United States
Environmental Protection
Agency

Office of
Radiation Programs
Washington, D.C. 20460

EPA 520/1-84-025
October 1984

Radiation

EPA

Radionuclides

Regulatory Impact Analysis of Emission Standards for Elemental Phosphorus Plants

NESHAP

EPA 520/1-84-025

40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants

REGULATORY IMPACT ANALYSIS

OF

EMISSION STANDARDS FOR

ELEMENTAL PHOSPHORUS PLANTS

October 1984

Prepared by:
Jack Faucett Associates
5454 Wisconsin Avenue
Suite 1155
Chevy Chase, Maryland 20815

Office of Radiation Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

ACKNOWLEDGEMENTS

This study of the impacts of alternative standards for radionuclide emissions under the Clear Air Act Amendments of 1977, (PL 95-95) was conducted by Jack Faucett Associates under the direction of Michael F. Lawrence. The principle analyses were conducted by and the report prepared by Dr. Harry Chmelynski, Jan T. Jablonski and Mr. Lawrence. Other JFA analysts contributing to the study included David Cozad and Dorothy Lehrman. The manuscript was prepared by Don Hutson and Polly Davis.

Technical direction and review of this study was provided by Dr. Byron M. Bunger and Paul Magno of the Office of Radiation Programs, US EPA.

TABLE OF CONTENTS

		PAGE
1.	Introduction and Summary	1
2.	Industry Profile	6
	2.1 Demand	6
	2.2 Supply	10
	2.3 Competitive Products and Processes	19
	2.4 Economic and Financial Characteristics	20
	2.5 Outlook	23
3.	Current Emissions, Risk Levels, and Feasible Control Methods	24
	3.0 Introduction	24
	3.1 Current Emissions and Estimated Risk Levels	25
	3.2 Control Technologies for Elemental Phosphorus Plants	29
4.	Benefit-Cost Analysis	35
	4.0 Introduction	35
	4.1 Least-Cost Control Technologies for Affected Plants	36
	4.2 Health Benefits of Controlling Polonium-210 Emissions	41
	4.3 Benefit-Cost Comparisons	44
	4.4 Sensitivity Analysis	46
	4.5 Addendum on Levelized Annual Cost and Present Value	53
5.	Industry Cost and Economic Impact Analysis	59
	5.0 Introduction	59
	5.1 Production Costs	62
	5.2 Measuring Economic Impacts	67
	5.3 Regulatory Flexibility Analysis	72

LIST OF EXHIBITS

EXHIBIT		PAGE
2-1	Production And Shipments Of Elemental Phosphorus	7
2-2	Uses For Phosphorus Chemicals	8
2-3	Elemental Phosphorus Producers And Estimated Capacity, 1984	12
2-4	Production Capacity By Producer	13
2-5	Revenues From Elemental Phosphorus Production and Total Corporate Revenues	14
2-6	Price Per Pound: 1977 To 1984	22
3-1	Emission Rates From Elemental Phosphorus Plants	26
3-2	Emission Rates Per Unit Of Elemental Phosphorus	27
3-3	Estimated Risks Due To Radionuclide Emissions From Elemental Phosphorus Plants	28
3-4	Available Control Technologies (Selected Examples)	33
4-1	Cost Per Ton For Selected Control Technologies	37
4-2	Least-Cost Control Strategies	39
4-3	Least-Cost Control Technologies By Plant For Selected Standard Options	40
4-4	Estimated Risk Levels By Alternative Standard	43
4-5	Average And Incremental Cost-Effectiveness For Alternative Standards	45
4-6	Sensitivity Of Costs To Assumed Useful Life And Discount Rate	48
4-7	Cost Per Ton For Selected Control Technologies For Sensitivity Analysis	49
4-8	Least-Control Cost Strategies For Sensitivity Analysis	51
4-9	Sensitivity Of The Cost Of Least-Cost Control Technologies For Alternative Standards	52
4-10	Sensitivity Of Average And Incremental Cost Per Statistical Death Avoided	54
4-11	Annualization Factors	57
5-1	Cost Of Elemental Phosphorus	63
5-2	Phosphate Rock	65
5-3	Electricity Costs	66
5-4	Labor Costs	68
5-5	Summary Of Cost Estimates, By Plant	69
5-6	Revenues From Elemental Phorphorus Production And Total Corporate Revenues	71
5-7	Impact On Capital Expenditures	73
5-8	Impact On After Tax Profits	74

CHAPTER 1

INTRODUCTION AND SUMMARY

On November 8, 1979, EPA listed radionuclides as a hazardous air pollutant under the provisions of Section 112 of the Clean Air Act. Pursuant to Section 112, EPA on April 6, 1983 proposed standards for sources of emissions of radionuclides in four categories: (1) Department of Energy facilities, (2) Nuclear Regulatory Commission licensed facilities and non-DOE Federal facilities, (3) underground uranium mines, and (4) elemental phosphorus plants. The standard proposed for elemental phosphorus plants, the subject of this analysis, was 1 curie per year of polonium-210 for each source.

There are currently six plants producing elemental phosphorus. These plants are owned by Monsanto Company (2 plants), FMC Corporation, Stauffer Chemical Company (2 plants), and Occidental Petroleum Company. EPA sampling of emissions at four plants and estimates of emissions at the remaining two indicate that, with current output levels and operating characteristics, only two plants will be affected by a 1 curie per year standard. These two are Monsanto's plant in Soda Springs, Idaho, and FMC's plant in Pocatello, Idaho. EPA measurements show the polonium-210 (Po-210) emissions of these plants are currently 21 Ci/year and 9 Ci/year, respectively. At these emission levels, the lifetime probability of cancer for nearby individuals is estimated to be 0.0005 at FMC and 0.001 at Monsanto. The risks to the populations around these plants are estimated to be 0.027 fatal cancers per year as a result of FMC emissions and 0.018 fatal cancers per year as a result of Monsanto emissions.

Three alternatives to the 1 curie per year standard were considered in performing the regulatory impact analysis: 2.5 Ci/year, 10 Ci/year, and no control. For each of these control options and for each plant, the analysis considered the technologies that are available to reduce emissions to the required level, examined the costs of these technologies, identified the least-cost options, evaluated the cost per fatal cancer eliminated, and assessed the economic impacts of the regulation. Findings in each of these areas are summarized in the following paragraphs.

The costs and emission reductions of seven control technology options were considered: venturi scrubbers at three pressure drops, wet electrostatic precipitators with three

specific collection areas, and a pulse-jet fabric filter. Of the three types of control technologies, scrubbers have the lowest estimated capital costs and the highest operating costs. Capital costs for precipitators and fabric filters are approximately twice those for scrubbers, while operating costs are greatly reduced. The efficiency of Po-210 removal varies from 65 to 98 percent for these control technologies, with fabric filters the most efficient and scrubbers the least efficient. Both affected plants can achieve compliance under any of the alternative standards using currently available particulate control technologies, although fabric filters have not been used in the elemental phosphorus industry.

Given the costs and efficiencies of available control technologies, and the current emissions levels, the least-cost control technology for each plant at each level of the standard was determined. The least-cost method was the lowest cost technology which would allow the plant to meet the standard with a 10 percent safety margin. Under the most restrictive standard, 1 Ci/year, least-cost control methods are estimated to have a before-tax real-resource cost of less than $17 per ton of elemental phosphorus, or 0.9 percent of the current selling price. The after-tax cost is less than $13 per ton. The capital costs, and costs per ton of phosphorus before and after taxes, for each plant and control level are summarized below.

LEAST-COST CONTROL TECHNOLOGIES BY PLANT
FOR SELECTED STANDARD OPTIONS

Alternative Standard	Least-Cost Technology		Levelized Unit Control Cost (before taxes) ($/ton)		Levelized Unit Control Cost (after taxes) ($/ton)	
(Ci/year)	FMC	Monsanto	FMC	Monsanto	FMC	Monsanto
10	None	10 to 15 inch P Scrubber	0	9.2	0	8.3
2.5	250 SCA precipitators	400 SCA precipitators	13.6	13.2	10.7	11.2
1	400 SCA precipitators	Fabric Filter	16.4	15.2	13.2	12.9

A sensitivity analysis was performed to determine the effects of a larger safety margin, reduced control equipment life, and a higher risk factor on control technology choice

and costs. Assuming a 25 percent safety margin, equipment life of 10 instead of 20 years, and a risk premium of 15 instead of 10 percent, least-cost control methods are estimated to have a before-tax real-resource cost of less than $23 per ton, or $17 per ton after taxes for the 1 Ci/year standard. Additional information on the cost per ton of the least-cost technologies is given in Exhibit 4-3 for the 10 percent safety margin, and Exhibit 4-9 for the sensitivity analysis.

