the population.

Size - Pollution abatement costs, abatement levels, and technologies will significantly vary based on the size of a particular facility. Large plants sometimes can achieve economies of scale; in other instances, certain control technologies may be limited in their ability to clean large volumes of emissions. To determine whether it is necessary to define distinct entities by size, the range of sizes in the population must be examined. Secondly, the extent to which different controls, levels of abatement and costs vary by size must also be determined. Again, if the variation is minor, or if a known relationship exists over the range of capacities present, only one entity will be required and a factor can be applied to aggregate to the population level. Most frequently, however, MCE analysis for two or more distinct entities will be required.

Engineering Process - Where populations are defined as an industry or a region, numerous distinct engineering processes will be relevant to an examination of the MCE of environmental regulations. Because these processes involve different control technologies and costs, they must be examined separately as distinct entities and later be aggregated based on their proportional representation in the industry.

Thus, if any of these factors are prevalent, and no factor (known relationship) exists capable of aggregating any variations, then the use of more than one distinct entity is required.

STEP 3: IDENTIFY ELEMENTS OF DATA BASE

This step of the methodology identifies and establishes the data specifications required for subsequent MCE analysis. In this step, we identify: the pollutants to be included in the analysis (Step 3.1) and the unit processes to control each of these pollutants (Step 3.2).

Identification of the appropriate data elements is a critical step to a workable MCE methodology. By systematically pulling together the relevant pollutants, potential unit processes, and abatement levels, this step provides a useful roadmap to guide the efforts of EPA's engineering and economic contractors and ultimately the Agency's own decisionmakers in analyzing the MCE of proposed actions.

3.1 Identify Key Pollutants

The first step in creating the data base is to identify the pollutants to be included. Ideally, all pollutants affecting a given entity would be included. For most entities, however, this would make the analysis unwieldy; there are no significant advantages from including relatively unimportant pollutants. On the other hand, "key" pollutants cannot be determined by considering mass emitted alone. This would eliminate from the analysis most toxic and non-conventional pollutants which cause significant damage to the environment and which may be extremely costly to abate.

No set rules can be articulated for deciding which pollutants are to be included in the data base. In part, the specific pollutants included will be determined by the entity being analyzed and the policy issues being addressed. In the context of development documents supporting standards, EPA has frequently addressed this exact issue and used reasoned judgment to make its determinations. If a question arises concerning a particular pollutant, we do recommend, however, that the analyst err on the side of being overinclusive.

It would also be useful at this point in the analysis to group pollutants into recognized categories. For water pollutants, there would be conventionals (e.g., BOD and COD), priority pollutants, and nonconventionals. For air, the groupings would be criteria pollutants, toxics and all others. Sludge should be treated as a distinct pollutant. The purpose of these groupings is to facilitate the analysis of pollutant control costs and abatement (Step 4).

3.2 Identify Unit Processes and Treatment Chains

A unit process is a piece of equipment, an engineering process, or a raw material which is employed to achieve a level of abatement of a pollutant. In its most simple construction, it is a piece of equipment which controls one pollutant to a specified level at specified costs. Frequently, however, a unit process will affect more than pollutant. Where this occurs, it must be incorporated into this analysis. A treatment chain is one or more unit processes used to abate pollution. For example, physical coal cleaning and a scrubber (both distinct unit processes) when used together to abate sulfur dioxide form a treatment chain. (A single unit process, such as an electrostatic precipitator, would also be considered a treatment chain.) Treatment chains occur most frequently in controlling water pollution. Here, higher levels of abatement, require adding new unit processes to existing controls. In many of these instances a particular ordering of additional unit processes (e.g., remove a certain amount of suspended solids before going after phenols) is required and must be followed in the development of treatment chains for the analysis to be credible.

The first task in this step is to identify all process-specific treatment chains (made up of one or more unit processes) capable of abating a particular pollutant. Where a treatment chain affects only one pollutant, this task will be straightforward; where process or chain affects two or more pollutants, complications arise. Specifically, a method must be developed to apportion costs of abatement among the affected pollutants. This problem is discussed in Section 4.4. For this step it is necessary only to identify those treatment chains which affect more than one pollutant.

A second complication is that many treatment chains can achieve more than one level of abatement. For example, an electrostatic precipitator can achieve a full range of abatement levels for particulates by changing the area of magnetic plates it contains. In cases where treatment chains can be designed to achieve a full range of abatement levels, a continuous function would exist for its costs. This problem is dealt with in detail in Step 4.4.

Again for this step, all that need be noted is whether a unit process is capable of achieving only one level of abatement, can achieve a full range of abatement levels or only several distinct points. The latter would be the case if an electrostatic precipitator could only be designed to meet 0.5 lbs/10^6 BTU or 1.0 lb/10^6 BTU and not any abatement levels in between. This is necessary because processes or chains which control to different levels at different costs will be entered separately into the Treatment Systems Cost and Abatement Table derived in Step 4 and must be analyzed as distinct control alternatives.

The process used in this step is almost identical to that currently used by EPA in its standards setting process. The one divergence is that EPA establishes standards based on available technology (here termed a treatment chain) and then does cost analysis for the proposed alternative standards. MCE analysis stops short of using standards and instead focuses on level of abatement. This is necessary because a particular unit treatment chain may abate pollution to a specific level, but when used in the presence of or in combination with other equipment, or with different material inputs (e.g., higher sulfur coal), it may attain a slightly higher or lower level of abatement. The costs of moving back to the original standard may be very high. Thus, by using abatement levels, we are able to achieve a more flexible analytical framework for MCE evaluation.

The final product of this step is a data base table (Exhibit 3) listing all "key" pollutants and their relevant treatment chains. For each treatment chain, it is essential that the particular unit process or combination of unit processes be identified. Where relationships exist among pollutants, control processes or combinations of the two, these must also be identified in this table. For example, total suspended solids may be defined separately from BOD, but they are indistinguishable from the perspective of abatement (i.e., reducing one also reduces the other); this should be noted under these pollutants. When unit processes are combined, the costs of the existing controls may be altered. This too must be noted in the table. Finally, the use of a treatment chain to control one pollutant sometimes affects the control of other pollutants and must be described in the Table.

A hypothetical example illustrates the contents of the Data Base Table. In this example, SO_2 and conventionals (e.g., BOD and COD) are the only key pollutants. For each, we describe the alternative treatment chains, the relevant relationships which exist, and the abatement characteristics. This table defines in general terms the inputs into the Treatment System Costs and Abatement Table developed in the next step.

STEP 5: CREATE TREATMENT SYSTEM COST AND ABATEMENT TABLE

The Treatment Systems Cost and Abatement Table[1] brings together the entire set of key pollutants, the applicable treatment chains and the abatement levels they achieve, and their costs of pollution control. This section first describes the Table, followed by sections which discuss how to determine the possible number of combinations (4.2), the relevant cost factors (4.3) and the effectiveness of the treatment chains (4.4).

4.1 Designing the Table

The Treatment Systems Cost and Abatement Table is designed to serve as the fundamental data base for evaluating any MCE-related policy questions which could be asked about the specified population. To accomplish this objective, it must be as comprehensive as possible. It must present the costs of pollution control broken down into detailed estimates assignable to specific pollutants. It must present all levels of effectiveness attainable by each treatment chain. More importantly, it must examine the costs and effectiveness of each plausible combination of pollutants and treatment chains.

For the purposes of this analysis, combinations of pollutants and applicable treatment chains are referred to as "treatment systems." Exhibit 4 illustrates the design of the data base. The initial task is to categorize the key pollutants into criteria and hazardous pollutant groups for air; groups of conventionals, priority pollutants and non-conventionals for water; and sludge.

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[1]This table is presented only as a prototype for a specific analysis. The data required and that available will vary significantly and could be combined in a number of equally acceptable alternative formats.

EXHIBIT 3

ELEMENTS OF DATA BASE

Pollutant	Treatment Chain	Abatement Characteristics
SO_2	Flue gas desulferizer (FGD)	Creates sulfur sludge; Requires increased use of water; Can be designed to various levels.
	Physical Coal Cleaning (PCC) and FGD	Creates sulfur sludge and requires disposal of coal tail washings; PCC "reduces sulfur content and requires less scrubbing to meet a specified standard; Can be designed to abate to various levels.
	Low Sulfur Coal (LSC)	Western coal contains less sulfur but has a lower heating value so more must be used to produce the same amount of electricity; Use of LSC adversely affects operation of electrostatic precipitator.

EXHIBIT 4

TREATEMENT SYSTEM COST AND ABATEMENT TABLE

HYPOTHETICAL ENTITY

TREATMENT SYSTEM COMBINATIONS	POLLUTANTS																								
	WATER												AIR								SLUDGE		NONSEPARABLES		TOTAL
	Conventionals				Priority				Nonconventionals				Criteria				Hazardous								
					Phenols				Heat				TSP				Trace Metals								
	Treat. Chain	Cost	Abate R	Abate E	Treat. Chain	Cost	Abate R	Abate E	Treat. Chain	Cost	Abate R	Abate E	Treat. Chain	Cost	Abate R	Abate E	Treat. Chain	Cost	Abate R	Abate E	Treat. Chain	Cost	Treat. Chain	Cost	Cost
1.	CC	50	400	300	XX	100	300	50	--	0			ESP	150	135	2	--	0			CF+L	25	--	0	310
2.	CC+VF	non-sep	300	200	CC+VF	non-sep	.01	.001	CT	10	7	0	ESP	150	135	2	--	0			CF+L	25	CC+VF	200	235
3.	YY CC+VF	70 non-sep	500	150	CC+VF	non-sep	.01	.001															CC+VF	150	70 150

R - Pollutant Removed

E - Pollutant Emitted

Conventionals (BOD and COD)

Chemical Coagulation (CC)	Affects both BOD and COD
Vacuum filtration (VF) and CC	Works only after installation of CC.

The specificity of these groups will be determined by the level of detail of the available data. Ideally, all costs of treatment chains will be allocated to specific pollutants, thus eliminating the need for groups. Realistically, however, where joints costs exist or where inadequate data is available the analysis can best be performed with groups of similar pollutants.

In Exhibit 2 we present the Treatment Systems Table. In doing so, we recognize that frequently only limited data will be available, thereby requiring modifications to the prescribed format. As discussed above, one simplication is to group similar pollutants. A second simplication involves the absence of all the possible combinations of treatment chains. The MCE analysis can still be employed with a limited number of treatment systems, but the results may be less than optimum. The format of the Table allows the analyst to determine when other points are possible but currently unavailable, and require additional data is required.

For each combination of pollutants, the required data includes:

(1) treatment system employed;
(2) the total cost of that system;
(3) the amount of pollutants removed by each treatment system; and
(4) the amount of pollutant still emitted.

A separate column to the right of the specific pollutants isolates those costs which are "nonseparable". This refers to those treatment chains which affect more than one pollutant and, which in some instances, must be assigned among the affected pollutants. As illustrated by the example, where nonseparable costs exist for those affected pollutants, "nonsep" would be written under their cost headings, and the total cost of the treatment chain would appear under the column labelled "Nonseparable Costs" to the right.

The final two columns would be summations of total costs and abatements. Nonseparable costs must be distinguished from situations where two or more pollutants are affected, but where the treatment chain is employed primarily to remove a particular pollutant and ancillary effects are incidental. Instances of "incidental removal" costs should not be considered nonseparable, all costs should be borne by the pollutant which requires the treatment chain. The rows would consist of all the possible combinations of treatment chains and pollutants. By costing out each of these treatment systems, it should be possible to determine which treatment chains achieve a given level of abatement for the least cost and how MCE can be improved by trading-off abatement levels among pollutants.

4.2 Determining the Number of Possible Combinations

In order to guide the analyst and to determine the amount of resources necessary to undertake the analysis, it is useful to identify the total number of combinations or treatment systems to be examined. This computation draws from Steps 3.1 and 3.2 where we identified the key pollutants, the related treatment chains, and levels of abatement.

For each pollutant, the number of combinations (rows in the table) is determined by the number of different treatment chains identified in Step 3.2. For example, particulates can be controlled by an electrostatic precipitator to reach abatement levels of 0.1 and 0.05 x 10^6/BTU and by fabric filters capable of reaching a control level of 0.03 x 10^6/BTU. Thus, there are three different options for particulates, each of which must be compared to all the other possible combinations of options for other pollutants. In a four pollutant example having three options for two pollutants and two options for the remaining two pollutants, the total number of rows would be 36 (3x3x2x2).

The number of possible treatment systems calculated in this manner represent a ceiling, with the actual number of options being considerably fewer. Some combinations of treatment chains are mutually exclusive or redundant and can be eliminated at the early stage of the analysis. Where the policy issue being addressed concerns a static situation (i.e., only one time period), any treatment system which does not achieve a certain level of abatement at the least cost can also be eliminated.

The one situation where the method understates the true number of treatment systems would be where a continuous function exists for a particular treatment chain. Because the chain can achieve any abatement level over a specified range, it does not fit neatly into this part of analysis and must be excluded.

4.3 Calculate Cost of Control

Calculating the cost of controlling each pollutant in each row is one of the more complex tasks in the MCE methodology. The costs used should include all elements relevant to the particular system application. These elements include investment and operating costs associated with the systems, generated pollutant disposal costs, interrupted production costs, and, for in-plant/ process change systems, costs associated with changes in production capacity.

Cost coverage is not the only complexity. Costs are best computed by the basic building blocks of the method, i.e., unit processes. Some unit processes attack only one pollutant, but others attack several pollutants. When considering treatment chains and systems, cost assignment problems exist. When a unit process involves only one pollutant, assignment is easy. This situation describes what are called "separable costs". Where multipollutants are involved, costs are "nonseparable". In some cases nonseparable costs are assignable to a group if not all pollutants are involved. These costs are termed "semi-separable". Costs are termed "unseparable" when they can be assigned only to all pollutants attacked by the particular chain.

The complexity of the cost analysis is reduced to the extent that separable costs can be identified. Sound engineering analysis can enhance this identification. In some cases, for example, a particular unit process is included in the treatment chain to attack a particular pollutant. The reduction of other pollutants by this process is often termed "incidental removal." It seems logical to assign all costs associated with the unit process to the prime pollutant where incidental removal can be demonstrated.

It will not be possible to apply the incidental removal criterion to most cases where multipollutants (hence joint costs) are involved. Some other method for assigning costs is required. For the purposes of filling in the Treatment Systems Cost and Abatement Table, all that is necessary is to enter these nonseparable costs under the specified column to the right of the distinct pollutants and to place "nonsep" in the cost column under those affected pollutants. The problem of allocating these costs need only be addressed when calculating certain MCE ratios and is discussed in Step 5.

A continuous cost-effectiveness function also requires special handling in completing the Table. In this instance, we may want to identify specific levels of control, calculate costs for these derived from the continuous function, and enter these in the Table. Alternatively, it may be more desirable not to include distinct points for this pollutant in the Table. Instead, these would be incorporated directly into the MCE analysis in Step 5.

Regardless of form, it is essential to include all relevant costs of compliance in the Table. Different types of unit processes require different types of analysis to determine total cost of compliance. These are discussed below.

Costs for"End-of-Pipe" Treatment. Costs for end-of-pipe treatment, used genericly to mean treatment upon discharge for a particular production plant or process, can be estimated in a relatively straightforward manner. Basically only two types of costs are involved: (1) investment costs, and (2) annual costs. Investment costs are defined to include the one-time costs associated with designing, procuring, installing and checking the unit treatment process. Annual costs are defined to include all recurring costs associated with operating, monitoring and rehabilitating the unit process.

Various general definitions of the relevant investment costs and annual costs may be presented. The intent, however, is to include all items that are affected by a decision to proceed with each prospective treatment option. In most cases, these costs included at least:

Investment Costs

- Construction
- Equipment
- Monitoring Equipment
- Engineering
- Contingencies

Annual Costs

O&M Labor
Maintenance
Sludge Disposal
Energy
Chemicals
Monitoring

Energy costs, which are quite properly included as an element of Annual Costs, may be of particular interest in some cases. Unusually high energy costs should be noted so that the energy impacts of proposed environmental regulations can be fully explored as appropriate. Although energy impacts are not part of this analysis, they are an important consideration when evaluating policy alternatives. Adverse energy impacts should therefore be reported when identified in model plant (process) analyses.