The health benefits which accrue to society over time from the control of Po-210 emissions at the affected elemental phosphorus plants consist largely of the reduction in expected fatal lung cancers and, to a smaller degree, the reduction in particulate emissions near the sites. The health benefits associated with reduction of Po-210 emissions are the major component of the total health benefits due to emission reductions at these plants. Total industry benefits amount to 0.009 avoided fatal cancers per year at the 10 Ci/year standard alternative, while 0.035 and 0.041 fatalities per year are avoided at the 2.5 and 1.0 Ci/year levels, respectively. Due to uncertainty, the level of these estimates may range up to a factor of 10 higher or lower.

Cost-effectiveness, defined as the ratio of the levelized annual cost to the annual benefit, is shown for the alternative standards in the following table.

AVERAGE AND INCREMENTAL COST-EFFECTIVENESS FOR ALTERNATIVE STANDARDS

Alternative Standard (Ci/yr)	Average Cost Per Death Avoided (mil $/fatality)	Incremental Cost Per Death Avoided (mil $/fatality)
10	78	78
2.5	70	67
1	71	75

The estimated average cost per statistical death avoided ranges from $78 million for a 10 Ci/year standard to $70 million for a 2.5 Ci/year standard. Given the potential errors in the benefits estimates, the actual cost per death avoided is uncertain. Additional information on cost-effectiveness is provided in Exhibit 4.5.

The economic impact of these standards on the elemental phosphorus industry was considered for each alternative control level. The transitional nature of this exhaustible resource industry prevented definitive forecasts of the future structure of the industry and thus quantification of the likelihood that manufacturers will pass along increases in cost to consumers. As most of the phosphorus produced is consumed by the parent company in another company-owned plant and the products are sold as inputs in highly competitive consumer goods such as detergents and soft drinks, it was assumed that each plant faced a flat demand curve. This demand curve and the existence of slightly less desirable substitute products led to the conclusion that price increases could not be utilized to mitigate the effect of increased cost on profitability. Thus prices and demand would not change and there would be no impact on employment, competition, consumers, or the communities where the plants were located. The only economic impacts anticipated are effects on the profitability of affected plants.

The two affected plants are the low cost producers in this industry and would remain so under all alternative standards evaluated. The pollution control costs would reduce the annual profitability of the FMC and Monsanto plants by $630,000 to $1,400,000. The present values of these losses are $5 million and $12 million, respectively. Reductions in profits for all manufacturers under each alternative are detailed below.

IMPACT ON AFTER-TAX PROFITS

Producer	Profits After Taxes, 1983[1] ($ in millions)	Standard Option (Ci/year)	Present Value of Profit Reduction (in millions)
Monsanto	$ 369.0	10	$ 5.4
		2.5	7.3
		1	8.4
FMC	$ 168.8	10	$ 0
		2.5	9.7
		1	11.9
Stauffer	$ (12.4)	10	$ 0
		2.5	0
		1	0
Occidental	$ 566.7	10	$ 0
		2.5	0
		1	0

[1] Parentheses are used to indicate a loss.

The costs of emissions control used in this analysis are based on engineering studies performed by Midwest Research Institute (MRI) under contract to EPA. MRI's studies were completed in late summer 1984. They were then placed in the docket and the public given an opportunity to comment on them. The short time between closure of the docket (September 21, 1984) and publication of this regulatory impact analysis prevented any reevaluation of MRI's cost estimates in response to public comments. All comments received by the date of closure of the docket, and EPA's response to these comments, are available in Volume II of EPA's Response to Comments (EPA 520/1-84-023-2).

The remainder of this report is organized into four chapters. Chapter 2 contains background information on the elemental phosphorus industry, including characteristics of demand, supply, competitive products and processes, other economic characteristics, and outlook. Chapter 3 presents the current emissions for each elemental phosphorus plant, risk levels associated with the emissions, and the cost and efficiency of each of seven technologies for controlling the emissions. Chapter 4 is a benefit-cost analysis of the standard. The chapter identifies least-cost control technologies for the plants that would be affected by the standard, describes the health benefits of controlling polonium-210 emissions, and compares costs and benefits. Chapter 5 concludes the report with an evaluation of the costs to industry of the regulation, including an analysis of the current cost structure of the industry by plant, and assesses the economic effects of the regulation.

CHAPTER 2
INDUSTRY PROFILE

Phosphate rock is the starting material for the production of elemental phosphorus and all phosphorus products. Of all the marketable phosphate rock mined in the United States, only about ten percent is used for the production of elemental phosphorus.[1] Elemental phosphorus is used primarily for the production of high grade phosphoric acids and their salts, and organic chemicals. In the U.S., major end uses are in laundry detergents and other products for homes and industry.

2.1. DEMAND

Elemental phosphorus (P_4)is used primarily for the production of high-grade phosphoric acid, phosphate-based detergents, and organic chemicals. In 1983, shipments of elemental phosphorus totalled about 350,000 tons, a 7 percent increase over 1982.[2] Plant production and shipments between 1964 and May 1984 are listed in Exhibit 2-1.

Products

In 1983-1984, 85 percent of the elemental phosphorus supply was used for production of phosphoric acid and derivatives, 10 percent was used to produce other chemicals, and 5 percent was exported. End uses of elemental phosphorus products include detergents (45 percent), metal treatment (15 percent), foods and beverages (10 percent), and chemicals (10 percent).[3] A chart of the intermediate and end products of the elemental phosphorus industry is provided in Exhibit 2-2.

Sodium phosphates, used extensively as builders and water treatment chemicals in detergents,[4] have historically been the primary product of the elemental phosphorus

---

[1]Mining of phosphate rock is the fifth largest mining industry in the United States in terms of quantity of material mined. Phosphate rock mines of significant commercial importance are located in Florida, North Carolina, Tennessee, Idaho, Wyoming, Utah, and Montana.

[2]Estimate: Shipments for 1978 to 1982 were compared to production for those years and the average ratio, 0.9575, applied to 1983 production data.

[3]"Key Chemicals: Phosphorus," Chemical and Engineering News, July 30, 1984, p. 19.

[4]"Builder" is an industrial term for any ingredient that increases the detergent power of a soap or surfactant.

EXHIBIT 2-1:

PRODUCTION AND SHIPMENTS OF ELEMENTAL PHOSPHORUS
1964-1984
(tons)

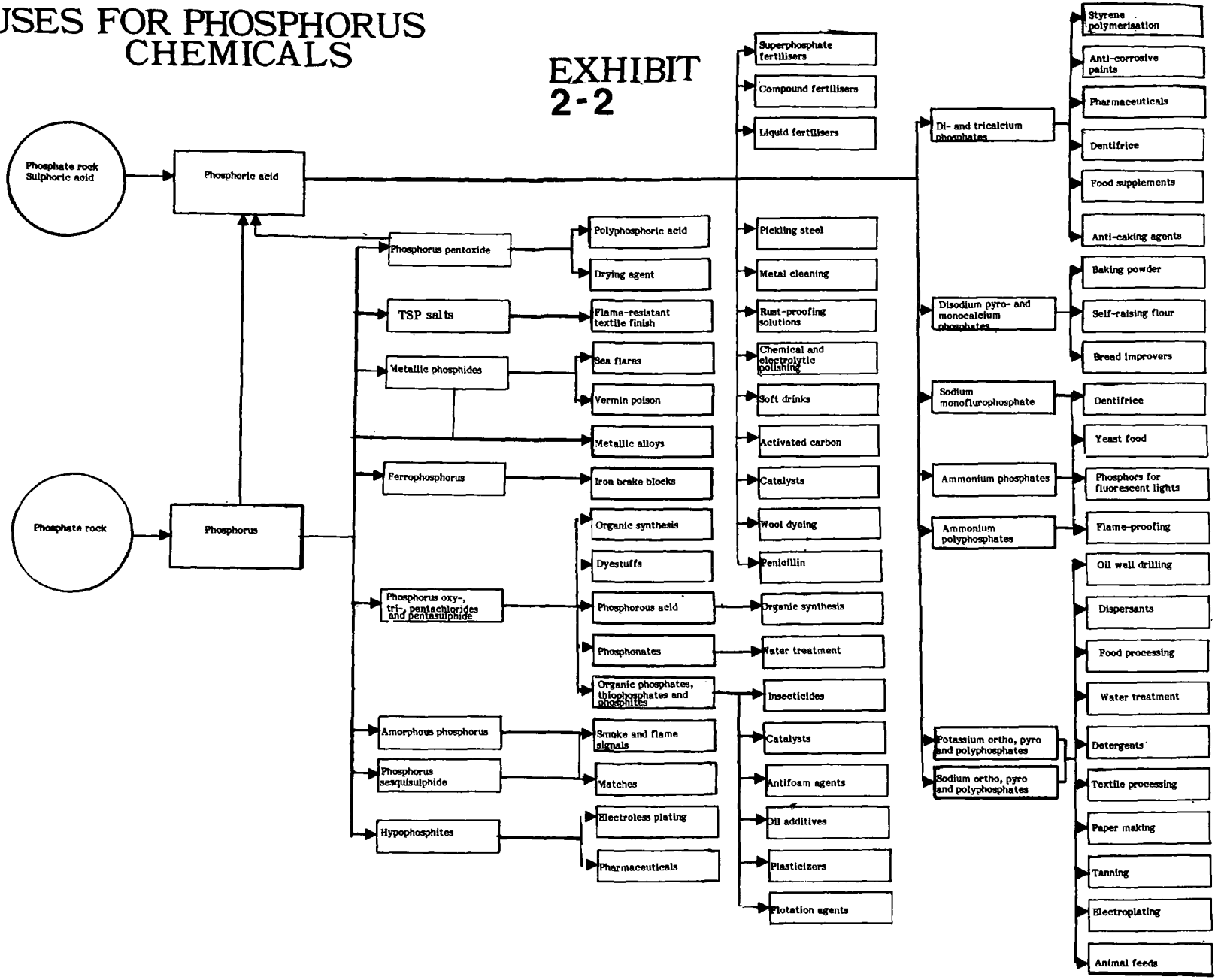
Year	Production	Total Shipments Including Interplant Transfers
1984 (January-May)	155,409	148,804[1]
1983	366,050	350,493[1]
1982	361,189	327,472
1981	426,067	376,262
1980	431,730	429,462
1979	459,541	462,259
1978	441,274	442,619
1977	430,291	423,620
1976	436,655	425,374
1975	449,506	424,305
1974	524,175	497,612
1973	525,523	488,527
1972	540,089	502,197
1971	545,089	502,197
1970	596,555	549,920
1969	622,982	567,997
1968	613,343	567,531
1967	587,006	536,166
1966	565,550	512,583
1965	555,368	512,459
1964	503,880	452,324

[1]Estimated. Total shipments were compared to production for 1978 to 1982, and the average ratio (0.9575) applied to production for 1983 and 1984.

Source: Bureau of the Census, U.S. Department of Commerce, Current Industrial Reports: Inorganic Chemicals, May 1984, p. 1; and annuals, 1968-1982, Table 4.

USES FOR PHOSPHORUS CHEMICALS

EXHIBIT 2-2



industry. The detergent market is comprised of household detergent (85 to 90 percent) and industrial detergents (10 to 15 percent). Accounting for 60 percent of elemental phosphorus use 15 years ago, detergent applications declined in the early 1970's because of environmental concern over the effects of phosphates on fresh water bodies in some areas.[1] Controls or bans on the use of phosphates in detergents have been imposed in New York, Indiana, Michigan, Wisconsin, Minnesota, Connecticut, Maine, and miscellaneous localities.[2] These controls resulted in the halving, to about 6 percent, the average phosphate content of detergents.[3]

Metals treating is a second major end use of elemental phosphorus. Valuable in controlling corrosion, phosphorus is used in aluminum polishing and paint bases. Demand for phosphorus in metals treating depends heavily on demand for automobiles and durable goods, the major end users of these products, and thus tends to fluctuate with the business cycle. For example, with a slump in the automobile and other consuming industries between 1979 and 1980, consumption of elemental phosphorus products by these industries fell by 25 to 33 percent. In 1984, this use was the most active in growth, due to the increased demand for durable goods, especially automobiles.[4]

For use by the food and beverage industry, elemental phosphorus is converted to phosphoric acid and other derivatives. Phosphoric acid is used in soft drinks, powdered drinks, baby foods, puddings, baking powder, and dentrifices, for example. Demand for these products, which has grown slowly in the past decade, has been below the industry's forecasts, possibly because of the effect of recession on demand for convenience foods, the decline in sales of cakes and cookies as part of the national trend toward physical fitness, and reformulation of soft drinks. Demand was up, however, in 1983, possibly because of inventory needs of producers of newly introduced noncaffeine and other soft drinks.[5]

---

[1] "Key Chemicals: Phosphorus," Chemical and Engineering News, March 23, 1981, p. 27; and July 30, 1984, p. 19.

[2] SRI, Chemical Economics Handbook, January, 1983.

[3] "Key Chemicals: Phosphorus," Chemical and Engineering News, April 24, 1978, p. 26.

[4] "Key Chemicals," op. cit., July 30, 1984, p. 19; and March 23, 1981, p. 27.

[5] "Key Chemicals," op. cit., March 23, 1981, p. 27; and July 11, 1983, p.11.

Chemical derivatives of phosphorus, other than phosphoric acid, at 10 percent of consumption, are equal to the food and beverage industry in importance to the elemental phosphorus market. Current uses include lubricating oils, insecticides, flame-resistant textile finishes, matches, and pharmaceuticals. In the last half of the 1970's, these uses were considered the market with the highest growth potential. Some companies added capacity during the period to produce pentasulfide, trichloride, and oxychloride phosphorus compounds, which are then used in agricultural chemicals, lubricating oil additives, and many other products. However, growth in these uses has been impeded by the longer life of lubricating oils, and competition from substitute products. Furthermore, though in the early 1980's producers increased investment in R&D, no new significant uses of phosphorus products have been discovered. Growth in non-acid uses has approximated 3 percent per year since the middle 1970's.[1]

The export market is the only other major consumer of U.S. produced elemental phosphorus. Most countries that have a continuing requirement for phosphorus produce it domestically, largely because water transportation requires extensive precautions. However, exports have accounted for some 5 to 7 percent of U.S. elemental phosphorus production since the middle 1970's.[2] In 1982, most of the exports were destined for Japan (45 percent), Brazil (38 percent), and Canada (8 percent).[3] In 1984, exports are expected to equal 20,000 tons, or 5.3 percent of production.[4]

2.2. SUPPLY

Producers

There are four corporations operating a total of six elemental phosphorus plants in the United States today. The largest producer is Monsanto Company (two plants), followed

[1]"Key Chemicals: Phosphorus," Chemical and Engineering News," April 24, 1978, p. 26; and March 23, 1981, p. 27.

[2]"Key Chemicals: Phosphorus," Chemical and Engineering News, July 30, 1984; July 11, 1983; March 23, 1981; April 24, 1979.

[3]William Stowasser, "Phosphate Rock," Minerals Yearbook, Vol. 1, 1982, p. 666. In the past, Mexico has been a major export market, accounting for 40 to 55 percent of the export market since the mid-1970's (7,500 - 13,500 metric tons per year). In 1982, after Mexico installed its own elemental phosphorus production facilities, exports to that country dropped to only 236 metric tons.

[4]"Key Chemicals," op. cit., July 30, 1984, p. 19.

closely by FMC Corporation (one plant), with Stauffer Chemical Company a distant third (two plants), and Occidental Petroleum Corporation fourth (one plant). The corporations, plants, capacity, and plant employment are listed in Exhibit 2-3.

Elemental phosphorus producers are vertically integrated. All producers operate phosphate rock mines in the vicinity of their elemental phosphorus plants. After manufacturing the elemental phosphorus, producers ship it to burning plants, where it is converted to other chemicals for use in consumer and industrial products. These plants, operated by the elemental phosphorus producers, are typically located near the market for the product. The mix of chemicals produced varies, depending on the producer's cost and market structure.

The current production capacity of the industry and each producer was listed in Exhibit 2-3. Total capacity, at about 450,000 tons per year,[1] has been reduced substantially since its peak of 686,000 tons per year in 1969 in response to slack demand and forecasts of little or no growth. Plants in Florida, operational until the early 1980's, have probably been closed permanently because electricity costs, which account for at least 20 percent of total production costs, are especially high in that state. Capacity in other locations has also been declining, with installed capacities reduced to lower operating capacity levels. Overcapacity places financial strain on the industry because of high capital investment in electric furnace plants. At current capacity, the operating rate for the industry is about 83 percent, a more desirable level for the producers.[2] Capacity in the industry for 1964 to 1984, by producer, is shown in Exhibit 2-4.

All elemental phosphorus producers are major corporations, with the smallest corporation, Stauffer, ranked in 1983 as number 213 in Fortune's list of the 500 largest U.S. companies. Elemental phosphorus represents a relatively small portion of the total revenues from corporate production, ranging from an estimated 0.5 percent for Occidental to 10.9 percent for Stauffer (Exhibit 2-5). However, since the phosphorus is an intermediate good which is consumed in other company products, its importance to company operations is more significant than revenues would indicate.