Computing Annualized Costs. The cost elements listed above represent out-of-pocket expenditures for goods and services required to utilize each unit process. A single cost entry representing these elements and incorporating cost-of-capital and capital recovery concepts is required for entry in the Table. The "annualized" cost of each unit process will serve the purpose. Annualized costs are defined as operating costs for a base year plus investment costs amortized over the useful life of the project at the real cost of capital (weighted) before taxes.

Annualized costs should be expressed in constant year (e.g., 1980) dollars so that all entries in the Table are comparable. Appropriate inflation factors should therefore be applied to convert the reported investment and operating costs to the level of the selected year. The effects of taxes, which would have a different impact on different companies, have been excluded.

The amortized costs developed in this manner will be suitable for most static MCE analyses. They are, however, incomplete when dynamic problems such as the utility of interim standards are being considered -- the amortized costs exclude salvage value. Most pollution abatement equipment will have little salvage value as the dynamic problem may instead involve cost of removal and replacement rather than salvage cost considerations.

Generated Pollutant Costs: The removal of pollutants from one environmental medium will necessarily involve the generation of pollutants for disposal in another medium. A commonly generated "pollutant" is sludge, usually from the wastewater treatment system. The simplest approach is to estimate a sludge disposal cost -- given a cost per ton factor -- for the total volume of sludge generated.

The use of a standard sludge disposal cost may be satisfactory, particularly in a static situation. However, another type of cost concern is that associated with increasingly toxic sludge disposal -- which could increase abatement costs substantially.

Sludge generated contains both the pollutants removed from the waste water and any chemicals used to treat the water. Toxic pollutants such as phenols, sulfides and chromium may be present. Moreover, many of the organic priority pollutants (chlorinated hydrocarbons) can be removed using activated carbon, and others (heavy metals) may be removed by filtration. Thus, depending on influent and treatment process, the sludge generated could contain concentrations of priority pollutants high enough to require special sludge disposal techniques. If so, these costs are relevant to water pollution abatement and would show up in the Table under the sludge column.[1]

Interrupted Production Costs: The installation of abatement equipment could cause a production stoppage or slow-down at the model plant or process. If this occurs, the costs associated with the interruption are relevant to pollution abatement. Quantifying these costs can be a difficult task requiring a case-by-case analysis. The following guidelines will be helpful in such an analysis:

(1) Value of Lost Production: Lost production can, when data are available, be valued in terms of contribution to profits -- that is, the selling price less the variable (or out-of-pocket) cost of production. It is generally more difficult to determine if production is lost or merely delayed. Unless a plant is operating at or near capacity and the interruption is significant, the cost of lost production may be more illusionary than real. In those cases where production can easily be made up at a later date, the value of lost production approaches zero.

(2) Shutdown or Slowdown Costs: Some costs may be incurred whether or not the plant is in operation. Many of these costs are fixed in nature and would include supervisory salaries and rent. All such costs are relevant to pollution abatement.

In-Plant Control/Process Change Costs: A variety of in-plant controls or process changes can be postulated. Changing from high-sulfur to low-sulfur coal to reduce SO_2 or using staged combustion to reduce NO_x are two examples from the coal-fired power plant case. The textile case provides several examples useful to illustrate cost analysis methodology so that the discussion here centers on water pollution in general and the textile industry specifically.

In-plant controls and process changes are measures a firm can take to reduce water usage (e.g., water reuse and reduction) and the production of pollutants (e.g., substitution and material reuse). In some instances, there may be both costs and benefits associated with in-plant controls. Hence, "relevant costs" can be either positive or negative. Cost will include investment and operating categories such as those discussed above. These costs will, however, be reduced by the benefits derived which include:

(1) energy savings associated with the reuse of cooling water
(2) potential reduction in the cost of water
(3) potential reduction in process material costs through reuse
(4) sale of any residuals from control process.

Process changes (as opposed to in-plant controls) tend to be complex and costly. Solvent processing can, for example, be substituted for conventional processing for scouring wool and some knit fabrics and for finishing fabrics

[1]Note that sludge disposal was included as an element of operating costs.

sensitive to water, but with limited effectiveness. Changing material and process flow procedures from batch to continuous, substituting standing baths for moving baths or combining operations where possible, tend to decrease hydraulic loading. Newer equipment tends to be less polluting. Pressure dyeing uses dyestuffs more efficiently, uses less water and reduces the levels of toxic dye carriers compared to atmospheric dyeing.

The determination of costs relevant to process changes is slightly more complex than determining the cost relative to in-plant control. Cost estimates for both the new and the existing process are required using investment and operating categories similar to those discussed above. These costs should be time phased over some reasonable planning horizon with any interruption of production noted so that the value of lost production can be considered. The new process costs should also include the cost of abandoning the old system less salvage value. A first estimate of the net cost of the process change is the cost of the new process less the cost of continuing the old process totalled over the planning horizon.

This net cost (which could in theory be negative) represents the cost of abatement relevant to the process change. In some cases, the new process may increase production capacity significantly. When this occurs, it does not seem logical to charge all of the costs of the change to pollution abatement provided that the increased capacity can be utilized at the model plant. The separation of costs associated with capacity from the cost associated with abatement requires some additional analysis.

When capacity is increased and the cost of production does not decrease costs can be allocated between abatement and extra usable capacity on a percentage basis, that is

$$R_A = \frac{P_o}{P_n}$$

where R_A is the percent allocated to abatement, P_o is the original capacity and P_n is the new capacity. The percentage allocated to capacity (R_c) is

$$R_c = \frac{P_n - P_o}{P_n}$$

These ratios would assign too much costs in those cases where unit production costs decreased. Under these conditions, the percent of net cost allocated to capacity (R_c') is

$$R_c' = \frac{P_n U_o}{P_n U_n}$$

where U_o and U_n are the old and new unit costs. Since unit cost is the ratio C/N, the equation reduces to

$$R_c' = \frac{C_n P_o}{C_o P_n}$$

where C_o and C_n are the old and new process costs respectively. The percent charge to abatement (R_A') is

$$R_A' = \frac{C_oP_n - C_NP_o}{C_oP_n}$$

Note that R_A' is always less than R_A so long as unit costs have decreased.

4.4 Computing Effectiveness in the Table

Quantifying effectiveness in the Table results in measures of the level of abatement and of the level of emissions from the entity when the unit process combination is applied. For each key pollutant, an appropriate physical measure should be devised. For example annual kilos removed and kilos emitted should be used for most conventional pollutants. To the extent possible, all measures should be expressed in the same units.

Both the amount of pollution removed and the amount emitted must be included for clarity. For some treatment chains, the amount removed will increase, but at the same time the amount emitted will also increase. An example of the phenomenon would be the use of high-sulfur coal with a scrubber. Even though the scrubber is operating properly, the amount of sulfur emitted may increase because more sulfur is being put into the system. It will be important in answering policy questions and performing marginal analy- sis to identify this occurrence. By reporting both kilos emitted and removed, we also will be able to calculate percent removal, which may be useful to com- pare MCE ratios.

One other aspect of effectiveness in the Table is the lack of data in the "Nonseparable" column and Total Effectiveness column. Although it would be useful to have an overall effectiveness measure for nonseparables and the total system, it is not possible to create one until weights are assigned to pollutants. In the next section, this will be discussed further.

STEP 5: COMPUTE MCE RATIOS

Having identified all possible unit process combinations and their associated costs and levels of abatement in the data base Table (Exhibit 2), the essential elements are now present for doing MCE analysis. By enumerating all the possible relevant combinations of unit processes, the data base contains enough detailed information to address a variety of policy issues.

5.1 Define the Policy Issues

The exact data drawn from the Table will depend on the particular policy question being addressed. Drawing from the table of costs and abatement, it is possible to analyze the MCE of the relevant policy questions defined in Step 1 including:

- What is the MCE for controlling a particular pollutant at alternative, more stringent standards?
- What is the overall MCE of pollution controls affecting an industry?
- How does the MCE of controlling a pollutant in one industry compare to that of controlling the same pollutant in another industry?

5.2 Identify Relevant Rows in Table

Once the policy issues are defined, the next step is to identify the relevant rows in the Table which directly affect them. As expressed in the previous section, the Table was constructed to be comprehensive and therefore represents an extremely flexible policy tool. If a policy question involved the MCE of changing the standard for a particular pollutant, then only those rows which accomplish this, while holding all other pollutants constant (or by allocating costs to those affected pollutants where costs are nonseparable) must be analyzed.

Furthermore, the Table presents data for all possible combinations of treatment chains, abatement levels, and costs for each pollutant. In static situations (only one time period being examined), where two treatment systems can achieve the same level of abatement or where one can achieve a higher level of abatement for less money, it is possible to eliminate the more expensive treatment system from this analysis. Where more than two time periods are being considered (e.g., the use of interim standards, the MCE of alternative dates of compliance), all unit processes, regardless of costs for meeting any one level of abatement, must be analyzed. This issue will be examined in greater detail in Step 6.

5.3 Assign Nonseparable Costs

Having identified the rows relevant to the specified policy issue, we now have a measure of costs and abatement for each pollutant. Before using this data to compute the desired MCE ratios, a final manipulation may be required. To determine marginal costs where nonseparable costs exists, some allocation scheme must be employed. Ideally, all unit processes can be defined in such a way that there exists a direct, one-to-one relationship between that treatment chain and the level of abatement for a particular pollutant. Where this is not possible, some form of cost allocation will be required. Exhibit 2 identified these instances. Remember however, that a distinction must be made between situations where two or more pollutants are significantly affected (i.e., where joint costs must be allocated) and where only one pollutant is significantly affected, with others being incidentally affected and therefore not assigned any costs.

We analyzed numerous different ways to assign nonseparable costs and propose several alternative methods. Each of these methods is described and illustrated using the following example of nonseparable costs.

Treatment Chains	Pollutant Affected	Costs	Pollutant Removed
UP_1	A	10	10
UP_2	A,B	30	10(A) 5(B)
UP_3	B	50	5

The choice of these methods to be employed will depend in part on the availability of data and the particular policy question being addressed. One of these methods may require significant amounts of added resources to perform the analysis (i.e., separate facilities); another is based on the questionable assumption that credible relative weights can be assigned to pollutants (i.e., effectiveness-weighting approach). We emphasize that there appears to be no correct way to assign joint costs. We have listed the methods of allocating costs in an order of preference established for the general case. For specific cases, the best advice we can offer is to apply two or more of the methods and compare results. What must be at all times avoided is a mechanical application of any of these methods. If done, any of these methods could produce results which will be misleading.

Target Pollutant: Where a treatment chain was employed for a particular pollutant, it may be most credible to assign all the costs to this one pollutant. The reasoning behind this approach is that the abatement of target pollutant was the primary objective and could be achieved only by incurring the total costs; thus, any effects on other pollutants would be borne by the target pollutant. This would however, tend to understate total effectiveness for the costs incurred (i.e., other non-target pollutants increasing or decreasing). In many instances, a target pollutant cannot be identified. For example if UP_2 was used because it was the least costly way to meet the requirement of 20 units of removal of pollutant A, we could assign all of its costs to A. Thus, the total cost of removing 20 units of A would be 40.

Ratio of Separable Costs: In some situations where non-separable costs occur they may only comprise part of the total costs of controlling the affected pollutants. Where separable costs do exist their ratio can be used as the basis for allocating nonseparable costs. Using the example above, the separable costs for A and B are 10 and 50. Using a ratio of 1/6 and 5/6, the total costs of UP_2 (30) would be allocated to 5 to pollutant A and 25 to pollutant B.

$$A = 30 \frac{10}{10 + 50} = 5$$

$$B = 30 \frac{50}{10 + 50} = 25$$

Allocation Based on Effectiveness-Weighting: This alternative takes into account the environmental damage averted by the unit process and uses this as the basis of cost allocation. It serves as a proxy for the benefits received by abating pollution.

To use the above example, we must assume a damage function exists between pollutants A and B. We will assume that B is a toxic substance and therefore, cause 15 times more damage to the environment than A. A's share of the cost of UP_2 would be:

$$A = 30 \frac{(5)(12)}{5\ (12) + 10} = 25.7$$

$$B = 30 \frac{10}{5\ (12) + 10} = 4.3$$

Separate Facilities: Another option is to determine the costs of controlling the pollutant to the desired abatement level using exogenous means. This method requires several separate engineering analyses to identify the costs of each control option.

In our example, we would determine separately the costs of controlling pollutants A and B at the incremental levels (e.g., for A going from 10 to 20 units of pollutant removed).

Equal Allocation of Costs: This least preferred method allocates cost equally across all affected pollutants. In doing so, however, we are forced to ignore the amount of each of the relevant pollutants removed and the relative costliness for each. In the above example, using this allocation method, the costs would be equally divided, to pollutants A and B, 15 units each.

5.4 Assign Weights

The denominator of the MCE ratio derived from the Table will show some physical measure (amount removed or emitted) of the effectiveness of the treatment system. In some situations, this information alone will be adequate for making a policy decision. For example, if the decision involves a single pollutant an MCE ratio can be derived.

Where several pollutants are involved in the policy question some method is necessary for bringing them together into one MCE ratio. Without this step, the policymaker has a series of disjointed MCE ratios for each pollutant and no acceptable means of comparing them. Ideally, the method of comparing effectiveness across pollutants would be based on the relative damage functions of each pollutant. The state of the art for developing damage functions for pollution emissions has not yet developed to a point where it can be directly used appropriately in this methodology. In its place we suggest using weights for each pollutant based on subjective estimations of relative damage done by each pollutant.

We have designed the methodology to avoid this problem whenever possible and to minimize its impact when it is unavoidable. First, when only one pollutant is being analyzed, weights are not required, so this step of the methodology is inapplicable. When two or more pollutants are being compared and a single MCE ratio is desired, weights are employed as one of the last steps in the methodology. They are inserted simply as a term to be multiplied by the physical measure of effectiveness (e.g. usually kilos emitted) in the demoninator of the MCE ratios. If no weight is assigned, it implicitly means that all pollutants are considered to be equal.

Because weights are imposed as a distinct substep late in the methodology, it is a simple matter to redo the analysis using different weighting schemes. No additional data will be required. Thus, where some weighting scheme is required we suggest the use of sensitivity analysis to determine the effect of alternative weighting schemes.

STEP 6: ANALYZE MCE RATIOS

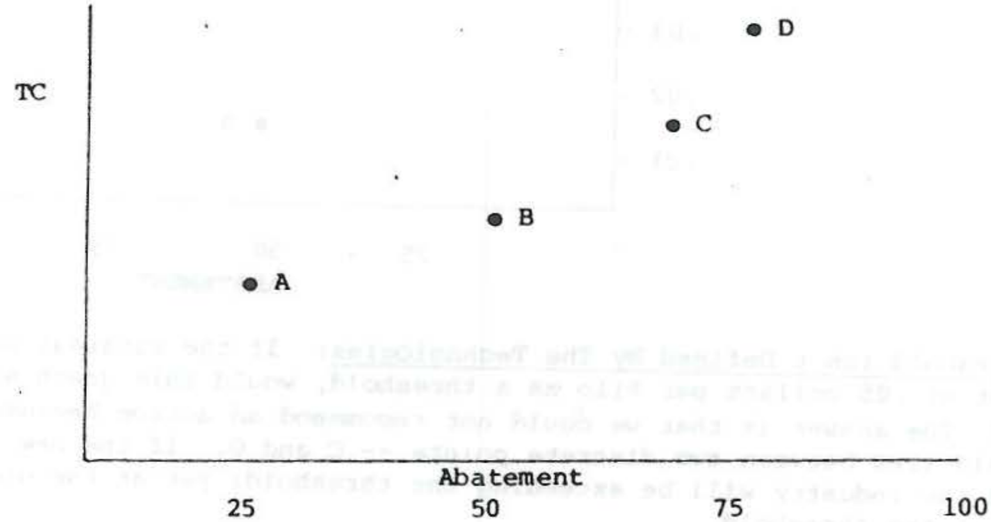
The next step in the methodology requires the analyst to evaluate the MCE ratios before drawing conclusions. This step is critical because the derived ratios are subject to misinterpretation; they must not be mechanically applied in the decisionmaking process. These situations where misinterpretation is likely are: (a) where thresholds are used as the determination of acceptable MCE ratios; (b) where major pollutors are permitted to continue at the expense of minor pollutors; and (c) where the percentage of removal varies (e.g., one firm moves from 10 to 50% abatement, another moves from 80-90% abatement). Two additional situations are discussed in this section. These involve situations where different time periods are included as an aspect of the policy issue being addressed. In theory, MCE analysis is timeless. To use this analysis in situations which are not static requires certain manipulations discussed in sections (d) where interim standards phased-in over a period of time are being used; and (e) where the timing of implementation of a standard remains at issue. Each of these is discussed below.