The operating and market characteristics of each producer are described below.

---

[1] Industry estimates.

[2] "Key Chemicals," op. cit., July 30, 1984, p. 19.

EXHIBIT 2-3:

ELEMENTAL PHOSPHORUS PRODUCERS AND ESTIMATED CAPACITY, 1984

Producer	Plant Location	Capacity (Tons per year, 1984)	Employment (1983)
Monsanto	Columbia, TN	75,000	440
	Soda Springs, ID	90,000	397
FMC	Pocatello, ID	125,000	600
Stauffer	Mt. Pleasant, TN	50,000	305
	Silver Bow, MT	40,000	185
Occidental	Columbia, TN	57,000	275
TOTAL		437,000	2,202

Source: Industry information.

EXHIBIT 2-4:

PRODUCTION CAPACITY BY PRODUCER

Producer	Capacity (thousands of tons per year)							
	1964	1966	1969	1972	1975	1978	1981	1984[2]
AAC,[1] Pierce, FL	40	30	22	11	11	20	20	—
FMC, Pocatello, ID	75	100	145	145	145	145	145	125
Occidental, Columbia, TN	69	69	70	45	57	57	57	57
Occidental, Niagara Falls, NY	6	—	—	—	—	—	—	—
Monsanto, Columbia, TN	110	110	135	135	135	120	134	75
Monsanto, Soda Springs, ID	40	80	110	110	110	110	95	90
Stauffer, Mt. Pleasant, TN	80	80	63	55	45	45	45	50
Stauffer, Silver Bow, MT	30	30	42	42	42	37	37	40
Stauffer, Tarpon Springs, FL	13	13	23	25	25	23	23	—
TVA, Wilson Dam, AL	36	36	40	18	36	—	—	—
Mobil, Charleston, SC	8	10	8	—	—	—	—	—
Mobil, Nichols, FL	6	6	4	5	5	8	—	—
Mobil, Mt. Pleasant, TN	—	20	24	—	—	—	—	—
TOTAL	513	584	686	591	610	565	556	437

[1]Producer became Continental Oil, (1966), Agrico (1972), Holmes (1975), Electro-Phos (1978), and Mobil (1981).

[2]Industry estimate. Chemical and Engineering News estimates capacity for 1984 at 450,000 tons (C&EN, op. cit., p. 19).

[3]"—" represents "no production".

Sources: "Chemical Profile: Phosphorus," Chemical Marketing Reporter, 1964-1981 (for 1964 to 1981 data); and industry information (for 1984 estimates).

EXHIBIT 2-5:

REVENUES FROM ELEMENTAL PHOSPHORUS PRODUCTION
AND
TOTAL CORPORATE REVENUES

Producer	Elemental Phosphorus Revenue (in millions)	Total Corporate Revenue (in millions)	Elemental Phosphorus as a Percent of Total Revenue
Monsanto	$ 266.5	$ 6,299.0	4.2%
FMC	$ 201.9	$ 3,572.0	5.7%
Stauffer	$ 145.4	$ 1,339.9	10.9%
Occidental	$ 92.1	$ 19,709.9	0.5%

Source: 1983 annual reports, for total corporate revenue. Stauffer revenues are for the fiscal year ending September 30, 1983. JFA estimates for elemental phosphorus revenues.

Monsanto Company

Monsanto, with a total of 165,000 tons per year of operating capacity in two elemental phosphorus plants, is the largest producer of elemental phosphorus. The Soda Springs, Idaho plant, with three furnaces, was built in the middle and late 1960's and is currently rated at 90,000 tons per year of capacity. The Columbia, Tennessee plant, with six furnaces, was constructed in the 1940's and modernized in the 1960's.[1] Originally rated at 134,000 tons per year, operating capacity has been reduced to 75,000.[2]

Phosphate rock for Monsanto's operations is obtained from 5,320 acres surrounding Columbia, where in 1980 it had an estimated 11 to 20 million tons of ore reserves, and from a mine near Henry, Idaho. When the Henry mine is depleted in 1985 to 1986, the company will likely shift to mines in nearby North Henry, Idaho, then eventually to property in Trail Creek, Idaho. The latter location may be a more expensive source of the rock because of problems in transporting the rock to Soda Springs. All phosphate rock mined by Monsanto is used to produce elemental phosphorus.

Monsanto is the most diversified producer of elemental phosphorus, dominating in most of the nonagricultural markets. The company has been aggressive in developing new markets and upgrading P_4 into high-value specialty products. The company's share of each end use market within the industry, and the share of each end use within the company's line of phosphorus products, are listed below.[3]

Products	Share of Monsanto's Phosphorus Products (1982) (%)	Share of Industry Market[4] (1982) (%)
Acid Uses		
Builders and Water Treatment	50	35
Foods, Beverages, and Toothpaste	14	34
Metals Treating	2	9
Exports, Other	19	35
Non-Acid Uses	15	35
TOTAL	100	29

[1] SRI, Chemical Economics Handbook, January 1983.

[2] "Key Chemicals," op. cit., July 30, 1984, p. 19.

[3] SRI, Chemical Economics Handbook, March 1980.

[4] In 1982, part of the market for elemental phosphorus was held by wet-process acid producers and by Mobil, a furnace acid producer who is not currently in the market. Thus, market shares for the producers discussed here do not sum to 100 percent.

The value of production from Monsanto's elemental phosphorus plants in 1983 is estimated to have amounted to $266.5 million (Exhibit 2-5), or 4.2 percent of total corporate revenues of $6,299.0 million.

FMC Corporation

The second largest producer of elemental phosphorus is FMC Corporation. FMC operates a single plant, with four furnaces and an operating capacity of 125,000 tons per year, in Pocatello, Idaho. Furnaces in the plant are maintained on a rotating schedule in which each furnace is completely refitted or rebuilt every six to eight years.[1]

Phosphate rock for FMC's elemental phosphorus plant is obtained from the low grade shale at the Gay mine, a mine operated jointly by FMC and Simplot. All of FMC's share of the Gay mine's output is used to produce elemental phosphorus. With the Gay mine expected to be depleted in the last half of the 1980's, FMC will probably shift its mining to land it has leased or subleased from Federal and state governments in Caribou County, Idaho. The company is believed to hold all the permits required for this change.[2]

FMC's largest market area for its elemental phosphorus products is in builders and water treatment for detergents, with other market areas small by comparison. Details of FMC's market position are provided below.[3]

Products	Share of FMC's Phosphorus Products (1982) (%)	Share of Industry Market (1982) (%)
Acid Uses		
Builders and Water Treatment	62	38
Foods, Beverages, and Toothpaste	8	16
Metals Treating	4	14
Exports, Other	20	29
Non-Acid Uses	6	12
TOTAL	100	28

[1] SRI, op. cit., January 1983.

[2] SRI, op. cit., March 1980.

[3] SRI, op. cit., January 1983.

In 1983, the value of elemental phosphorus production for FMC was approximately $201.9 million, or 5.7 percent of total corporate revenues of $3,572.0 million (Exhibit 2-5).

Stauffer Chemical Company

The third largest producer of elemental phosphorus is Stauffer Chemical Company, with two plants and annual capacity of 90,000 tons. Stauffer's Mt. Pleasant, Tennessee plant has three furnaces and capacity of 50,000 tons per year. The Silver Bow, Montana plant has two furnaces and capacity of 40,000 tons per year.

The source of phosphate rock for Stauffer's Tennessee plant is the company's Globe mine in Mt. Pleasant, which is operated at about 0.4 to 0.5 million metric tons per year of ore and in 1980 had 3.5 to 4.0 million metric tons of reserves. The sources of rock for the Montana plant are mines in Wooley Valley, Idaho; Wyoming; and Utah. The first is the primary source, with 45 million metric tons of reserves in 1980. All rock mined by Stauffer in Tennessee is used to produce elemental phosphorus. A portion of the rock mined in the western states is sold to other users, possibly phosphate producers in Canada.[1]

Stauffer is considered the second most diverse producer of elemental phosphorus. In the early 1970's when environmental concerns were mounting, Stauffer turned its focus away from the laundry detergent market to produce phosphorus compounds for end-use areas that at the time were more highly valued. One such product is chlorinated trisodium phosphate, a cleanser and bacteriocide used in dishwashing compounds and metal cleaners. The company is expected to continue its focus on these areas, plus food uses and miscellaneous phosphorus chemicals. The market position of Stauffer in each end-use area is indicated below.[2]

---

[1] SRI, op. cit., March 1980.

[2] SRI, op. cit., January 1983.

Products	Share of Stauffer's Phosphorus Products (1982) (%)	Share of Industry Market (1982) (%)
Acid Uses		
Builders and Water Treatment	neg.	neg.
Foods, Beverages, and Toothpaste	35	50
Metals Treating	3	8
Exports, Other	31	25
Non-Acid Uses	31	29
TOTAL	100	16

In 1983, the value of production from Stauffer's elemental phosphorus plants was estimated to equal $145.4 million. This represents 10.9 percent of Stauffer's total revenues of $1,339.9 million (Exhibit 2-5).

Occidental Petroleum Corporation

The smallest producer of elemental phosphorus is Occidental Petroleum, with one three-furnace plant in Columbia, Tennessee. The annual capacity of the plant is 57,000 tons.

Phosphate rock for the Occidental plant is obtained from a local mine where the company owns 2,300 acres of reserves. In 1980, the reserves were estimated at 8 to 10 million metric tons, about 12 to 14 years of remaining life.[1]

Occidental's market has been dominated by builder phosphates manufactured at facilities in Texas and Indiana. Little change is expected in the next few years, though some decline in the company's position in phosphorus pentasulfide (P_2S_5) products may occur due to the entry of FMC into this market. The position of Occidental in each end-use market is detailed below.[2]

[1] SRI, op. cit., March 1980.

[2] SRI, op. cit., January 1983.

Products	Share of Occidental's Phosphorus Products (1982) (%)	Share of Industry Market (1982) (%)
Acid Uses		
Builders and Water Treatment	60	15
Foods, Beverages, and Toothpaste	neg.	neg
Metals Treating	5	8
Exports, Other	23	14
Non-Acid Uses	12	10
TOTAL	100	14

In 1983, elemental phosphorus is estimated to have contributed $92.1 million to Occidental's total corporate revenues of $19,709.9 million, or 0.5 percent (Exhibit 2.5). The company is known to have attempted to sell its industrial phosphate operations and may continue to seek a buyer.[1]

2.3. COMPETITIVE PRODUCTS AND PROCESSES

Demand for elemental phosphorus has been substantially affected by bans on their use and the availability of alternative products and processes. The prices of substitutes compared to phosphoric acid and elemental phosphorus derivatives are a critical factor.[2]

Consumption in detergents, the major end use of elemental phosphorus, has been particularly affected by the availability of substitutes. With the controls or bans on phosphates in some states imposed in the 1970's, and threat of regulation by others, detergent manufacturers have reformulated their products, replacing phosphorus with carbonates, silicates, citrates, zeolites, and NTA. Sodium carbonate (soda ash) is used in markets that have completely banned phosphorus. Though cost-effective, sodium carbonate is less effective in cleaning than sodium tripolyphosphate (STPP), sometimes leaving residues on fabrics and being less thorough as a soil deflocculant. (FMC and Stauffer are among the producing firms). Citrates are another cost-effective alternative. With their high solubility characteristics, citrates have become the major builder used in heavy-duty liquid laundry detergents. However, citrates may cake when prepared in powders and thus are not attractive substitutes in powder formulations.

[1] SRI, op. cit., January 1983.

[2] "Key Chemicals: Phosphorus," Chemical and Engineering News, 1980.

A third product competing with STPP for use in detergents is zeolites, sodium aluminosilicates that soften water by ion exchange. Alone, zeolites are not as effective as STPP in cleaning, but are often combined with it to produce a builder system with lower phosphate content. Since 1978, zeolites have become commercially significant. The fourth challenge to STPP in detergents is NTA, nitrilotriacetic acid. In 1970, use of NTA as a builder was voluntarily suspended in response to an unpublished government report suggesting the compound was teratogenic. In 1980, EPA issued a statement that NTA posed no threat to human health. NTA is now considered among the most attractive alternatives to STPP.

Another source of competition for the elemental phosphorus industry is the phosphoric acid produced through wet-process methods. Wet-process acid has historically been less pure than acid produced from elemental phosphorus (called furnace-method acid). When furnace acid costs and prices were low, it was not economical for wet-process acid producers to purify their product to compete with the furnace acid. However, the increasingly high costs and prices of furnace-method acid have opened some traditionally furnace acid markets to wet-process acid manufacturers who can now produce comparably pure acids at a competitive price. For example, Olin Corporation, a wet acid producer, now has a seven percent share of the market for phosphorus in detergents.

2.4. ECONOMIC AND FINANCIAL CHARACTERISTICS

The major economic and social factors affecting demand for phosphorus derivatives are population growth, GNP growth, and to a lesser extent, demand for certain durable goods.

The largest end use for elemental phosphorus, detergents, has historically grown about 1 percent per year, approximately equal to population growth. With the controls on phosphates imposed in some states and subsequent reformulation of detergents, this use declined in the 1970's. By 1981, demand appeared to have restabilized at a 1 percent per year growth rate.[1]

---

[1] "Key Chemicals," op. cit., March 23, 1981, p. 27.

Demand for phosphorus in food and beverages has reached maturity and closely follows changes in GNP. Oil additives uses have historically grown at GNP rates or less. Uses in metal treating are more cyclical, fluctuating with demand for durable goods, especially automobiles.[1]

Prices

Most elemental phosphorus is shipped by the producer to another of its own plants for use as an input to other products. The meaning of the price data available for elemental phosphorus is thus somewhat ambiguous. However, since at least a small portion is sold outside of the companies, comparison of the changes in the phosphorus prices listed in industry publications may indicate changes in supply and demand relationships.

The 1984 price for elemental phosphorus is $0.90 to $1.00 per pound, approximately equal to the 1983 price. In constant dollars, the 1984 price is marginally lower than the 1983 price, but higher than any other year since 1977.[2] Given the highly competitive market for elemental phosphorus, prices do not vary much among the producers.[3] Prices in constant 1972 dollars for 1977 to 1984 are shown in Exhibit 2-6.

Employment

In 1983, approximately 2200 persons were employed directly by the elemental phosphorus industry. Employment in each state is listed below.[4] Estimated employment in each plant was listed in Exhibit 2-3.

State	Number of Employees
Idaho	1,000
Tennessee	1,000
Montana	200

Direct employment in the elemental phosphorus industry represents only a part of the employment that could be affected by a change in demand for elemental phosphorus.

[1] "Key Chemicals," op. cit., April 24, 1978, p. 26; and July 30, 1984, p. 19.

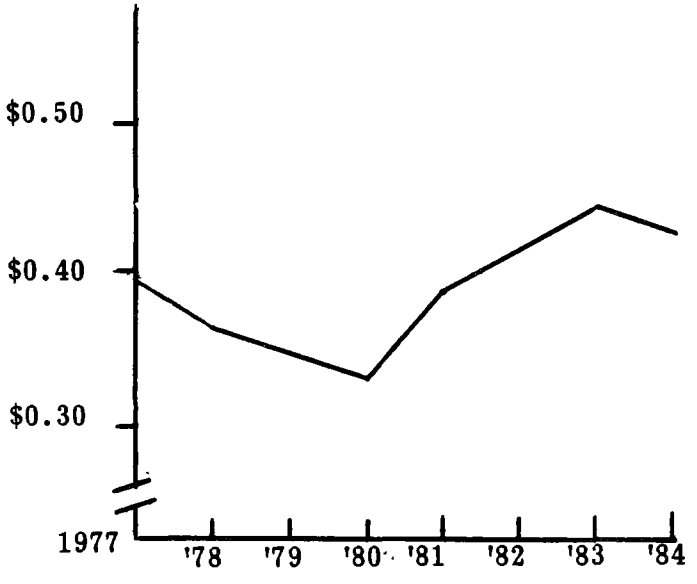
[2] Ibid., p. 19.

[3] Industry information.

[4] Industry information.

EXHIBIT 2-6:

PRICE PER POUND: 1977 TO 1984
(constant 1972 dollars)



Source: "Key Chemicals: Phosphorus," Chemical and Engineering News; and Council of Economic Advisers, "Economic Indicators," July 1984, p. 2.

Others potentially affected would include phosphate rock miners and workers in other phosphorus chemical manufacturing facilities.

2.5 OUTLOOK

Current forecasts for the elemental phosphorus industry indicate low growth and low prospects for industry expansion. Major factors leading to the forecast are increasing costs of production, competition from substitutes, consumer and social trends, and lack of new uses for elemental phosphorus and its derivatives.