A. Using a "Threshold" to Evaluate MCE Ratio

Among the most important considerations when analyzing the MCE ratios is to understand its role in choosing standards. Ideally we need the MCE curves and pollutant-based curves. However, these curves do not exist. Instead we have discrete points for particular industry segments and industries, none of which is truly comparable. But in many cases it may be possible by manipulating the available data to fit a representative curve through the existing points. A typical set of points is shown in Exhibit 5.

EXHIBIT 5

TYPICAL TOTAL COST DATA



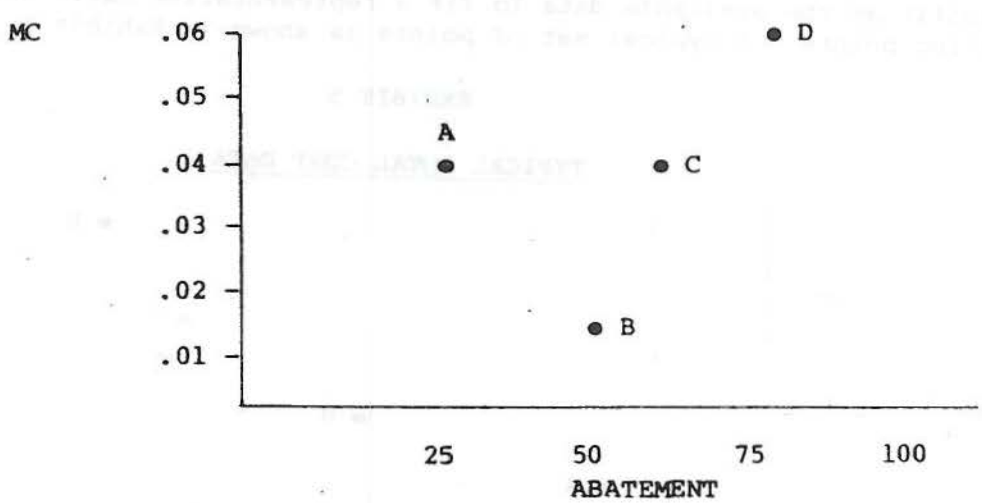
The points represent unit processes or treatment chains and correspond to rows in the Treatment Systems table. When only these points exist, MCE then becomes incremental cost effectiveness (see Chapter 2 for a more detailed discussion). So long as the analyst is aware of this distinction no problems should necessarily arise.

However, the lack of continuous curves does create problems when "thresholds" are important. A threshold is a dollar amount per unit of abatement at the margin which has been judged reasonable value for firms to spend. A threshold could be set based on the costs of similar treatment at a publicly-owned treatment works or it could employ the existing MCE as a floor. For example if municipal waste treatment facilities spend $3/ton at the margin, this might be considered a threshold for private industry to meet. Because the Table includes discrete points, it is sometimes impossible to find a value at the threshold. Furthermore, the threshold may be such that for one industry compliance will require that only 2 percent of the total pollution of the industry be abated; in another industry 100 percent removal may be neces sary. Yet the economic problem faced by these industries of how to pay for the cleanup is not considered. It could be that the industry which should remove 100 percent of its pollution cannot obtain the resources to install the necessary equipment. Each of these two problems is discussed in the succeeding paragraphs.

Exhibit 5 shows what the Treatment System Table, looks like in graph form when discrete points are identified. Theslope of the total cost curve is the marginal cost curve. This is shown in Exhibit 6.

EXHIBIT 6

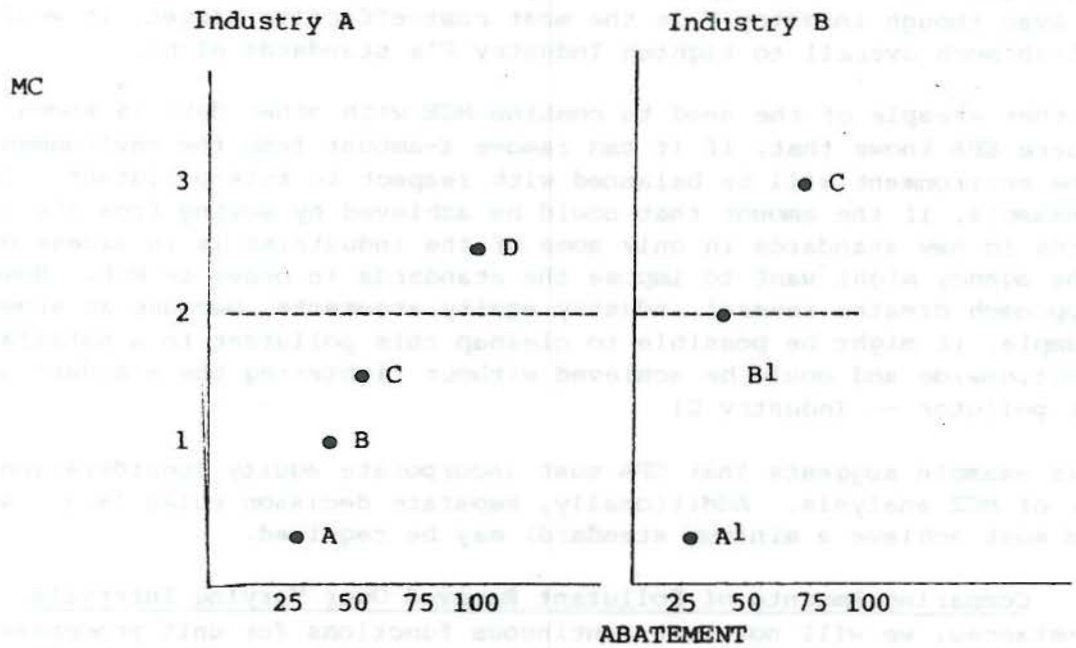
<u>**TYPICAL MCE CURVE DERIVED FROM EXHIBIT 5**</u>



<u>The Threshold Isn't Defined By The Technologies:</u> If the marginal cost per kilo were set at .05 dollars per kilo as a threshold, would this graph supply an answer? The answer is that we could not recommend an action because the threshold lies between two discrete points -- C and D. If the new standard is imposed the industry will be exceeding the threshold; yet at the old standard it is not at the threshold.

EXHIBIT 7

MCE CURVE FOR TWO INDUSTRIES



Industry Equity Issues and the Threshold Concept: Exhibit 7 shows hypothetical MCE graphs for two industries. The MCE graphs again are discrete points represented by the available technologies. In addition to the threshold problems, in this case an additional problem arises. If the threshold is \$2 per kilo, then Industry A will have to remove 100 kilos, and Industry B will have to remove 45 kilos. Thus, it is possible that Industry A will have to pay far more than Industry B in order to remove the efficient amount of pollution. The issue then is "Can Industry A afford these costs?"

B. Relative Significance of Control. Consider the example where several industries have different existing standards and different proposed future standards for some pollutant. The policy issue is which future standard will create the greatest benefit for the cost. Determining the most cost-effective new standard is not difficult, using the procedures shown above for a single pollutant in a single industry, it is possible to create a list of MCE like those shown below:

Industry	Marginal Cost-effectivenss of Possible Standards	Percent of Total Pollution Emitted
A	2.0	12
B	2.5	12
C	2.3	12
D	3.0	60
E	4.0	3
F	.5	1

Using these values, EPA could develop a MCE-based priority schedule for implementation of regulations. However, in many ways, this would not be prudent. For example, Industry F whose MCE is .5 is responsible for only 1% of all the pollution of this type, Industry D causes 60% of this type of pollution. Even though Industry F is the most cost-effective target, it would not accomplish much overall to tighten Industry F's standards alone.

Another example of the need to combine MCE with other data is shown in the case where EPA knows that, if it can remove X-amount from the environment, then the environment will be balanced with respect to this pollutant. In the above example, if the amount that could be achieved by moving from the current standards to new standards in only some of the industries is in excess of X, then the agency might want to impose the standards in order of MCE. However, this approach creates several industry equity arguments, because as shown in the example, it might be possible to cleanup this pollutant to a satisfactory level nationwide and could be achieved without tightening the standard on the biggest pollutor -- Industry D!

This example suggests that EPA must incorporate equity considerations into its use of MCE analysis. Additionally, separate decision rules (e.g., all sources must achieve a minimum standard) may be required.

C. Comparing Amounts of Pollutant Removed Over Varying Intervals. In most instances, we will not have continuous functions for unit processes. Instead, we will have a series of distinct points determined by the level of abatement that specific unit processes are capable of achieving. When computing MCE ratios for different intervals, the results may not be directly comparable. For example, we may want to compare the MCE of going from 30 to 60 percent removal for BOD in one industry to going from 80 to 95 percent removal of the same pollutant in another industry. According to MCE theory, because neither the costs nor the measure of effectiveness are being held constant, the ratios should not be comparable. But if effectiveness weighting were used and a kilo removed of BOD from one industry equaled a kilo removed from the other, the ratios would be comparable. Thus to be efficient, EPA should require the next kilo removed to come from that industry which has the lowest MCE ratio.

Where intervals are large, however, an "efficient" decision may not be possible. For example, suppose that EPA's goal is to decrease BOD effluent by 100 kilos. It must choose between Industry A which could install unit process two at a cost of $20 to remove 110 kilos (MCE equals .18) and Industry B which could install unit process Y at a cost of $10, to remove 80 kilos (MCE equals .125). No obvious solution exists. It may be necessary to accept less clean-up to achieve a better cost-effectiveness.

If continuous functions existed for the unit processes in each of these industries, the above problems would not arise. To optimize clean-up in this situation, it would take the mix of abatement in each industry totalling 100 kilos which minimized total costs. Without continuous functions, however, some judgment will be necessary where the MCE of large intervals are being compared.

D. Using Interim Standards

Where EPA's main concern is deciding which of alternative, more stringent standards to adopt for a specified date, timing does not enter into the MCE analysis. All that is required is to estimate the incremental costs of compliance for the proposed standards and to compare these costs for the incremental levels of abatement that result. But EPA often chooses to adopt a less stringent interim level of required abatement in an effort to lessen the burden its regulations impose on industry. This interim standard is followed at some later date by a more stringent target standard. (This is one of the options EPA is currently evaluating for air pollution control on new coal-fired power plants.)

The use of interim standards affects two aspects of the MCE methodology. When employing the traditional methodology in situations where alternative levels of abatement are being compared for implementation at the same point in time, we can reasonably assume a firm will select the least-cost treatment chain to meet each of the proposed standards.

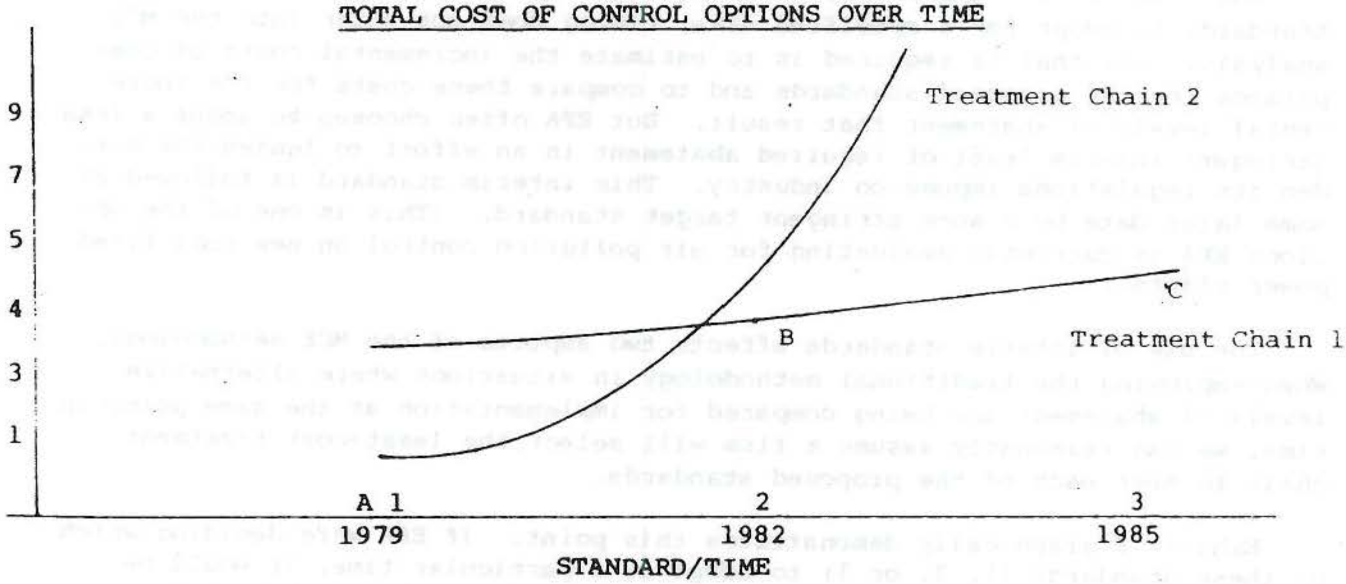
Exhibit 8 graphically demonstrates this point. If EPA were deciding which of these standards (1, 2, or 3) to adopt at a particular time, it would be reasonable to consider only the least-cost unit process for each standard. Thus, the numerator of the cost-effectiveness ratio is based on compliance costs using an estimate of points A, B and C on treatment chains 1 and 2.

Where the use of interim standards is being considered, examining only the least-cost treatment chain to comply with the alternative standards imposed at different points in time would be misleading. With the likelihood of shifting overtime from a given standard to a more stringent one, it may be less costly for a firm to select a unit process which actually costs more than another at the initial period. Turning again to Exhibit 8, we observe that using treatment chain 2 at 3.5 (point B) is the least cost way to comply with Standard 2. But the MCE analysis would suggest that treatment chain 1 be employed. In moving from Standard 1 to Standard 2, the marginal cost of maintaining treatment chain 1 is 3 (4 minus 1). Instead, if we were to shift to treatment chain 2 to meet standard 2, the marginal cost would be 3.5 (3.5 minus 0). More accurately, the marginal cost of shifting from treatment chain 1 to 2 to comply with standard 2 would be 3.5 units less any salvage value from abandoning treatment chain 1. But pollution control equipment is generally plant specific and would have minimal salvage value. For this reason, future calculations will omit this consideration.

Thus, from a marginal cost standpoint, in situations where two or more time periods are being considered, it is essential to examine the full range of possible unit processes to comply with each standard. The burden this requirement imposes on EPA will be reduced to the extent that the unit processes being considered have a limited range of applicability and therefore, are incapable of reaching certain standards. Exhibit 8 illustrates this point. Treatment chain 2 can be used to comply with abatement levels 1 and 2, but as it is currently designed, cannot remove an adequate amount of pollution to comply with standard 3.

EXHIBIT 8

TOTAL COST OF CONTROL OPTIONS OVER TIME



In addition to necessitating that we examine the costs of compliance for each unit process and not just the least cost one, the issue of timing presents a second interesting implication for the development of an MCE methodology. By focusing attention on marginal costs, we may in fact, through the use of interim standards, be adopting a regulatory program where total costs are higher than they need be. Exhibit 9 illustrates this point. The two possibilities are to either require standard 1 and at a later date impose standard 2, or immediately require compliance with standard 2. The total costs would be:

EXHIBIT 9

TOTAL COSTS FOR MEETING INTERIM STANDARDS

Option	Treatment Chain	Total Costs
Standard 1, then 2	1	4.0
Standard 2, immediately	2	3.5

If EPA's main concern is to minimize the costs its regulations impose on industry, Exhibit 9 indicates that this can best be accomplished by imposing the most stringent level of abatement attainable using an available treatment chain. This analysis suggests that in situations where phasing-in more stringent standards is being considered, EPA may want to consider both the total and marginal cost implications of its actions.

E. Comparing MCE of Alternative Dates for Implementation.

The previous section examined the complications arising from timing issues as they effect the numerator (i.e., the costs of the MCE methodology). Although timing is straightforward as it relates to costs, it severely complicates attempts to measure effectiveness. This problem arises when the MCE methodology is used to compare a proposed standard which is to take effect immediately to one to take effect at some future date. This policy question most frequently arises when EPA considers requests seeking extensions of abatement deadlines.