Costs of elemental phosphorus in recent years have been determined largely by electricity costs, which have been increasing steadily and are expected to continue to increase. The increased cost of phosphorus and its derivatives has made substitutes more attractive. Substitutes in detergents, such as zeolites, NTA, and wet-process phosphoric acid, are attractive both economically and because of environmental concerns and, in the case of zeolites and NTA, restrictions on phosphate use. Other uses of elemental phosphorus are deterred by substitutes and/or social factors. Phosphate-containing insecticides, a small market for the industry which had been growing at about 10 percent per year, face competition from non-phosphate insecticides. Uses in lubricating oils are increasing, but the lubricating oils are also lasting longer, offsetting the gains. Detergent uses resumed a slight upward trend in 1981-1984, but are still threatened by growth in consumer use of liquid detergents, trends toward lower washing temperatures, and use of zeolite builders in place of phosphates in formulas. Bans on phosphates have been imposed, removed, and re-imposed in some states. Additional states may join New York, Indiana, Michigan, Wisconsin, Minnesota, Connecticut, and Maine in banning or controlling phosphates. On the brighter side for detergent uses are the continued consumer demand for the new concentrated detergent powders, which have high concentrations of phosphates, and demand for phosphates in industrial detergents, which has been growing in the 1980's at 3 percent per year or greater. Industrial detergents account for 10 to 15 percent of the total detergent market for phosphorus, or 4 to 7 percent of total phosphorus demand.[1]

---

[1]"Key Chemicals," op. cit., July 30, 1984, p. 19; March 23, 1981, p. 27.

CHAPTER 3:

CURRENT EMISSIONS, RISK LEVELS, AND FEASIBLE CONTROL METHODS

3.0 INTRODUCTION

Radionuclides are listed as a hazardous pollutant under Section 112 of the Clean Air Act. The U.S. Environmental Protection Agency (EPA) is in the process of developing national emission of standards for hazardous air pollutants (NESHAPS) for the emission of radionuclides. The standards must limit emissions to values that will protect public health with an adequate margin of safety. This analysis examines alternative standards for emissions of radionuclides from calcining operations in the manufacture of elemental phosphorus.

Radionuclides of the uranium series, including polonium 210 (Po-210), lead 210 (Pb-210), and uranium 238 (U-238), occur naturally in phosphate rock. The exhaust gases from phosphate rock nodulizing calciners at elemental phosphorus plants are considerably enriched with radionuclides because the Po-210 and Pb-210 volatilize at the elevated temperatures in the calciner. As the exhaust gases cool, the radionuclides condense on the surface of mineral particulate matter or condense to form new particles. In the absence of adequate particulate controls, these emissions are vented to stacks for release to the atmosphere. The EPA conducted emission tests at several elemental phosphorus plants to characterize and quantify uncontrolled particulate and radionuclide emissions from the calciners and controlled emissions from the existing control systems. Estimated levels of emissions from the six elemental phosphorus plants in the U.S. range from 0.1 to 21 Ci/year of Po-210 and .05 to 5 Ci/year of Pb-210 with current controls. These emissions increase the risk of radiation-induced cancer for individuals living near these plants.

Emissions of particulate matter and condensed radionuclides from these plants can be reduced by the application of modern particulate control technology. Presently, low pressure drop scrubbers are being used to reduce emissions of particulate matter from the nodulizing calciners. Emission control efficiencies for these low-pressure-drop scrubbers are relatively low compared to those for high-pressure-drop scrubbers, wet electrostatic precipitators (ESP's), or fabric filters (baghouses). These more efficient devices could potentially be used to control particulate and condensed radionuclide emissions from calciners at elemental phosphorus plants.

3.1 CURRENT EMISSIONS AND ESTIMATED RISK LEVELS

The EPA conducted emission sampling at four of the six domestic elemental phosphorus plants. The results of this sampling are presented in Exhibit 3-1. Estimated emission rates for the unsampled Tennessee plants operated by Stauffer and Occidental are also shown. Estimated Po-210 emission rates for the two Idaho plants, FMC and Monsanto, are more than a factor of ten greater than those for the remaining four plants in Tennessee and Montana.

Emission rates per unit output would be expected to be the lowest in Tennessee, due to the lower uranium content of Tennessee phosphate rock as compared with rocks mined in Montana or Idaho. Exhibit 3-2 shows emissions per million tons of elemental phosphorus for the three radionuclides. The Idaho and Montana plants show higher Po-210 emissions per unit output than the Tennessee plants.

Examination of Exhibits 3-1 and 3-2 demonstrates that there is a wide range of variation in the efficiency of current particulate control methods at the elemental phosphorus plants. The estimated health impacts, primarily lung cancers due to inhalation of the Po-210, also vary widely across plants due to the range of population density near the plants. These health effects were estimated using EPA's AIRDOSE model for estimating exposures to individuals and RADRISK computer code to estimate the health impacts of these exposures. The results of this analysis are presented in Exhibit 3-3, which shows the expected fatal cancers per year in the population within an 80 km (50 mile) radius of the plants due to the measured or estimated emissions given in Exhibit 3-1. The exhibit also shows the estimated lifetime risk to nearby individuals, which is the probability of a fatal cancer during the lifetime of an individual residing at a distance of 1500 meters (1 mile) from the plant.

Although the regional population densities are higher near the Tennessee plants than for the western plants, the regional population risk is highest near the Idaho plants operated by FMC and Monsanto. Out of the total regional population risk of 0.058 fatal cancers/year, the Idaho sites account for 0.045 fatal cancers/year, or approximately 80 percent. The risk to nearby individuals is higher by a factor of 5 at FMC than the plants outside of Idaho, and Monsanto's Soda Springs plant has an individual risk twice that of the FMC plant. It should be noted that the estimated risks shown in Exhibit 3-3 have a large degree of uncertainty. It is clear, however, that the Po-210 emissions of

EXHIBIT 3-1:

EMISSION RATES FROM ELEMENTAL PHOSPHORUS PLANTS

Location/Plant	Emission Rate (Ci/yr)		
	U-238	Pb-210	Po-210
Idaho			
FMC, Pocatello[a]	4 E-3	0.1	9
Monsanto, Soda Springs[a]	6 E-3	5	21
Tennessee			
Monsanto, Columbia[a]	2 E-3	0.4	0.6
Occidental, Columbia[b]	2 E-4	0.05	0.1
Stauffer, Mt. Pleasant[b]	2 E-4	0.05	0.1
Montana			
Stauffer, Silver Bow[a]	6 E-4	0.1	0.7
TOTAL	3.5E-2	5.7	31.5

(a) - measured emission rates

(b) - estimated emission rates

EXHIBIT 3-2:

EMISSION RATES PER UNIT OF ELEMENTAL PHOSPHORUS

Location/Plant	Emission Rate ($Ci/10^6$ ton)		
	U-238	Pb-210	Po-210
Idaho			
FMC[a]	.038	0.9	85
Monsanto[a]	.078	65	275
Tennessee			
Monsanto[a]	.031	6.3	9.4
Occidental[b]	.004	1.0	2.1
Stauffer[b]	.005	1.2	2.4
Montana			
Stauffer[a]	.018	2.9	21
Production Weighted Average	.035	15	85

(a) - based on measured emission rates.

(b) - based on estimated emission rates.

EXHIBIT 3-3

ESTIMATED RISKS DUE TO RADIONUCLIDE EMISSIONS FROM ELEMENTAL PHOSPHORUS PLANTS

Location/Plant	Risks to Nearby Individuals (lifetime probability of fatal cancer)	Regional Population Risks (within 80 km) (fatal cancers/yr.)
Idaho		
FMC[a]	5 E-4	.027
Monsanto[a]	1 E-3	.018
Tennessee		
Monsanto[a]	6 E-5	.007
Occidental[b]	9 E-6	.002
Stauffer[b]	1 E-5	.001
Montana		
Stauffer[a]	1 E-4	.003
TOTAL	—	.058

(a) - based on measured emission rates.

(b) - based on estimated emission rates.

the Idaho plants are much higher than those for other plants. Adjusting for population density reduces the ratio of the risks for Idaho as compared to the remaining plants from a factor of 10 for emissions to a factor of 3 for regional population risk. The operations and current control methods of the two Idaho plants are examined in detail in the next section.

3.2 CONTROL TECHNOLOGIES FOR ELEMENTAL PHOSPHORUS PLANTS

Methods of reducing radionuclide emissions through the application of more efficient particulate control technologies at FMC's Pocatello plant and Monsanto's Soda Springs plant, and the costs of these methods, were studied by the Midwest Research Institute (MRI).[1] The results of this analysis are summarized in this section. The study determined the costs and the polonium 210 emission reductions achievable for a sample of seven control technology options: venturi scrubbers at three pressure drops, wet electrostatic precipitators (ESP's) with three specific collection areas (SCA's), and a pulse-jet fabric filter (baghouse). The cost and performance of the seven control technologies were based on adding new controls to the existing low-energy scrubber systems.