Comparing costs in this situation is relatively easy. Although there may be some debate about the appropriate discount rate when applied to the estimated future costs, these costs can be directly compared to present investments.

But no such clear-cut manipulation exists for comparing the effectiveness of the same standards imposed at different points in time. If we were to ignore this problem, the MCE of a standard imposed today would be exactly the same as that of the same standard if its implementation were delayed for a period of time. In Exhibit 10, the problem is shown in numerical terms.

EXHIBIT 10

MCE OF DELAYING IMPLEMENTATION

Year	Annual Costs	Annual Pollutant Removed	Number of Years in Effect	PV of Total Costs	Discounted Effectiveness*	MCE Ratio
1	100	50	30	1,037	$\frac{50 \times 30}{30} = 50$	20.74
5	100	50	25	998	$\frac{50 \times 25}{30} = 41.67$	23.95

*Assumes a 10% discount rate.

In this example, we assume the choice is between requiring 50 kilos of abatement now or delaying implementation for four years. In either case, the annualized costs would be 100. We first calculate the costs by determining the present value of the annualized costs over a 30-year timeframe. To determine effectiveness, we would divide the total amount of pollutant removed for each option over 30 years and divide this by the 30-year timeframe. The MCE ratio for these options suggests immediate implementation (20.74 compared to 23.94) would be the best policy for EPA to pursue.

STEP 7: AGGREGATING ENTITIES

Marginal cost-effectiveness analysis, although most applicable at the entity level, can be conceptually extended to apply to industry segments and industries. Further, multiple industry analyses within regions or nationally might be conducted though the data base requirements are potentially massive.

Nevertheless, many macroeconmic policy questions of interest to EPA decisionsmakers cannot be appropriately assessed unless model plant data regarding marginal cost-effectiveness are suitably aggregated.

Policy Issues and Aggregation

EPA wants to answer several types of policy questions that could be accomplished with the proposed methodology, including the following:

- What is the marginal cost-effectiveness of cleaning up one pollutant to the same degree in different industries?
- What is the marginal cost-effectiveness curve for cleaning up one pollutant in all industries?
- What is the marginal cost-effectiveness of cleaning up all pollutants in one region of the country?
- What is the marginal cost-effectiveness of cleaning up one pollutant across all industries in one region?

Types of Aggregation

To respond to these policy questions requires that model plant data be aggregated along any of three dimensions:

- pollutant
- industry
- geography

In addition to the data created in previous steps, identification of all present and planned entities and segments in an industry by size, age and location is also necessary. Most of this data is readily available from the Commerce Department.

With the above information available, it is possible to aggregate along any of the three dimensions, i.e., pollutant, industry, and geography. We discuss each of these further after describing them briefly here.

Pollutant. A relevant policy question is the extent to which different industries must remove a particular pollutant at a specified marginal cost. In general, when exploring this question it is necessary to 1) identify all of the industries in which the pollutant of interest is present, 2) construct and analyze a model plant or several plants (depending on production processes in the industry), 3) identify the total number of plants (of each type modeled) in each industry and 4) sum the abatement at each specified marginal cost across all industries. Marginal cost-effectiveness could be compared for several different pollutants to respond to another policy question, i.e., "What are the most/least cost-effective standards?"

Industry. Aggregation by industry is essential for EPA to know how one industry's burden compares to others across all pollutants and for individual pollutants. Furthermore, industry aggregation discloses those industries where the most effectiveness is achieved per dollar spent. In this case the necessary elements are the model plants, the number of plants in the industry, and the marginal cost-effectiveness curves.

Geography. To understand the impact of pollution control on different economic and environmental regions, aggregation by geography is important. Geography is important because of the varying levels of pollution found in the waters and atmosphere in different regions of the country. The ele- ments necessary to perform this kind of analysis are: 1) model entities by relevant segment for each industry, 2) the number of entities by segment in the region and 3) the marginal cost-effectiveness curves for the entities.

As explained in Chapter 2, aggregation is equivalent to summing the applicable entity-level MCE curves over a constant range of marginal costs. This results in an expanded effectiveness range (horizontal axis) for the given pollutants being aggregated. Such an expansion procedure is not unlike an aggregate supply curve of abatement for the specified aggregation case, e.g., segment, industry, region. However, all applicable entities must be included and weighted by the number of equivalent model entities to accomplish the aggregation.

In actuality, two main problems will typically exist even when MCE analysis as been performed for all applicable entities to be aggregated. First, the range of marginal costs estimated for each entity may not be common among all entities because their data bases are different. In effect, the MCE curve for each entity should be extrapolated (potentially for both higher and lower marginal costs) to a common marginal cost range, e.g., from the lowest to the highest observed MCE's among the entities being aggregated.

Second, aggregation of MCE curves of different pollutants -- which is possible only with the introduction of effectiveness weights -- presents the problem of judgmentally obtaining such weights that are exogenous to this analysis. Furthermore, unless the MCE ratios of the separate pollutant are comparable, MCE extrapolation problems as presented above may be compounded. Although, alternatively, and appropriately, the standard physical units of each pollutant should be scaled in such a manner that the mean MCE ratios analyzed are normalized. That is, the different pollutants' observed MCE ratios should first be made to have comparable ranges of marginal costs by scaling the physical units of abatement so that standard units have similar marginal costs, e.g., if MCE_1 = \$10 for pollutants at its means abatement of 100 units (kg), and MCE_2 = \$20 for pollutants at its mean abatement of 40 units (g), then $MCE_1 = MCE_2 = 10$ if the standard unit for pollutant 2 is changed to be (1/2g) rather than (g).

Following this conversion, effectiveness weights per standard units must then be applied to create a comparable horizontal axis. Returning to the extrapolation problem as described above, certain theoretical principles should be followed when extrapolations are made (often judgemental- ly rather than statistically because of limited observations). Namely, MCE curves theoretically are high as abatement approaches 100 percent, e.g., asym- totic to the line extended vertically upward from 100 percent abatement for each entity. Also, as abatements are lowered, the MCE curve theoretically has a non-zero minimum point (due to fixed costs). Hence, extrapolations "downward" should not approach zero marginal costs as might be implied by limited

data. Recognizing these principles for each entity's MCE curves over the relevant MC range is critical when aggregations are to be made.

* * *

The following two chapters present applications of this methodology to the textile and coal-fired power plant industries.

4. TEXTILE INDUSTRY: A CASE STUDY

This application of marginal cost effectiveness to the textile industry focuses on water. The data used in the examples were derived from the recent Effluent Guidelines Document entitled, Technical Study Report BATEA-NSPS-PESE-PSNS, Textile Mills Point Source Category[1] and associated unreported data from the study. This industry was chosen, in part, due to the large amount of data available. However, as will be subsequently noted, even the large amount of available data was found to be limited for a rigorous MCE analysis, in terms of logical alternatives generated and accompanying engineering descriptions and explanations of the unit processes and technologies involved.

The serious limitations, have restricted the pilot study and we caution the reader that the MCE applications and results should be used more as illustrative of the methodological and problems encountered rather than indicative of conclusions regarding abatement levels.

1. IDENTIFICATION ANALYSIS

The Clean Water Act[2] requires existing industrial dischargers to waters to achieve effluent limitations requiring the application of the best practicable control technology currently available (BPT) by July 1, 1977. By July 1, 1984, these same dischargers are required to achieve effluent limiations requiring the application of the best available technology economically achieveable (BATEA) and the best conventional pollutant control technology (BCT). Additionally, new industrial dischargers are required to comply with New Source Performance Standards (NSPS) under Section 306 of the Clean Water Act (the Act), and new and existing industrial dischargers to Publicly Owned Treatment Works (POTW's) are subject to Pretreatment Standards (PSES for existing sources and PSNS for new sources).

The textile industry[3] is composed of over 1,100 individual textile mills engaged in manufacturing processes which, in one form or another, generate wastewaters and are thus subject to these abatement regulations. Approximately 80 percent of these mills discharge into publically owned treatment works (POTW) and are classified as indirect dischargers; the remaining 20 percent discharge directly into receiving waters and are classified as direct dischargers. Although indirect dischargers will be subject to certain pretreatment standards, the segment of interest for this analysis is existing direct dischargers.

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[1]Sverdrup and Parcel and Associates, Inc., Technical Study Report BATEA-NSPS-PSES-PSNS, "Textile Mills Point Source Category", prepared under contract Nos. 68-01-3289 and 68-01-3884, Nov. 1978.

[2]The Federal Water Pollution Control Act Amendments of 1972, as amended by P.L. 95-217, the Clean Water Act of 1977.

[3]The textile industry consists of establishments which typically create and/or process textile related materials for further processing into apparel, home furnishings, or industrial goods.

2. DEFINE ENTITY

Direct dischargers in the textile industry are comprised of a diverse group of establishments varying in size, process, and product. The general characteristics of the industry establishments range from small family-owned mills utilizing traditional manufacturing and managerial practices to large multi-mill corporations who rely on the latest managerial practices and sophisticated processes available.

The most common structural depiction of the industry is the standard industrial classification (SIC) system used by the U.S. Bureau of the Census. However, for purposes of an analysis of effluent controls, a classification system based on manufacturing or process functions performed at the facility is more appropriate. This is because wastewater characteristics are predominately dependent upon the process functions performed at a facility. Such a classification industry establishment to be grouped into categories with similar wastewater characteristics.

Based on extensive industry analysis, in which SIC, functional, and other characteristics were used, -- direct dischargers can be defined according to the entities shown in Exhibit 11. These entity descriptions, in this instance, were adopted from the Effluent Guideline Document[4] and the associated economic impact analysis.[5] In many instances previous studies will provide entity definitions, although they should be evaluated with regard to their representativeness.

Twenty-six entities were defined to represent this industry. The number of entities in practice will depend upon the extent of variation in the population of interest, availability of data, time and budget constraints. Generally, the larger the number of model plants, the greater the accuracy of the analysis.

In addition to the entity descriptions, the number of plants and/or other weight measures should be reported as shown in Exhibit 11.

3. ESTABLISH DATA BASE

3.1 Identify Key Pollutants

As previously noted the data base for the analysis was taken from a recent Effluent Guideline Document. A large number of pollutant parameters are found in the textile industry. Out of the large number of parameter and pollutant constituents, seven were selected and reported. These include conventionals: biochemical oxygen demand (BOD), chemical oxygen demand (COD); total suspended solids (TSS); oil and grease (O & G); two nonconventional pollutants - total phenols and sulfide; and one priority pollutant - chromium, which will be included with the nonconventional group as a matter of ease.

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[4] Sverdrup and Parcels, op. cit.

[5] Development Planning and Research Associates, Inc., Economic Impact Analysis of Proposed Effluent Limitations Guidelines For the Textile Industry, EPA Contract No. 68-01-4632, in preparation.

EXHIBIT 11

DEFINITION OF MODEL PLANTS FOR DIRECT DISCHARGERS, TEXTILE INDUSTRY

No.	Segment	Process Type	Code	Size	Size: Daily Production Capacity (kkg/d)	Size: Water Flow (mgd)	Estimated Number Plants[1] Represented
1.	Wool Scouring		WS	Small	16.2	.05	4
2.				Medium	35.6	.11	2
3.				Large	80.9	.25	1
4.	Wool Finishing		WF	Small	8.0	.6	8
5.				Medium	20.0	1.5	1
6.				Large	40.0	3.0	1
7.	Woven Fabric Finishing	Simple	WFFS	Small	5.3	.11	25
8.	Woven Fabric Finishing	Complex	WFFC	Small	26	.6	20
9.				Medium	130	3.0	5
10.				Large	220	5.0	5
11.	Woven Fabric Finishing	Complex plus designing	WFFCD	Small	20	.6	17
12.				Medium	50	1.5	10
13.	Knit Fabric Finishing	Simple	KFFS	Small	7.7	.6	20
14.	Knit Fabric Finishing	Complex	KFFS	Small	7.7	.25	20
15.				Medium	18.6	.6	8
16.	Hosiery Finishing		HF	Small	2.7	.05	7
17.				Medium	6.0	.11	1
18.	Carpet Finishing		CF	Small	20.0	.25	7
19.				Medium	49.0	.6	3
20.				Large	120.0	1.5	3
21.	Stock and Yarn Finishing		SYF	Small	9.4	.25	25
22.				Medium	23.0	.6	8
23.				Large	38.0	1.0	2
24.				X-Large	57.0	1.5	1
25.	Nonwoven Fabric Finishing	Woven	NFFW	Medium	10.4	.11	11
26.	Nonwoven Fabric Finishing	Felt	NFFF	Medium	2.0	.11	5
	Total						220

[1]Estimated from two base studies.

This analysis was based available data. However, in other studies, it will be beneficial to carry out detailed technical analyses of waste characteristics and relationships.

3.2 Identify Unit Process and Treatment Chains

The next step is to determine the range of unit processes which will provide abatement. The unit processes reported in the Effluent Guideline Document on Textiles, were used herein as shown in Exhibit 12. This Exhibit also presents the treatment chains, that is the basic combinations of unit processes. Available alternatives may or may not be sufficient for rigorous MCE analysis, depending upon the number and the logic of the resulting abatement levels.

In this application, an analysis of the unit processes and resulting treatment chains was not performed, as it was outside the purpose of the effort. However, as will be discussed, the treatment chains and resulting abatement levels were limited, indicating the need for presenting additional unit processes or treatment chains.

Both water and sludge were included in the data base; sludge characteristics were not separately reported. Although it will depend upon the nature of the policy question, the analyst should include all media and pollutants that will be affected by the policies being evaluated.

3.3 Relationship Among Unit Processes and Pollutants.

A critical factor in this step is to identify the unit process treatment chain-pollutant relationships, starting at the unit process level. The textile data were deficient in this regard; which limited the ability to create additional treatment chains and to identify unit processes with specific pollutant parameters. Additionally, we noted that the sequence of treatment chains may influence abatement levels. For example in this textile case we found by deductive analysis, that treatment chain C -- chemical coagulation (1), sedimentation (2) and multi-media filtration (3) -- resulted in a different level of abatement, depending on whether it was compared against multimedia filtration or against chemical coagulation. Other words unit processes may not be strictly additive. Nonadditive relationships should be explained and reflected in specifying the associated abatement levels.

3.4 Cost Estimates

The other critical data component is cost estimates. In this case, total annual costs were used as reported.[8] Investment costs were reported by unit processes, but operating and maintenance costs were only reported by element within a treatment chain. Consequently, the ability to assign costs to unit processes was severely hampered. Both the unit process pollutant abatement and unit process cost relationships are necessary for rigorous MCE analysis.

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[8]Annual capital costs were estimated in the reported data as interest on total investment plus depreciation. Because of limitations of the data base, reestimating annual capital costs by the discounted cash flow method was not considered to be warranted.

EXHIBIT 12

ALTERNATIVE END-OF-PIPE TREATMENT TECHNOLOGIES
EXISTING SOURCES[6]

No.	Nos.	Treatment Chain
B	1,2	Chemical coagulation (1) and sedimentation (2)
C	3	Multi-media filtration (3)
D	1,2,3	Chemical coagulation (1),sedimentation (2), and multi-media filtration (3)
E	3,4	Multi-media filtration (3) and granular activated carbon (4)
F	1,2,3,4	Chemical coagulation (1), sedimentation (2), multi-media filtration (3), and granular activated carbon (4)
G	5	Ozonation (5)
H	1,2,5	Chemical coagulation (2), sedimentation (2), and ozonation (5)
J	3,5	Multi-media filtration (3) and ozonation (5)
K	1,2,3,5	Chemical coagulation (1), sedimentation (2), multi-media filtration (3), and ozonation (5)
M[7]	1,6	Chemical coagulation (1) and dissolved air flotation (6)
N	1,6,3,4	Chemical coagulation (1), dissolved air flotation (6), multi-media filtration (3), and granular activated carbon (4)
P	1,6,5	Chemical coagulation (1), dissolved air flotation (6), and ozonation (5)

b

[6]BPT consisting of screening, extended aeration activated sludge, sedimentation and solids recycle to creation basin assumed to be in place.

[7]Alternatives M, N, and P apply to wool scouring.

4. CREATE POLLUTION CONTROL COST AND ABATEMENT

As noted in the preceeding discussion, it is important to create the necessary data base. The limited data available in this allows only those combinations reported to be used. Had additional unit process pollutant information been developed or available, additional treatment chains might have been developed. Due to the làrge number of entities involved in this population of existing direct dischargers, a table for only one entity -- a medium sized complex plus desizing woven fabric finishing mill (No 12 in Exhibit 1) is presented as Exhibit 13. Normally, Tables would have to be prepared for each entity.