The FMC Corporation's Phosphorus Chemicals Division facility at Pocatello, Idaho, produces elemental phosphorus from phosphate ore. Phosphate rock is crushed, screened, and briquetted before being fed into a moving grate calciner. The phosphate rock is heated in the calciner to approximately 1315°C (2400°F) to remove organic material and to heat-harden the briquettes (nodules) so that they will withstand further processing without disintegrating. The nodules are cooled and passed through a proportioning building where they are blended with sized coke and silica into a material called the "burden," which is fed into a reducing furnace.

FMC operates two similar calciners. The exhaust gases from each calciner enter manifolds which split the exhaust into two parallel streams. The two parallel

[1] "Analysis of Achievable Po-210 Emission Reductions and Associated Costs for FMC's Pocatello, Idaho, Plant" and "Analysis of Achievable Po-210 Emission Reductions and Associated Costs for Monsanto's Elemental Phosphorus Plant at Soda Spring, Idaho." Prepared by Midwest Research Institute for the Office of Radiation Programs, EPA, under Contract No. 68-02-3817, August 1984.

exhaust streams from each calciner pass through a fan, slinger scrubber/fluoride absorber (a spray/quench chamber, a horizontal scrubber, and a mist eliminator/spray chamber), a second fan, and out the stack.

At the second Idaho plant, the Monsanto Industrial Chemical plant at Soda Springs, Idaho, the process involves feeding the ore to a rotary kiln calciner to form heat-hardened nodules, reducing the nodules in one of three electric furnaces, and collecting the elemental phosphorus from the furnace off-gases. The ore feed rate, fuel input rate, induced draft fan volumetric flow rate, and kiln speed are controlled so that the finely divided ore feed forms into the larger, stable agglomerates (nodules) needed for proper operation of the electric furnaces. The hot nodules pass through a cooler and crusher before being conveyed to storage.

Exhaust gases from the kiln pass through an emission control system prior to entering the atmosphere. The initial emission control device is a settling chamber where large particles from the kiln off-gas are collected. In normal operation, a damper in the settling chamber directs the exhaust gases to a waste heat boiler. The waste heat boiler and settling chamber both serve as particulate matter collectors. The collected particulate matter (settling chamber dust) is recycled to the kiln.

After exiting the settling chamber, the exhaust gases go to a concrete spray tower, where the gases pass through a water spray to remove soluble gases and particulate matter. After exiting the spray tower and passing through the induced draft fan, the exhaust gases enter a redwood demister assembly prior to entering the atmosphere. The exhaust gases enter the demister tangentially to impart a cyclonic action that removes the entrained moisture in the flue gas. The entrained water removed in the demister drains back into the spray tower.

The liquid effluent from the spray tower is collected in a clarifier, where lime is added for pH control. The solids from the clarifier are dried and collected and eventually are recycled into the process by blending with the feedstock.

In the MRI study, seven higher efficiency control technologies were selected for cost and performance analyses. Venturi scrubbers at pressure drops of 3.7, 7.5, and 11.2 kilopascals (kPa) (15, 30, and 45 inches water column), electrostatic precipitators with specific collection areas of 200, 300, and 400 ft^2/1,000 cubic feet per minute of

airflow, and one pulse jet baghouse with an air-to-cloth ratio of four to one were selected as representative of state-of-the-art, higher efficiency control devices. The sample scrubber sizes selected for cost analysis span the mid-range of feasible scrubber control units. Pressure drops ranging from 4 to over 75 inches water column pressure are considered feasible for Venturi scrubbers. Similarly the ESP's sampled for cost analysis span the mid-range of feasible wet precipitator controls. Wet ESP's ranging from 100 to 600 SCA are technologically feasible. Fabric filters down to a 2 to 1 air-to-cloth ratio are considered feasible. Hence the scales of technology selected for detailed cost analysis are not meant to give the feasible range of sizes for the available control technologies, but rather these scales are all representative of the mid-range of feasible sizes for each type of control. Cost estimates presented in the benefit-cost analysis of the following chapter are based on interpolations and extrapolations of the costs of sampled scales of each technology where necessary.

The capital and annualized costs for each of the three types of control technologies considered were determined following the guidelines established in Capital and Operating Costs of Selected Air Pollution Control Systems (GARD Manual).[1] This manual was prepared for the EPA to provide technical assistance to regulatory agencies in estimating the cost of air pollution control systems. The costs in the GARD Manual are based on December 1977 dollars. The costs were adjusted to January 1984 dollars using indices provided in Chemical Engineering and by the Bureau of Labor statistics.[2,3]

The costs were calculated assuming that each of the higher efficiency control alternatives were added-on to control the exhaust from the existing scrubber control systems. The existing system removes most of the large particles, quenches and cools the exhaust gas stream (thus, reducing gas volume and ensuring condensation of gaseous radionuclide emissions), and properly conditions the stream for treatment by the ESP options. Assuming that the existing system is retained substantially reduces the costs associated with each control technology. The annualized costs for each control system include the total utility costs, the total operating labor costs, the total maintenance costs, the total overhead costs, the capital charges, and the total waste disposal costs. The annualized costs were based on 7,400 hours per year of operation.

---

[1] GARD, Inc., Capital and Operating Costs of Selected Air Pollution Control Systems. U.S. Environmental Protection Agency. Research Triangle Park, North Carolina. Publication No. EPA-45/5-80-002.

[2] MRI, "Monsanto," op. cit., p. 4-1.

[3] U.S. Department of Labor, Bureau of Labor Statistics, Producer Prices and Price Indexes, Data for February 1984. Washington, D.C., April 1984.

The capital costs for each control technology include the direct and indirect costs to purchase and install the necessary ductwork, control devices, fan systems, and stack. Direct capital costs include instruments, controls, taxes, freight, foundations, supports, erection and handling, electrical work, piping, insulation, painting, and site preparation. Indirect capital costs include the engineering and supervision, construction and field expenses, construction fee, start-up performance test, and contingencies. The fan costs are based on a facility altitude of 1,220 m (4,000 ft) above sea level. All stack heights are assumed to be 30 m for the add-on equipment.

The quantity of sludge or dry waste collected by the add-on control devices was determined based on the efficiency of particulate removal. The cost to dispose of the waste in a secured landfill was assumed to be $23.50/ton (1984 dollars). The waste is considered to be hazardous for these calculations because of the concentration of radioactive material in the sludge. For comparison, it should be note that the cost of disposal of nonhazardous wastes is approximately $5/ton.

The efficiency of removal of Po-210 emissions from the exhaust gas stream from the current control devices was also estimated by MRI for each add-on technology. This estimation is based on the percent efficiency of each control technology, by particle size, as applied to the measured particle size distribution of emissions from the FMC plant. The estimated costs and efficiencies of Po-210 removal are shown in Exhibit 3-4.

Of the three types of control technologies, scrubbers have the lowest estimated capital cost and the highest operating costs. Capital costs for precipitators and fabric filters are approximately twice those for scrubbers, while operating costs are greatly reduced. The annualized capital costs in the exhibit were calculated assuming that the private discount rate is 10% and that the useful life of the control system is 20 years. A four percent annual surcharge based on purchase value was added for administrative costs (2 percent), property tax (1 percent), and insurance (1 percent). Alternative assumptions for annualizing the capital costs are considered in the sensitivity analysis of section 4.5.

Total annualized costs for the scrubbers selected for analysis range from $1.6 to $3.5 million for FMC and from $0.9 to $2.0 million for Monsanto, depending on the scale of the equipment. Wet electrostatic precipitator annualized costs range from $1.4 to $1.7 million for FMC and from $0.8 to $1.1 million for Monsanto. The fabric filter technology has costs which are slightly higher than precipitators, but lower than the

EXHIBIT 3-4:

AVAILABLE CONTROL TECHNOLOGIES (Selected Examples)

Technology Type	Scale	Efficiency of Po-210 Removal (%)	Capital Cost Total (mil $)		Capital Cost Annualized[a] (mil $/yr)		Operating Costs (mil $/yr)		Total[c] Annualized Cost (mil $/yr)	
			FMC	Monsanto	FMC	Monsanto	FMC	Monsanto	FMC	Monsanto
Scrubbers	15" p	65	2.1	1.1	.32	.17	1.3	.7	1.6	.9
	30" p	77	2.8	1.5	.43	.23	2.1	1.2	2.5	1.4
	45" p	83	3.7	2.0	.59	.31	3.0	1.6	3.5	2.0
Electrostatic	200 SCA	72	5.2	2.9	.82	.45	.6	.3	1.4	.8
Precipitators	300 SCA	83	5.9	3.2	.93	.50	.6	.4	1.5	.9
	400 SCA	90	6.7	4.3	1.05	.68	.7	.4	1.7	1.1
Fabric Filters	(b)	98	7.3	4.2	1.15	.65	.7	.6	1.9	1.3

(a) - Assumes a 10 percent real social rate of time preference over 20 year useful life. All direct resource costs are expressed in constant 1984 dollars. Also includes a charge of four percent of original purchase value for administrative costs (2 percent), property tax (1 percent), and insurance (1 percent).