The lower portion of the table was ordered from the reported data set as shown in the top nine rows of the Table. Though analysis we ordered each set of treatment chains such that the abatement of each pollutant in a pollutant vector remained equal or increased and that total annual costs were increasing, pursuant to the principles of marginal analysis. This produced the nine unique sets of logical paths.

The indicated cost separation was done by examining the marginal effectiveness of each treatment path vector. From this analysis we could separate certain costs to conventional pollutants and in five instances, directly to COD. Had we additional technical information, additional cost separation might have been. We suspect that a considerable degree of incidental removal is in fact occurring with some unit processes. If this is true, we would recommend that no costs be assigned to the incidentally impacted pollutants.[9] Hence there may be a greater degree of separation than shown in Exhibit 13.

5. PERFORM INITIAL ANALYSIS

The creation of the data table resulted in several readily observations, particularly with regard to the paucity of separable costs and the relatively few and large effectiveness intervals. This suggests that joint cost allocation and aggregate are significant issues in water. This is in contrast to the air media presented in Chapter 5, which had few joint costs.

With the paucity of separable costs and technical background regarding incidental removals (that is, unit process-treatment chain-pollutant relationships), cost allocations was limited to target pollutant group or equally among impacted pollutant groups. Because of these limitations,[10] the answers to policy questions regarding specific pollutants or pollutant parameters would of limited value and were not addressed in this illustration.

This illustration does present a situation that may typical when existing, available data are being used for MCE analysis. The following discussion will provide possible short cut.

For each of the ordered sets of data, the incremental effectiveness and cost tables were computed for each ordered data set. Then, the MCE ratios were computed for each incremental by dividing the incremental cost by the corresponding

[9]This should not be considered as a hard and fast rule, particularly for priority pollutants.

[10]In practice, some additional but limited, techincal background work might prove of value and should be explored.

EXHIBIT 13. TEXTILE COST/ABATEMENT TABLE

CONVENTIONAL

Treatment Chain	Unit Process	BOD Abated (kkg/y)	BOD Emitted (kkg/y)	BOD Cost ($1,000)	COD Abated (kkg/y)	COD Emitted (kkg/y)	COD Cost ($1,000)	TSS Abated (kkg/y)	TSS Emitted (kkg/y)	TSS Cost ($1,000)	O & G Abated (kkg/y)	O & G Emitted (kkg/y)	O & G Cost ($1,000)	Total Abated (kkg/y)	Total Emitted (kkg/y)	Total Cost ($1,000)
B		25.6	17.1		188.1	239.6		58.9	25.6		0.0	15.4		272.6	297.8	243
C		34.3	8.4		102.6	325.1		68.3	17.2		6.9	8.4		212.1	359.1	146
D		34.3	8.4		205.3	222.4		68.3	17.2		6.9	8.4		314.8	256.2	334
E		38.5	4.2		342.2	85.5		68.3	17.2		15.4	0.0		464.4	106.9	
F		38.5	4.2		367.8	59.9		68.3	17.2		15.4	0.0		490.0	81.3	
G		0.0	42.7		239.6	188.1		0.0	85.5		0.0	15.4		239.6	169.6	
H		25.5	17.2		316.4	111.4		58.9	25.6		0.0	15.4		400.9	169.6	
J		34.3	8.4		282.3	145.4		68.3	8.4		6.9	8.4		391.8	170.6	
K		34.3	8.4		325.1	102.6		68.3	8.4		6.9	8.4		434.6	136.6	
C	1	34.3	8.4		102.6	325.1		68.3	17.2		6.9	8.4		212.1	359.1	146
D	3,1,2	34.3	8.4		205.3	222.4	188	68.3	17.2		6.9	8.4		314.8	256.2	334
F	3,1,2,4	38.5	4.2		367.8	59.9		68.3	17.2		15.4	0.0		490.0	81.3	
C	3	34.3	8.4		102.6	235.1		68.3	17.2		6.9	8.4		212.1	359.1	146
E	3,4	38.5	4.2		342.2	88.5		68.3	17.2		15.4	0.0		464.4	106.9	
F	3,4,1,2	38.5	4.2		367.8	59.9	182	68.3	17.2		15.4	0.0		490.0	81.3	
B	1,2	25.6	17.1		188.1	230.6		58.9	25.6		0.0	15.4		272.6	297.8	243
D	1,2,3	34.3	8.4		205.3	222.4		68.3	17.2		6.9	8.4		314.8	256.2	334
F	1,2,3,4	38.5	4.2		367.8	59.9		68.3	17.2		15.4	0.0		490.0	81.3	
G	5	0.0	42.7		239.6	188.1		0.0	85.5		0.0	15.4		239.6	331.7	
J	5,3	34.3	8.4		282.3	145.4		68.3	8.4		6.9	8.4		391.8	170.6	
K	5,3,1,2	34.3	8.4		325.1	102.6	188	68.3	8.4		6.9	8.4		434.6	136.6	
G	5	0.0	42.7		239.6	188.1		0.0	85.5		0.0	15.4		239.6	331.7	
H	5,1,2	25.5	17.2		316.4	111.4		59.9	25.6		0.0	15.4		400.9	169.6	
K	5,1,2,3	34.3	8.4		325.1	102.6		68.3	8.4		6.9	8.4		434.6	136.6	
C	3	34.3	8.4		102.6	325.1		68.3	17.2		6.9	8.4		212.1	359.1	146
D	3,1,2	34.3	8.4		205.3	222.4	188	68.3	17.2		6.9	8.4		314.8	256.2	334
K	3,2,5	34.3	8.4		325.1	102.6		68.3	8.9		6.9	8.4		434.6	136.6	
B	1,2	25.6	17.1		188.1	239.6		58.9	25.6		0.0	15.4		272.6	297.8	243
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B	1,2	25.6	17.1		188.1	239.6		58.9	25.6		0.0	15.4		272.6	297.8	243
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H	1,2	25.6	17.2		316.4	111.4		58.9	25.6		0.0	15.4		400.9	169.6	
K	1,2,5,3	34.3	8.4		325.1	102.6		68.3	8.4		6.9	8.4		434.6	136.6	
C	3	34.3	8.4		102.6	325.1		68.3	17.2		6.9	8.4		212.1	359.1	146
J	3,5	34.3	84.4		282.3	222.4		68.3	17.2		6.9	8.4		314.8	256.2	
K	3,5,1,2	34.3	8.4		325.1	102.6	188	68.3	8.4		6.9	8.4		434.6	136.6	

NONCONVENTIONAL[1]

Phenols Abated (kkg/y)	Phenols Emitted (kkg/y)	Phenols Cost ($1,000)	Chromium Abated (kkg/y)	Chromium Emitted (kkg/y)	Chromium Cost ($1,000)	Sulfide Abated (kkg/y)	Sulfide Emitted (kkg/y)	Sulfide Cost ($1,000)	Total Abated (kkg/y)	Total Emitted (kkg/y)	Total Cost ($1,000)	Annual Cost Separable	Annual Cost Semi Separable	Annual Cost Unseparable	Annual Cost Total
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01			243	0	243
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01			146	0	146
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01			334	0	334
.052	.008		.025	.026		0.0	1.9		.08	1.93				530	530
.052	.008		.025	.026		0.0	1.9		.08	1.93				712	712
.060	0.0		0.0	.051		1.6	.3		1.66	.35				108	108
.060	0.0		0.0	.051		1.6	.3		1.66	.35				508	508
.060	0.0		0.0	.051		1.6	.3		1.66	.35				407	407
.060	0.0		0.0	.051		1.6	.3		1.64	.35				595	595
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		0	146	0	146
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		188	146	0	334
.052	.008		.25	.026		0.0	1.9		.08	1.93		0	0	712	712
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		0	146	0	146
.052	.008		.025	.026		0.0	1.9		.08	1.93		0	0	530	530
.052	.008		.025	.026		0.0	1.9		.08	1.93		182	0	530	712
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		0	243	0	243
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		0	334	0	334
.052	.008		.025	.026		0.0	1.9		.08	1.93		0	0	712	712
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	308	308
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	407	407
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	407	595
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	308	308
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	508	508
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	595	595
0.0	.060		0.0	.51		0.0	1.9		0.0	2.01		0	146	0	146
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		188	146	0	334
.060	0.0		0.0	.051		1.6	.3		1.66	3.5		0	0	595	595
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		0	243	0	243
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		188	146	0	334
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	595	595
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		0	243	0	243
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	508	508
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	595	595
0.0	.060		0.0	.051		0.0	1.9		0.0	2.01		0	146	0	146
.060	0.0		0.0	.051		1.6	.3		1.66	.35		0	0	407	407
.060	0.0		0.0	.051		1.6	.3		1.66	.35		188	0	407	595

[1] Chromium included for ease of presentation.

incremental effectiveness for each set of cost estimates (i.e., target group and equal allocation methods of the incremental cost where nonseparable costs were present. These procedures are illustrated in Exhibit 14.

In the case of the target group approach, it is assumed that any control of other pollutants is incidental. In the example, the middle increments indicate some control of nonconventionals. However, under the target assumption, all incremental costs were allocated to the conventional target.[11] This approach effectively provides an upper limit of the ratio, because any cost allocation would serve to reduce the incremental costs and hence, the MCE ratio.

The MCE ratio resulting from these computations are summarized in Exhibit 15. Additionally, this Exhibit carries data information regarding total abatement and the incremental impacts on nonconventionals as reference points for analysis of the results.

Examination of the Exhibit indicates that the range of MCE ratios is $.64 to $7.11. However, the comparability of the sets is imperfect because nonconventionals are accounted for in different increments.[12] Recognizing this limitation and in the absence of additional information, the MCE ratios can be used to estimate a marginal cost curve. One approach would be a statistical fitting of a function based on the data points shown in Exhibit 15. However, due to the gross nature of the data, we believe that graphical analysis would be more appropriate as a first approximation with limited data so that extreme points could be adjusted in or out depending on understanding of the control technologies and cost theory.

Exhibit 16 shows the plotting of the MCE ratios at this mid-point[13] of the respective intervals. For this estimate, all data points were plotted. Other plots could be made using allocated costs, omitting those points involving allocated costs or other adjustments as expertise permitted. An overall examination of this Exhibit indicates that the marginal cost for the conventionals increase relatively rapidly. Precise MCE ratios would not be warranted, although inferences could be drawn. For example, if a threshold of $.75 to $1.00 was considered, abatement levels are 100 to 125 kkg's (about 20 percent) per year would appear to be indicated. Moving the threshold upward would indicate higher abatement levels. Due to the limited data points and the nature of the varying widths of the increments, inferences about abatement levels above 75 percent would be tenuous. If the threshold criteria were sufficiently large, say above $3.00, the generation of additional data points might be warranted, if the affected pollutants were considered important.

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[11] If nonconventionals, were in fact the target, the increments would have to be reordered if treatment chain C were required (and not in place) to achieve treatment chain D.

[12] It was also observed in the data that the control of oil and grease appears to create abberations and technical analysis would be required to analyze the components of the conventional group.

[13] The mid-point is considered to be a better approximation than the end point, as the end point will consistently underestimate the MCE ratios in the rising portion of the marginal cost curve. The extent of the mid-point bias will depend on the shape of the "real" marginal cost curves.

EXHIBIT 14

Computation of Marginal Cost-Effectiveness Ratios for Conventionals
Under Two Cost Allocation Procedures

Treatment Chain	ABATEMENT (kkg/y)				ANNUAL COST ($1,000)				MCE RATIOS ($/kkg/y)	
	Conventional		Non-Conventional			Incremental			Target Allocation	Equal Allocation
	Total	Incremental	Total	Incremental	Total	Total	Separable	Non-Separable	Conventional	Non-Conventional
C	212.1	212.1	0.00	0.00	146	146	146		.69	.69
E	464.4	252.3	0.08	0.08	530	384		384	1.52	.76
F	490.0	25.6	0.08	0.00	712	182	182		7.11	7.11

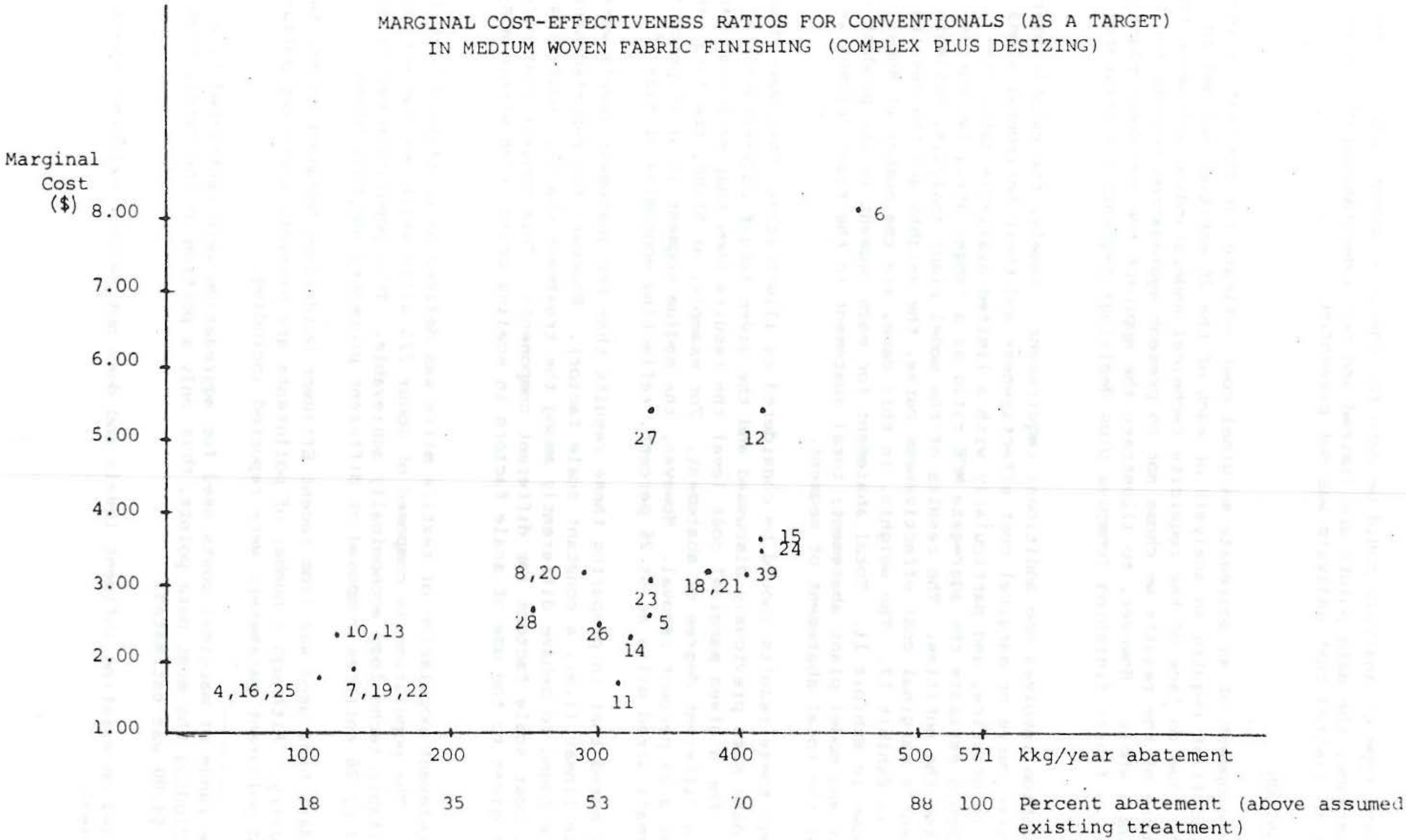
EXHIBIT 15

A Summary of MCE Ratios for Conventionals

	ABATEMENT			MCE RATIO		Incremental Abatement of Non-Conventionals			
Number	Treatment Chain	Total	Mid-Point of Increment	Target	Equal	Phenols	Chromium	Sulfide	Total
1.	C	212.1	106.0	.69	.69	0.0	0.0	0.0	0.0
2.	D	314.8	263.4	1.83	1.83	0.0	0.0	0.0	0.0
3.	F	490.0	402.4	2.16	1.08	.052	.025	0.0	.077
4.	C	212.1	106.0	.69	.69	0.0	0.0	0.0	0.0
5.	E	464.4	338.2	1.52	.76	.052	.025	0.0	.077
6.	F	490.0	477.2	7.11	7.11	0.0	0.0	0.0	0.0
7.	B	272.6	136.3	.89	.89	0.0	0.0	0.0	0.0
8.	D	314.8	293.7	2.16	2.16	0.0	0.0	0.0	0.0
9.	F	490.0	402.4	2.16	1.08	.052	.025	0.0	.077
10.	G	239.6	119.8	1.29	.64	.060	0.0	1.6	1.66
11.	J	391.8	315.7	.65	.65	0.0	0.0	0.0	0.0
12.	K	434.6	413.2	4.39	4.39	0.0	0.0	0.0	0.0
13.	G	239.6	119.8	1.29	.64	.060	0.0	1.6	1.60
14.	H	400.9	320.7	1.23	1.23	0.0	0.0	0.0	0.0
15.	K	434.6	417.3	2.65	2.65	0.0	0.0	0.0	0.0
16.	C	212.1	106.0	.69	.69	0.0	0.0	0.0	0.0
17.	D	314.8	263.4	1.83	1.83	0.0	0.0	0.0	0.0
18.	K	434.6	374.7	2.18	1.09	.060	0.0	1.6	1.6
19.	B	272.6	136.3	.89	.89	0.0	0.0	0.0	0.0
20.	D	314.8	293.7	2.16	2.16	0.0	0.0	0.0	0.0
21.	K	434.6	374.7	2.18	1.09	.060	0.0	1.6	1.6
22.	B	272.6	136.3	.89	.89	0.0	0.0	0.0	0.0
23.	H	400.9	336.8	2.07	1.04	.060	0.0	1.6	1.6
24.	K	434.6	417.8	2.58	2.58	0.0	0.0	0.0	0.0
25.	C	212.1	106.0	.69	.69	0.0	0.0	0.0	0.0
26.	J	314.8	302.0	1.45	.73	.060	0.0	1.6	1.66
27.	K	434.6	336.2	4.39	4.39	0.0	0.0	0.0	0.0

EXHIBIT 16

MARGINAL COST-EFFECTIVENESS RATIOS FOR CONVENTIONALS (AS A TARGET) IN MEDIUM WOVEN FABRIC FINISHING (COMPLEX PLUS DESIZING)



This same type of analysis could be done for the non-conventionals, although in this instance, the data points are limited and our understanding of the technology was so limited that analysis was not presented.

6. AGGREGATION

The development of an aggregate marginal cost estimate for the textile industry would first require an analysis of each of the 26 entities defined in Exhibit 11. Due to lack of the requisite technical understanding and hence the tenous nature of the results we chose not to present aggregation results for the industry as a whole. However, to illustrate the approach the two model plants for the woven fabric finishing (complex plus desizing) segments are presented below.

Aggregation involves one additional requirement - namely, the establishment of a specific curve or marginal cost effectiveness and their horizontal summations.[13] In practice, and particularly with a limited available data, the analyst should estimate the aggregate MCE ratio as a range, using two curves representing the entities. The results of the model plant analysis, estimate of each segment's marginal cost effectiveness curve, the weights and the results are shown in Exhibit 17. The weights, in this case, are the number of model plants shown in Exhibit 11. Total abatement for each segment is the product of the weight and model plant abatement; total abatement in the right columns is the sum of the total abatement of segment.

Athough these results should be considered as illustrative, they were drawn from the data sets previously discussed and the given target conventional target approach. For a given marginal cost level the results show that each component achieves a different degree of abatement. For example, at $1.00, the total segment shows a 25 percent removal. However, the medium segment is at 29 percent and the small sized mills as at 26 percent, reflecting economies of size.[14]

It is noted that in preparing these results that the abatement levels were assumed be linear (i.e., a constant scale factor). However, the reported annual costs were found to behave differently among the treatment chains, indicating different cost scale factors for different components. This suggest that care should be given to the use of scale factors in scaling costs, even within a segment.

The relevant population of textile mills was defined as existing direct dischargers. The population is composed of about 220 mills which are subject to best available technology economically achievable. This population can be represented by 26 entities composed of different processes and mill sizes.

The data base used was from recent Effluent Guidelines Document on the textile industry. Although a number of pollutants are present, seven key pollutants and pollutant parameters were reported including:

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[13]The range of marginal costs used for aggregation were restricted to a range including the most data points, thus only a portion of the curve, from $1.00 to $4.00 was estimated.

[14]Based on existing influent levels and does not reflect existing levels of abatement.

EXHIBIT 17

Illustration of Aggregation of Marginal Cost-Effectiveness of Conventionals For Woven Fabric Finishing

Marginal Cost	SMALL SEGMENT Weight	SMALL SEGMENT Abated Pct	SMALL SEGMENT Abated Model - (kkg/y) -	SMALL SEGMENT Abated Total - (kkg/y) -	MEDIUM SEGMENT Weight	MEDIUM SEGMENT Abated Pct	MEDIUM SEGMENT Abated Model - (kkg/y) -	MEDIUM SEGMENT Abated Total - (kkg/y) -	Total Abatement Amount (kkg/y)	Total Abatement Pct
$1.00	17	20	45	765	10	29	165	1,650	2,415	25
1.50	17	33	75	1,275	10	46	260	2,600	3,875	40
2.00	17	44	100	1,700	10	57	325	3,250	4,950	52
2.50	17	57	130	2,210	10	63	360	3,600	5,810	61
3.00	17	66	150	2,550	10	68	390	3,900	6,450	67
3.50	17	72	165	2,805	10	73	415	4,150	6,955	73
4.00	17	77	175	2,925	10	76	435	4,350	7,325	76

[1]Per model plant data.

Conventional	BOD, COD, TSS, O & G
Nonconventional[15]	Phenols, Chromium, Sulfide

The Textile Industry case study demonstrated that marginal cost-effectiveness can be developed but only after significant analytical effort not normally included in the industry engineering studies. Model plant information can be aggregated to industry or regional totals provided that the study includes geographic as well as size/type of plant parameters.

These positive results are offset by the following factors. The results actually generated are useful only as an example application of the methodology and cannot be used for policy decisions. Moreover, the additional analysis required is substantial and requires a degree of sophistication not normally needed in engineering studies -- the methodology relies on data that may be available during the engineering analysis but not generally required to achieve study objectives. Finally, MCE results of the type possible exclude such salient considerations as economic impacts and are therefore only one tool of several required for sound policy decisions.

Because of the data limitations the MCE analysis was confined to one of the 26 segments: "complex plus desizing" mills of the woven fabric finishing segment. Also, the analysis was confined to one of conventional pollutants. This stemed from the lack of technical background information for detailed cost assignment.

Within a relevant range of the available data, we found a marginal cost curve for conventional pollutants for woven fabric finishing composed of 17 small and 10 large plants. This components of this curve are:

Marginal Cost ($)	Abatement Amount kkg/y	Percent
1.00	2415	25
1.50	3875	40
2.00	4950	52
2.50	5810	61
3.00	6450	67
3.50	6955	73
4.00	7325	76

At a marginal cost of $1.50, the small mills could reach a 33 percent abatement level and medium mills could remove 46 percent of the conventionals. This illustrates the different amounts of abatement among a subsegment for a given marginal cost.

The overall finding of this analysis was that, even though the source document used for data points is one of the better ones we have reviewed, a large amount of additional background information is required for carrying out the detailed analysis as represented by MCE analysis.

[15] The inclusion of chromium was done as a matter of convention and ease of presentation of the analysis.

5. NEW COAL-FIRED POWER PLANTS: A CASE STUDY

In this case study, we apply the marginal cost effectiveness methodology to evaluate alternative new source performance standards (NSPS) for coal-fired power plants. This example was selected because it is a regulation currently being evaluated by EPA. Significant resources have recently been expended to develop data necessary to evaluate the alternative proposals under consideration. We initially believed that this data would be adequate to meet the needs of MCE analyses. Although the costs and abatement estimates developed for use by EPA in setting NSPS were a useful starting point for developing this methodology, we found that extensive data gaps remain.

Because of these data limitations, we caution the reader that the applications of the MCE methodology presented in this case study are only for illustrative purposes and should not be interpreted as meaningful analysis of NSPS for coal-fired power plants.

1. PERFORM POPULATION ANALYSIS

This case study shows how the MCE methodology could be used to evaluate alternative new source performance standards currently being proposed for coal-fired power plants. The population must be defined to include those coal-fired power plants likely to be built if specific environmental regulations are adopted. Because we are only addressing issues involving the proposed standards for coal-fired power plants, we can limit this analysis to this subset of total electric generating facilities. The types of policy questions likely to arise include:

- What is the MCE of alternative, more stringent sulfur dioxide standards for new coal-fired power plants?
- What is the MCE of trading-off particulate control for sulfur dioxide control in new coal-fired power plants?

Each of these questions can be addressed using the information derived from the population defined as new coal-fired power plants.

2. PERFORM ENTITY ANALYSIS

Defining the entity is also straightforward in this case study. Because we are dealing with a new source performance standard, neither age nor varying engineering processes are relevant considerations. We assume that all new facilities employ the same boiler processes. The one exception to this would be the type of coal (high or low-sulfur content) used as an input. This can be expected to vary by region; low-sulfur coal is predominantly mined and used in the West; eastern coal typically has a high-sulfur content. There are two possible ways to handle this difference. We could define two distinct entities -- one located in the West and burning low-sulfur coal, and the other in the East using high-sulfur coal --, perform MCE analysis on each, and then aggregate to the total industry. Alternatively, we could define a single entity and incorporate variations in sulfur content of coal as an alternative unit process. The method of analysis that is adopted depends on the specific policy question being addressed.

For the purposes of this case study, we have defined the entity to be a 500-megawatt power plant. This facility was selected because it is considered to be the optimum size to achieve economies of scale. Most new facilities will be comprised of multiples of 500-MW units. Additionally, a single 500-MW entity is all that was needed in the analysis because it is possible using a factor of .7 to scale the costs of scrubbers (used to control sulfur dioxide emissions) for different size facilities.[1]

3. ESTABLISH DATA BASE

3.1: Identify Key Pollutants

The Development Documents for coal-fired electric utilities and the numerous studies supporting the development documents have identified over 50 pollutants which are emitted by electric utilities.[2] These fifty pollutants include conventional, nonconventional and priority water pollutants plus criteria and hazardous air pollutants. Additionally, sludge is created in substantial quantities. Of these fifty, the most serious are:

Air:
- SO_2
- Flyash (TSP)

Water:
- Suspended and Dissolved Solids
- Heat
- PH
- Chlorine
- Oil and Grease
- Trace Metals

Sludge

Two important technical relationships exist among these key pollutants which is independent of the unit process employed to control them. One is the air/sludge relationship. To eliminate air pollution by any process in a controlled plant requires that sludge be created. The second is that suspended and dissolved solids as defined contain chlorine, oil and grease, and trace metals.

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[1]This figure was derived from Battelle's analysis of the scrubber costs for different size power plants. It is inadequate for MCE analysis though it is useful in other instances.

[2]For water pollution, see EPA, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for Steam Electric Power Generating Point Source Category" October 1974.

3.2: Identify Unit Processes

The second substep in creating the data base is to identify all available unit processes which will provide control of one or more of the key pollutants. In this example, several unit processes are available for controlling SO_2 emissions, two unit processes control particulates, and one unit process is available for NO_x. Sludge is chemically treated and landfilled. Because the data was insufficient, water pollution unit processes have not been analyzed.

SO_2 Control: The most well-known unit process to control SO_2 is a flue-gas desulfurizer (FGD), also known as a scrubber. Scrubbers use any of a variety of materials including lime, limestone and magnesium oxide to absorb the SO_2. In this analysis we limit the discussion to lime scrubbers, which to date have proven to be the most reliable at the lowest cost. Scrubbers can be designed to a control to any of a variety of abatement levels. In the model plant, the scrubber could be correlated with the tons of SO_2 abated by the equation.

Annualized cost = 24,000,000 + 166 x tons abated.

As mentioned in the methodology section, this function could be combined with functions for other unit processes, if all unit process functions had continuous characteristics. However, one of the reasons for this equation so closely matching actual data is that the tons abated are all close together. (The 1.2, 90%, and .5 standards represent the range from 80 to 98% removal of SO_2.) Additionally continuous functions are not available for other unit processes.

A second unit process to control SO_2 emissions is physical coal cleaning (PCC). Physical coal cleaning removes significant amounts of SO_2 and ash before they enter the boiler. The removed residual is called coal tailings. In the model plant, we used PCC with a scrubber because PCC alone could not meet current standards.[3] (We had no data on PCC applied to low-sulfur coal.)

The final unit process for SO_2 control is low-sulfur coal (LSC). LSC is defined as a unit process because it achieves a lower level of abatement when compared to high sulfur coal. LSC can achieve dramatic levels of abatement because it would emit annually only 30% as much sulfur as typical high-sulfur coal. For example, uncontrolled emissions from a 500 MW plant burning low sulfur coal total about 21,000 tons per year while uncontrolled emissions from a plant burning high-sulfur coal would total 78,000 tons. Uncontrolled levels of emissions using LSC would achieve a level of abatement close to 1.2 lbs 10^6 BTU. LSC must be used in tandem with a scrubber to meet the proposed standards examined in this case study.

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[3]An interesting analysis would be to compare PCC of low-sulfur coal (LSC) with the current standards. It may be that PCC is impractical on LSC.

Particulates: For particulates, two unit processes have been identified. The most common is an electrostatic precipitator (ESP). Like scrubbers, ESPs can be designed to control to almost any level desired. In our model plant, all the ESPs were designed to remove more than 99% of the uncontrolled emissions.

The second unit process which controls particulates is a fabric filter. This unit process can achieve very low emission levels provided that the chemical composition of the flyash is well matched to the cloth used.

Nitrogen Oxide: The only unit process available to control NO_x is two-stage combustion. This process has no cost associated with it in our example because:

- The "population" was new coal fired power plants
- An EPA report claimed that the costs of two-stage combustion were practically identical to the costs of conventional combustion techniques when designed into new plants.[4]

Sludge: Several unit processes exist to dispose of sludge. These unit processes are:

- ponding
- chemical treatment and landfill
- mine disposal
- ocean disposal
- conversion to gypsum
- conversion to sulfuric acid or sulfur
- use as synthetic aggregate

The current costs of these unit processes reduce the practical options to ponding and chemical treatment and landfill (CT&L).[5] Because not all power plants would be able to pond, we only examine chemical treatment and landfill in our model plant. The cost of chemical treatment and landfill is different for flyash than for SO_2. Flyash sludge costs about $3.50 per ton; sulfur sludge costs $12.10 per ton.[6] The abatement level reached with this unit process is difficult to quantify; however, no untreated sludge leaves the facility.

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[4]See "Electric Utility Steam Generating Units: Background Information for Proposed NO_x Emission Standards," EPA 450/2-78-006a, pages 8-22.

[5]Aerospace Corporation, "Controlling SO_2 Emissions from Coal-Fired Steam Electric Generators: Solid Waste Impact," Vol. II, Technical Discussion, pages 103-108.

Water: Because data was inadequate for MCE analysis, as compared to the partial inadequacy of air and sludge data, we were unable to incorporate water unit processes into this analysis.

3.3 Relationships Among Unit Processes

In the model plant, the most important relationship which exists among unit processes is between low-sulfur coal and electrostatic precipitators (ESP). It is much more difficult for an ESP to remove particulates from a stream of emissions from a plant burning low-sulfur coal.

3.4 Relationships Among Unit Processes and Pollutants

Exhibit 18 lists the alternatives examined in our case study. Several complexities of the table should be noted.

First, it should be noted that most air pollution control processes can be designed to achieve more than one level of abatement. For example, FGD can abate SO_2 to any of the three levels of control examined in this case study. In fact, there probably should be a continuous cost function for FGD use, but the limited data available restricts this analysis to the three discrete points. Secondly, as is more frequently the case with water, it is possible in controlling SO_2 to use two or more unit processes together to enhance the level of abatement. In this example, physical coal cleaning serves to augment FGD to reach more stringent levels of control. Likewise, FGDs and low-sulfur coal may be used in tandem. Another important complexity is the relationship between tons of flyash and SO_2 removed, and sludge disposal costs. Generally, if the choice of coal is known a linear multivariable function could describe the relationship. (Sludge cost = flyash removed x A_1 plus SO_2 removed x A_2.) When physical coal cleaning is used, the relationship does not hold because coal tailings can be removed less expensively, and in some instances, are removed from the coal at the mine site and not at the power plant. In our model plant, we assumed that the plant paid the costs of disposing of the coal tailings.

4. CREATE KEY POLLUTANT UNIT PROCESS COMBINATION TABLE

Before determining the entries in each row of the table it is first necessary to estimate the relevant capital and operating and maintenance costs for each of the treatment chains. Exhibit 19 presents this data in aggregate form. In developing the data for the case study we were limited to existing, readily accessible cost estimates which in many instances we believe are inaccurate. In part, this is because for several sources of data it is impossible to determine what cost are included as part "relevant costs" in these estimates.

Exhibit 20 is the Treatment System Table for our example. Because no joint costs exist it does not have a nonseparable column. No water pollutant data is shown because of the inadequacy of available data.

5. PERFORM INCREMENTAL ANALYSIS

After creating the Treatment Systems Table it is useful to review the table for obvious relationships. Often this process will help the analyst understand the pollution problems of the entity, and identify serious gaps in data. (Much

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[6] Ibid. pages 118, 121.

EXHIBIT 18

UNIT PROCESS/TREATMENT CHAIN TABLE

Unit Processes/ Treatment Chains	Abbreviation	Description
Flue Gas Desulfurizer	FGD	Also known as a scrubber. Washes SO_2 with an absorbent, usually lime or limestone. Removes to any of a variety of levels. Does not remove other pollutants.
Physical Coal Cleaning	PCC	Removes ash and sulfur from coal. Often done by mines which charge higher prices for cleaned coal, but sometimes done by power plant. Allows for reduced (partial) scrubbing.
Low Sulfur Coal	LSC	Contains 20% as much sulfur as typical coal, but lower heating value requires that more be burned. Also contains 1/18 the ash of typical coal, but much harder to remove the remaining ash. Costs more than typical coal today.
Electrostatic Precipitators	ESP	Removes ash from the stack emissions to any of a variety of levels. Relatively inexpensive compared to scrubbers. Do not affect other pollutants.
Fabric Filter	FF	Removes ash to even lower levels provided chemical composition allows. Works best and at least cost with low-sulfur coal; but will work with high-sulfur.
Staged Combustion	SC	Practically eliminates NO_x. Costs the same as other combustion techniques except when retrofitted.
Chemical treatment and landfill	CT&L	Removes acidity and toxicity from sludge so that it can be landfilled.

EXHIBIT 19

TOTAL COST ESTIMATES OF POLLUTION CONTROL UNIT PROCESSES

Pollutant Unit Process	Coal Type (% sulfur)	Level of Abatement (10^6 BUT)	Capital Costs ($/kw)	O&M Costs (mills/kwh)	Annualized Costs (millions)
SO_2[1]					
FGD	3.5	1.2	124.93	8.99	$33.15
FGD	7.0	1.2	156	11.68	$42.97
FGD and PCC	3.5	1.2	126.82	14.38	$52.18
FGD	3.5	90% removal	139.46	9.95	$36.69
FGD	7.0	90% removal	157.17	12.22	$44.91
FGD	.8	90% removal	119.42	7.69	$28.49
FGD and PCC	7.0	.5	153.22	19.15	$69.26
FGD	.8	.5	105.54	6.87	$25.43
Particulates[2]					
ESP	.8	.1	66.34	2.91	$11.02
ESP	3.5	.1	28.75	1.34	$ 5.06
ESP	.8	.05	74.74	3.32	$12.56
ESP	3.5	.05	32.77	1.46	$ 5.55
ESP	.8	.03	80.71	3.57	$13.59
ESP	3.5	.03	36.32	1.59	$ 6.02
FF	.8	.03	58.45	1.96	$ 7.59
FF	3.5	.03	51.83	1.72	$ 6.64

[1] SO_2 control costs derived from Pedco Environmental "Particulate and Sulfur Dioxide Emission Control Costs for Large Coal-Fired Boilers" (1977). Annualized costs are in 1977 dollars, derived from capital and O&M costs which are given in 1980 dollars using an annual inflation factor of 7.5%. Annualized capital costs were straightline depreciated over 35 years.

[2] Particulate control costs derived from Pedco, see footnote 1 above. Low-sulfur coal is assumed to have an ash content of 8%, high sulfur coal 14%. All cost assumptions are the same as above.

TREATMENT SYSTEM COST AND ABATEMENT TABLE

COAL-FIRED POWER PLANTS

	AIR													SLUDGE				TOTAL[1]
	SOx				Particulates				NOx									
	Treat.	Abated	Emitted	Cost	Treat.	Abated	Emitted	Cost	Treat.	Abated	Emitted	Cost[2]	Tech	Abated	Emitted	Cost	Cost
1.	FGD	61.8	17.1	33.15	ESP	135.2	1.4	5.06	SC	.8	9.9	0	CF+L	223.0	223.0	1.7	39.91
2.	FGD	61.8	17.1	33.15	ESP	135.9	.7	5.55	SC	.8	9.9	0	CF+L	223.0	223.0	1.7	40.41
3.	FGD	61.8	17.1	33.15	ESP	136.2	.4	6.02	SC	.8	9.9	0	CF+L	223.0	223.0	1.7	40.88
4.	FGD	61.8	17.1	33.15	FF	136.2	.4	6.64	SC	.8	9.9	0	CF+L	223.0	223.0	1.7	41.50
5.	FGD	61.8	17.1	33.15	ESP	135.2	1.4	5.06	SC	10.3	.4	0	CF+L	223.0	223.0	1.7	39.91
6.	FGD	61.8	17.1	33.15	ESP	135.9	.7	5.55	SC	10.3	.4	0	CF+L	223.0	223.0	1.7	40.41
7.	FGD	61.8	17.1	33.15	ESP	136.2	.4	6.02	SC	10.3	.4	0	CF+L	223.0	223.0	1.7	40.88
8.	FGD	61.8	17.1	33.15	FF	136.2	.4	6.64	SC	10.3	.4	0	CF+L	223.0	223.0	1.7	41.50
9.	FGD+PCC	71.8	7.1	52.18	ESP	135.2	1.4	5.06	SC	.8	9.9	0	CF+L	157.0	157.9	1.1	58.34
10.	FGD+PCC	71.8	7.1	52.18	ESP	135.9	.7	5.55	SC	.8	9.9	0	CF+L	157.0	157.9	1.1	58.65
11.	FGD+PCC	71.8	7.1	52.18	ESP	136.2	.4	6.02	SC	.8	9.9	0	CF+L	157.0	157.9	1.1	58.83
12.	FGD+PCC	71.8	7.1	52.18	FF	136.2	.4	6.64	SC	.8	9.9	0	CF+L	157.0	157.9	1.1	59.92
13.	FGD+PCC	71.8	7.1	52.18	ESP	135.2	1.4	5.06	SC	10.3	.4	0	CF+L	157.0	157.9	1.1	58.34
14.	FGD+PCC	71.8	7.1	52.18	ESP	135.9	.7	5.55	SC	10.3	.4	0	CF+L	157.0	157.9	1.1	58.65
15.	FGD+PCC	71.8	7.1	52.18	ESP	136.2	.4	6.02	SC	10.3	.4	0	CF+L	157.0	157.9	1.1	58.83
16.	FGD	70.9	7.9	36.69	FF	136.2	.4	6.64	SC	10.3	.4	0	CF+L	157.0	157.9	1.1	59.92
17.	FGD	70.9	7.9	36.69	ESP	135.2	1.4	5.06	SC	.8	9.9	0	CF+L	237.0	237.0	1.5	43.25
18.	FGD	70.9	7.9	36.69	ESP	135.9	.7	5.55	SC	.8	9.9	0	CF+L	237.0	237.0	1.5	43.74
19.	FGD	70.9	7.9	36.69	ESP	136.2	.4	6.02	SC	.8	9.9	0	CF+L	237.0	237.0	1.5	44.21
20.	FGD	70.9	7.9	36.69	FF	136.2	.4	6.64	SC	.8	9.9	0	CF+L	237.0	237.0	1.5	44.83
21.	FGD	70.9	7.9	36.69	ESP	135.2	1.4	5.06	SC	10.3	.4	0	CF+L	237.0	237.0	1.5	43.25
22.	FGD	70.9	7.9	36.69	ESP	135.9	.4	5.55	SC	10.3	.4	0	CF+L	237.0	237.0	1.5	43.74
23.	FGD	70.9	7.9	36.69	ESP	136.2	.4	6.02	SC	10.3	.4	0	CF+L	237.0	237.0	1.5	44.21
24.	FGD	70.9	7.9	36.69	FF	136.2	.4	6.64	SC	10.3	.4	0	CF+L	237.0	237.0	1.5	44.83
25.	FGD+LSC	19.2	2.9	28.49	ESP	89.4	1.7	11.01	SC	2.9	9.9	0	CF+L	112.0	112.0	0.7	40.2
26.	FGD+LSC	19.2	2.9	28.49	ESP	90.2	.9	12.55	SC	2.9	9.9	0	CF+L	112.0	112.0	0.7	41.74
27.	FGD+LSC	19.2	2.9	28.49	ESP	90.6	.5	13.59	SC	2.9	9.9	0	CF+L	112.0	112.0	0.7	42.78
28.	FGD+LSC	19.2	2.9	28.49	FF	90.6	.5	7.60	SC	2.9	9.9	0	CF+L	112.0	112.0	0.7	36.79
29.	FGD+LSC	19.2	2.9	28.49	ESP	89.4	1.7	11.01	SC	12.4	.4	0	CF+L	112.0	112.0	0.7	40.2
30.	FGD+LSC	19.2	2.9	28.49	ESP	90.2	.9	12.55	SC	12.4	.4	0	CF+L	112.0	112.0	0.7	41.74
31.	FGD+LSC	19.2	2.9	28.49	ESP	90.6	.5	13.59	SC	12.4	.4	0	CF+L	112.0	112.0	0.7	42.78
32.	FGD+LSC	19.2	2.9	28.49	FF	90.6	.5	7.60	SC	12.4	.4	0	CF+L	112.0	112.0	0.7	36.79
33.	FGD+LSC	14.2	7.1	25.43	ESP	89.4	1.7	11.01	SC	2.9	9.9	0	CF+L	105.0	105.0	0.6	37.04
34.	FGD+LSC	14.2	7.1	25.43	ESP	90.2	.9	12.55	SC	2.9	9.9	0	CF+L	105.0	105.0	0.6	38.58
35.	FGD+LSC	14.2	7.1	25.43	ESP	90.6	.5	13.59	SC	2.9	9.9	0	CF+L	105.0	105.0	0.6	39.62
36.	FGD+LSC	14.2	7.1	25.43	FF	90.6	.5	7.60	SC	2.9	9.9	0	CF+L	105.0	105.0	0.6	33.63
37.	FGD+LSC	14.2	7.1	25.43	ESP	89.4	1.7	11.01	SC	12.4	.4	0	CF+L	105.0	105.0	0.6	37.04
38.	FGD+LSC	14.2	7.1	25.43	ESP	90.2	.9	12.55	SC	12.4	.4	0	CF+L	105.0	105.0	0.6	38.58
39.	FGD+LSC	14.2	7.1	25.43	ESP	90.6	.5	13.59	SC	12.4	.4	0	CF+L	105.0	105.0	0.6	39.62
40.	FGD+LSC	14.2	7.1	25.43	FF	90.6	.5	7.60	SC	12.4	.4	0	CF+L	105.0	105.0	0.6	33.63
41.	FGD+PCC	150.7	7.1	69.26	ESP	135.2	1.4	5.06	SC	.8	9.9	0	CF+L	359.0	359.0	3.3	77.62
42.	FGD+PCC	150.7	7.1	69.26	ESP	135.9	.9	5.55	SC	.8	9.9	0	CF+L	359.0	359.0	3.3	78.11
43.	FGD+PCC	150.7	7.1	69.26	ESP	136.2	.5	6.02	SC	.8	9.9	0	CF+L	359.0	359.0	3.3	78.58
44.	FGD+PCC	150.7	7.1	69.26	FF	136.2	.5	6.64	SC	.8	9.9	0	CF+L	359.0	359.0	3.3	79.20
45.	FGD+PCC	150.7	7.1	69.26	ESP	135.2	1.7	5.06	SC	.8	9.9	0	CF+L	359.0	359.0	3.3	77.62
46.	FGD+PCC	150.7	7.1	69.26	ESP	135.9	.9	5.55	SC	10.3	.4	0	CF+L	359.0	359.0	3.3	78.11
47.	FGD+PCC	150.7	7.1	69.26	ESP	136.2	.5	6.02	SC	10.3	.4	0	CF+L	359.0	359.0	3.3	78.58
48.	FGD+PCC	150.7	7.1	69.26	FF	136.2	.4	6.64	SC	10.3	.4	0	CF+L	359.0	359.0	3.3	79.20
		K TONS/YR		$M		K TONS/YR		$M		K TONS/YR		$M		K TONS/YR		$M	$M

1. Insufficient data were available to develop entries for water. The key pollutants for which data are required include: TSS, chlorine, oil and grease, trace metals, pH, and heat.
2. The only available source argued that efficiency achieved when staged combustion is employed resulted in no additional cost for new plants.

of what falls out of the Treatment Systems Table will have been recognized in the process of defining the key pollutants and unit processes. However, some things may be revealed for the first time only after the system of treatment chains has been put together in the table.)

In this case study, several points are immediately obvious. The first of these is that SO_2 control costs drive the costs of the system. In the case of high-sulfur coal plants at a 1.2 standard for SO_2 and a .1 standard for TSP, they represent about 85% of the total system cost. For very dirty coal, the ratio is even higher at nearly 90%. Additionally, removal of sludge is relatively cheap amounting to less than 3% of the total system cost; and particulate control is similarly small, accounting for between 15 and 35% of total system costs depending on the type of coal being burned.

The second interesting point is the relationship of <u>average</u> cost per ton removed of SO_2 and TSP. For 3.5% coal the average cost per ton removed at the 1.2 standard is 8 times greater than the average cost per ton removed for TSP at the .1 standard. Because these are the current standards for these pollutants it might be worthwhile to ask the question "Did EPA decide that removal of a ton of SO_2 is really worth eight times as much as removal of a ton of particulates?" "How did they arrive at this relationship?"

The third point is the sharp jump in total costs between a .5 standard and a 1.2 standard for SO_2 when 3.5%-sulfur coal is burned. Upon closer examination, it becomes apparent that the extra cost is related to physical coal cleaning. Because this jump is so large ($26M), it raises the question as to whether it might be possible to reach the .5 standard without physical coal cleaning? And, if so, why hasn't this alternative been analyzed?

A fourth obvious point is that a 1.2 standard for low-sulfur coal plants is very expensive on a ton-removed basis. The reason for this is that low-sulfur coal itself contains only 25% more sulfur than the standard allows to be emitted. In contrast 3.5%-coal emits almost five times as much potential sulfur emissions as the standard permits.

Unfortunately, we place little credence in these numbers as representing the total systems cost for the model entity. In part, this is because we were unable to find enough quality data about water pollution costs. It is possible that some water and air pollution problems interact and are important to any analysis of the costs of cleaning up the entity. Finally, we can readily see the need for identification of more treatment systems than the 48 listed. Notwithstanding these limitations, we performed this analysis recognizing that the results are intended to show the application of the proposed methodology rather than to draw conclusions about the proper way to regulate new coal-fired power plants.

5.1 <u>Identify the Policy Question</u>

Earlier in this chapter we identified two plausible policy questions that the methodology should be able to address. These were:

-- What is the MCE of alternative, more stringent sulfur dioxide standards?

-- What is the MCE of trading-off particulate control for sulfur-dioxide control?

In the succeeding paragraphs we will analyze each of these questions applying the relevant steps identified in the methodology.

What is the MCE of alternative, more stringent sulfur dioxide standards for new coal-fired power plants? The first step in answering this question is to identify all of the relevant Treatment Systems from the Table. Holding all of the other standards constant indicates rows 1, 9, 17, 25, 33, and 41 are those of interest for analyzing changes in the SO_2 standard. The total costs associated with these systems are shown in Exhibit 21.

EXHIBIT 21

TOTAL COSTS OF THE RELEVANT TREATMENT SYSTEMS

Treatment System	Coal (Sulfur Content)	Standard	SO_2 Abated (1,000 tons)	SO_2 Emitted (1,000 tons)	Total Cost (Annualized)
1	3.5%	1.2	140.7	17.1	39.91
9	3.5%	.5	150.7	7.1	58.34
17	3.5%	90%	149.9	7.9	43.25
25	.8%	90%	155.7	2.1	40.2
33	.8%	.5	150.7	7.1	37.04
41	7.0%	.5	150.7	7.1	77.62

The next step is to assign nonseparable costs. In this example, there are none, so we may omit this step. Likewise, we do not have to assign weights to pollutants because this policy issue addresses only one pollutant.

Next, the MCE ratios are computed and analyzed. In this example a problem arises in that the alternative fuels (low-sulfur and high-sulfur) create different amounts of potential emissions to be abated (low-sulfur 21.3 thousand tons; high-sulfur 78.8 thousand tons; highest sulfur 157.8 thousand tons). By defining the entity as burning the highest sulfur coal, and using that as the base, it is possible to calculate the amount of abatement achieved by switching to either of the lower sulfur coals.

Having defined the amount of abatement, the question then is, "Over what interval/increment are we interested in the incremental costs?" Because we are choosing among alternative standards for new sources we assume that the most rational increment is from an uncontrolled condition.

Exhibit 22 shows the average cost-effectiveness for the 6 alternatives when the increment is from the uncontrolled base. Based on these results it would appear that the appropriate standard to impose would be .5% and that new coal-fired power plants should burn low-sulfur coal.

EXHIBIT 22

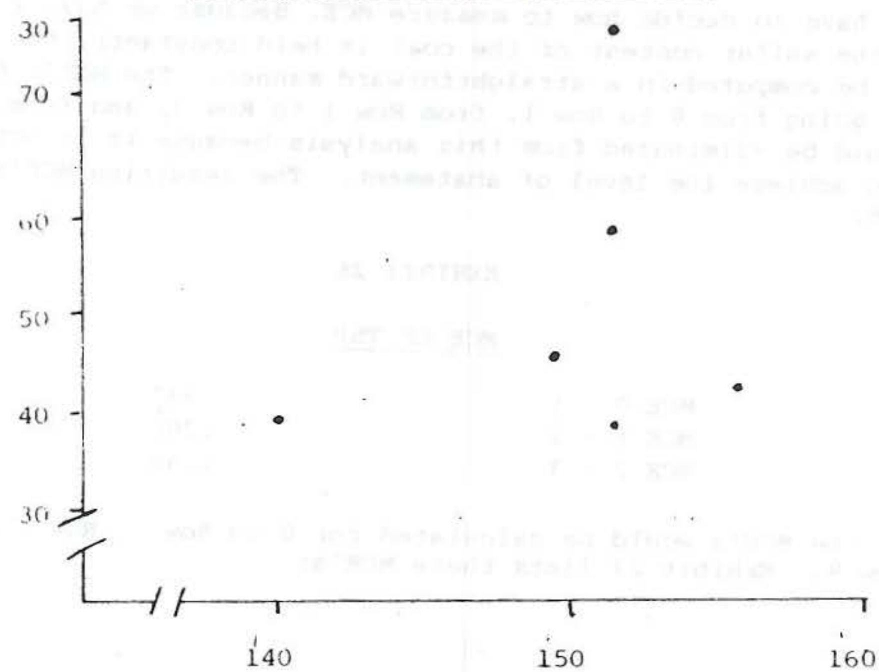
AVERAGE COST-EFFECTIVENESS FOR THE SIX ALTERNATIVES

Alternative Coal	Alternative Std.	Abatement	Average Cost-Effectiveness	Incremental Cost
3.5% S	1.2	140.7	.284	39.91
3.5%	0.5	150.7	.387	58.34
3.5%	90%	149.9	.289	43.25
0.8%	90%	155.7	.258	40.2
0.8%	.5	150.7	.246	37.0
7.0%	.5	150.7	.515	77.62

This application of the methodology illustrates a point worth noting. By comparing costs and effectiveness from one point (zero abatement) to three alternative points (standards set at 1.2, 90% and .5), we are in effect computing average and not marginal cost-effectiveness. Exhibit 23 displays the total cost and abatement points on a Total Cost/Total Abatement graph. As is readily apparent any effort to fit a curve to these particular points would be misleading. Furthermore, the marginal cost curve (the derivative of the speculatively created total costs curve) would not be useful to this decision unless EPA had chosen a threshold price per ton abated that represented the marginal social benefit of removing SO_2. Absent this price, the above analysis represents the best tool for answering the question.

EXHIBIT 23

TOTAL COST/TOTAL ABATEMENT GRAPH



What is the MCE of trading-off particulate control for sulfur dioxide control? This question requires comparison of the MCE curves for SO_2 control with those for TSP control. For clarity we will only examine the cases where the fuel is 3.5% sulfur and 14.0% ash. These cases are described by Rows 1 to 15. For TSP control the important rows where all pollutants except TSP are held constant, are shown in Exhibit 24.

EXHIBIT 24

TSP DATA FROM ROWS 1 to 4

Treatment System	Abatement	Emissions	Unit Process Cost
1	135.2	1.4	5.06
2	135.9	.7	5.55
3	136.2	0.4	6.02
4	136.2	0.4	6.64

For SO_2 control the relevant rows are shown in Exhibit 25.

EXHIBIT 25

SO_2 DATA FROM ROWS 1, 9 AND 17

Treatment System	Abatement	Emissions	Unit Process Cost
1	61.8	17.1	33.15
9	71.8	7.1	52.18
17	70.9	7.9	36.69

Again we have to decide how to measure MCE. Because we have a constant "influent" (the sulfur content of the coal is held constant), the data allows the value to be computed in a straightforward manner. The MCE's for TSP are the MCE's of going from 0 to Row 1, from Row 1 to Row 2, and from Row 2 to Row 3. Row 4 would be eliminated from this analysis because it is not the least costly way to achieve the level of abatement. The resulting MCE's are shown in Exhibit 26.

EXHIBIT 26

MCE OF TSP

MCE 0 - 1	.037
MCE 1 - 2	.700
MCE 2 - 3	1.56

For SO_2, the MCE's would be calculated for 0 to Row 1, Row 1 to Row 17, Row 17 to Row 9. Exhibit 27 lists these MCE's:

EXHIBIT 27

MCE OF SO_2

MCE 0 - 1	.536
MCE 1 - 17	.389
MCE 17 - 9	19.4

A comparison of the values for SO_2 reveals an interesting phenomena. The marginal cost effectiveness of going from Row 1 to 17 (where emissions decrease significantly) is less than the MCE of achieving the initial standard. This would suggest that the more appropriate initial standard would have been at row 17.

In contrast, the MCE for controlling TSP rises with increasingly stringent standards. This is consistent with expected results.

As for trade-offs between pollutants, the data suggests that if Row 1 represents current standards, it would be more cost effective to impose Row 17's standard of SO_2 than to impose Row 2's standard on TSP assuming equal weights for those pollutants. However, if a ton of SO_2 was considered twice as bad as a ton of TSP, then the two pollutants would have to be normalized on the vertical axis. In this case, the MCE of SO_2 would drop to .195 which would further confirm the desirability of imposing the tougher SO_2 standard rather than the tougher TSP standard.

Finally, it is worth noting the effect of employing a threshold in this analysis. If the MCE threshold was set at .5 and equal weights are assumed, then TSP would probably be controlled to the Row 2 level while SO_2 would be controlled to the Row 17 level.

SUMMARY

Because of the limitations and questionable validity of the available data, no firm conclusions concerning alternative new source performance standards for coal-fired power plants can be reached. This case study has, however, illustrated several interesting aspects of applying the MCE methodology. Above all, it demonstrated the methodology cannot be applied in a mechanical fashion. With less than the desired amount data available and with specific policy questions to address, manipulations of the basic methodology will often be required.

The case study convincingly demonstrates that the methodology does provide a comprehensive tool for use in setting agency policy. By first establishing a data base of all possible combinations of treatment chains with their respective cost and levels of abatement, it becomes possible to address a variety of policy decisions. The first example of this case study (comparing proposed standards for SO_2) showed that even though MCE may not be applicable to specific policy questions, the basic methodology still proves useful. In this instance, it provided the data for doing the more appropriate average cost-effectiveness analysis. In the second example, we introduced the use of weights in comparing the composite MCE where the standards for two pollutants were being examined concurrently.

Finally, we suspect that future applications of the methodology will result in further refinement of the methodology. At this juncture in the development of MCE analysis, we have attempted mainly to develop as comprehensive and flexible an analytical device as possible. For this reason, applications of the methodology to specific policy questions demand the use of careful judgment.

6. IMPLEMENTATION CONCERNS

The development and testing of methods for measuring the marginal cost effectiveness of EPA regulations was much more complex and difficult than originally thought. A number of factors affect the complexity of the analyses. These, in turn, raise theoretical issues which impact on the rigor of results obtainable. As a result, a serious application of MCE analyses by EPA may require collecting and analyzing a substantial amount of new data.

The implications of the complexity and theoretical issues raised in this phase will be clearer when the Phase II analysis is complete; the purpose of this Chapter is to summarize our major implementation concerns as of this point in the development of the methodology.

COMPLEXITY ISSUES

The methodology proposed is designed to answer some rather sophisticated policy questions. It is no longer practical to consider abatement of single pollutants alone. Moreover, EPA has come to recognize that standards in one media impact pollution in other media: removing SO_2 from smokestacks creates water problems, and abatement of water problems creates sludge disposal problems. Because of this, the MCE methods are designed for cross-media as well as intermedia comparisons.

The methods are also "future looking" and are therefore designed to consider new abatement processes. Moreover, most existing industrial plants have some abatement system in place which must be accounted for in the analysis. For these reasons, the methodology uses an entity (model plant, model process, mobile source) as the basic building block for both cost and abatement (effectiveness) analyses. Because the methods are designed for analysis of regional and national as well as industry-wide policy questions, the entity analysis must also identify factors for aggregating to appropriate levels.

Data and Technological Complexities

With this background in mind, several issues which introduce complexities into implementation can be presented. Some are associated with the amount and multidimensional nature of required data. Others center on technological complexities. The issues are:

- Number of Entities - the number of entities included in a single industry can be large. There were 26 model plants which required analysis in the Textile Industry case study. Moreover, each of the 26 had five or six separate and distinct production processes that, in theory, should be analyzed for potential in-plant/process change abatement options. Although the Textile Industry is not homogeneous, it is probably not atypical of what can be expected for other industries.

- Number of Unit Processes - The number of unit processes for abatement was small in both case studies, but the number of combinations of processes (treatment chains) that required analysis was large. Furthermore, the number of treatment chains for which data were provided by the literature were not sufficient for proper MCE; some apparently obvious combinations were not studied by the engineering contractors. Despite the lack of sufficient data, the combining of treatment chains or systems with entities led to large and unwieldy Treatment System Cost and Abatement Tables in both case studies.

- Interdependency Among Pollutants - Both case studies showed that there were interactions among pollutants. This seems fundamental to water pollution abatement. For example, a single organic substance in suspension will be recorded as all three conventional pollutants (BOD, COD, and TSS), and a unit process installed to remove solids will also remove other pollutants. This causes both theoretical and practical problems in cost assignment. Because of this, the Textile Industry case study was limited to a consideration of conventional pollutants as a group rather than on an individual basis.

A second complexity is introduced when some process, aimed say at TSS, removes nonconventional or priority pollutants in suspension. A determination must be made whether this removal is "incidental" or a principal concern.

Theoretical Complexities

Problems related to MCE theory also complicated the research effort and pose some complexities to implementing the methodology. These issues are:

- Well-Ordered Treatment Chains - The theory requires a nondecreasing cost-effectiveness function. This means that unit processes must be combined in such a manner that the total system cost increases and that the amount of each pollutant removed does not decrease. This process was somewhat easier in the case studies when individual pollutants were aggregated to conventional and nonconventional levels. Nonetheless, where ICE ratios were calculated, the resulting plot to obtain a MCE curve showed a surprising dispersion of points. We do not know whether this was the result of poor data (inclusion of treatment chains that were not cost effective) or poor analysis (improper measurement of abatement).

- Number of ICE (MCE) Data Points - The development of an MCE ratio envelope curve for an individual entity and the ability to aggregate to industry, region, or national totals require a reasonable number of data points covering a reasonable range of MCE values. Each data point requires a properly constructed treatment chain and data points are required over an extensive effectiveness range. Because many EPA studies have concentrated on a particular standard (level of effectiveness), alternatives to that standard and the cost-effectiveness relationships it imposes are not always available.

- ICE (MCE) Interval - The data available for the case studies was not sufficient to develop a statistical approximation to the underlying costeffectiveness function. Instead MCE results were approximated by ICE analysis. ICE is a good estimator of MCE under certain conditions, but the Textile study revealed a significant problem with its use. The addition of a unit process to a treatment chain produced a discrete increase in effectiveness, often a substantial change. These intervals were not only large but varied substantially from entity to entity. The direct comparison of ICE points is, therefore, difficult. The best solution to this problem uncovered to date involved using the longest interval among entities as a basis for comparison and aggregation. Because the accuracy of ICE as an estimator of the true MCE degrades with interval length, this practice is undesirable. Where possible, comparisons should be based on best estimates of the MCE function.

INCREASED DATA AND ANALYSIS REQUIREMENTS

The issues discussed above introduce complexities to implementation not so much because they cannot be resolved but because of the scope and detail of the tasks required. We believe that significant gaps exist in the data available, but that these gaps can be closed by more complete and effective systems analysis at the entity level. Moreover, it seems probable that the quality of data available in completed engineering studies can be improved by interaction with selected labs or contractors.

If one may generalize from the Textile Industry case study, information gaps for the analysis of water problems are:

- Raw Influent, BPT Effluent and BAT Effluent Characteristics - The study assumed that BTP was in place and that various unit processes and combinations would be added to achieve a reasonable BATEA goal. No information on raw influent was available; only aggregated characteristic data for BTP and treatment chain effluent was available. Knowledge of the effluent characteristics for each unit process in each treatment chain is essential for cost assignment. Knowledge of the actual constituents (compounds) in the effluent stream would be helpful. Knowledge of the hydraulic loading and effluent characteristics associated with each production process is essential for considering inplant/process change options.

- Treatment Chain Logic - The reasons for selecting particular unit processes and the sequence in which they are applied should be fully explained. Although infrences can be drawn if complete step-by-step effluent data are available, the logic of assembly will allow a sound engineering "incidental removal" criterion to be established. Furthermore, the data indicated that sequencing of the same unit processes influences total abatement, that is, arranging unit process A, B, and C in one order (A-B-C) gave a different toal abatement from another order (B-A-C). Finally, specifying the logic would insure that all logical combinations are considered and that all pollutants addressed are treated simultaneously. Curiously, the textile industry engineering analysis did not include a treatment chain that would reduce all pollutants and omitted one combination of unit processes (ozonation with activated carbon) which seemingly would reduce all pollutants.

- Complete Cost Analysis - Both investment and operating cost estimates should be prepared for each unit process in each treatment chain tested. This is essential when cost assignment is required.

- Cost-Effectiveness Analysis - A cost-effectiveness study, not a mere reporting of cost and effectiveness is required. Each treatment chain presented should be the least-cost method for achieving the desired level of effectiveness.

- Cross-Media Consideration - It is important to include impacts on other media. The sludge problem received some attention and sludge disposal was included as a cost element in the textile engineering analysis, but no discussion of potentially toxic content was included. As more and more nonconventional and perhaps priority pollutants are removed from waste water streams, the difficulties and costs of sludge treatment and disposal increase. Similarly, an analysis of emission problems is required particularly when the industry uses process stream in production processes.

The Coal-Fired Power Plant case study revealed similar information problems. More specifically, information on the interrelationships among pollutants and unit processes was sketchy, cost and effectiveness points were limited even when a continuous function was available, and data was lacking on at least several feasible combinations of unit processes.

Implications for Phase II and Beyond

The data and analysis problems cited above can be solved but at some cost in both money and time. The problems suggest that our Phase II effort be concentrated on a few key industries so that truly useful results can be obtained. It does not appear that a broad brush study of a large number of industries based on available data would produce results much more applicable than the two case studies completed in this Phase.

The Phase II study will, of course, clarify the issues raised here. It seems likely, however, that a comprehensive application of MCE methods will require increased resources for more detailed analyses of abatement options. EPA must therefore assess the cost effectiveness of employing MCE at some future time when better estimates of resource requirements are available.