(b) - Only one scale evaluated; assumes a pulse-jet cleaning mechanism and 4-to-1 air-to-cloth ratio.

(c) - Totals for FMC and Monsanto combined are inappropriate; proposed alternative standard imply different technologies for each plant under most alternatives.

costs of high energy scrubbers. Annualized costs for fabric filters at FMC are $1.9 million, and $1.3 million at Monsanto.

The efficiency of Po-210 removal varies from 65 to 98 percent for the selected examples. The 300 SCA precipitators have the same efficiency as the 45 inch pressure-drop scrubbers, with 40 percent lower annualized costs. Hence, high-pressure -drop scrubbers do not appear to be a cost-effective method of control. This issue is discussed in detail in the following chapter. As noted above, larger precipitators than the examples selected for cost analysis are also feasible up to the 500-600 SCA range. However, for efficiencies greater than approximately 95 percent, fabric filters appear to be more cost-effective.

CHAPTER 4

BENEFIT-COST ANALYSIS

4.0 INTRODUCTION

This chapter examines the benefits and costs of alternative polonium 210 (Po-210) standards for emissions from elemental phosphorus plants. Current emission levels of this isotope indicate that for the range of alternatives under consideration only FMC's Pocatello plant and Monsanto's Soda Springs plant would incur additional particulate control costs. The remaining four plants of the six discussed in the previous chapters have current emissions below the most stringent annual standard under consideration. If the geographical source of the supply of phosphate rock, or the level of output of any of these four plants, changes dramatically, these plants may also incur additional particulate control costs in the future. This eventuality has not been considered in this analysis. Costs and benefits are examined only for the Idaho plants.

The analysis of the costs and cost-effectiveness of controlling Po-210 emissions at the two affected plants is based on the results of cost studies[1] performed by Midwest Research Institute (MRI), under contract to the EPA. These studies provide estimates of the expected capital and operating costs at each plant for seven alternative particulate control technologies. The efficiency of Po-210 removal was also estimated for each technology. These estimates indicate that both affected plants can achieve compliance with all alternative standards by using the currently available particulate control technologies described in the previous chapter.

The analysis presented below indicates that estimated control costs per unit of elemental phosphorus are not significantly different at the two plants, although the least-cost choice of control technology differs for the two plants. The only exception is the 10 Ci/year standard alternative which would necessitate controls only at the Monsanto plant. For all alternatives considered, least-cost control methods are estimated to have a real-resource cost of less than $25 per ton of elemental phosphorus, which currently sells for approximately $1900 per ton. Private costs to the manu-

[1] "Analysis of Achievable Po-210 Emission Reductions and Associated Costs for FMC's Pocatello, Idaho, Plant" and "Analysis of Achievable Po-210 Emission Reductions and Associated Costs for Monsanto's Elemental Phosphorus Plant at Soda Springs, Idaho." Prepared by Midwest Research Institute for the Office of Radiation Programs, EPA, under Contract No. 68-02-3817.

facturers are estimated to be somewhat smaller, due to current tax provisions, which allow deductions and tax credits for investments. The impact of these private costs on the financial and market positions of the affected firms is discussed in the following chapter.

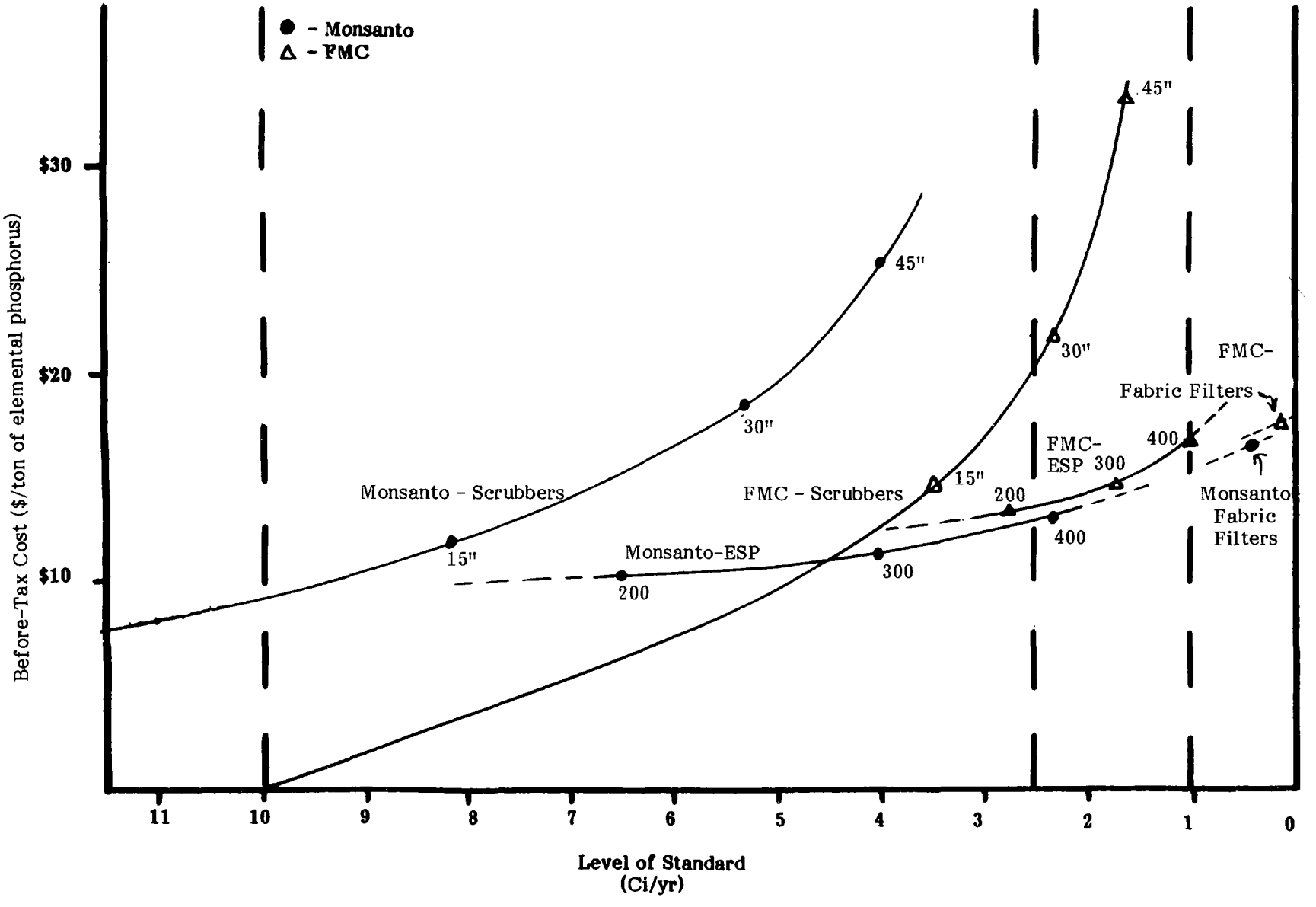
The health benefits of reducing Po-210 emissions from the two affected plants were estimated using the AIRDOS model to determine individual exposures at current levels of emissions and the RADRISK computer code to determine the expected fatal cancers which may result from the estimated cumulative exposure. The health benefits resulting from alternative standards were defined to be the avoided fatal cancers per year within an 80 km radius of each plant. While no attempt is made to place a monetary value on the individual lives saved by controlling emissions at these plants, the estimated real-resource costs range from $70 to $80 million per statistical death avoided. Also, no attempt has been made to quantify other monetary benefits associated with reduced particulate emissions from the plants or avoided morbidity costs. These monetary benefits are estimated to be small, and including them in the analysis would reduce only slightly the cost per statistical death avoided.

4.1: LEAST-COST CONTROL TECHNOLOGIES FOR AFFECTED PLANTS

The control technologies described in the previous chapter lead to unique cost-effective choices of technology for each plant under each alternative standard. The efficiency of polonium-210 control is, by assumption, the same for a given control technology applied to either plant. However, the plants have markedly different levels of emissions from the low-pressure-drop scrubber control units currently in place. This leads to the selection of different cost-effective technologies at each plant under some of the alternative standards. The least-cost choice of particulate control technology for each plant may be determined by examination of Exhibit 4-1. The exhibit shows the levelized control cost per unit output (expressed in dollars per ton of elemental phosphorus) for each plant and for each type of control technology, as functions of the statutory level of the standard. The relative efficiencies of Po-210 removal given in Exhibit 3-4 were applied to current emission levels to calculate expected emissions for each technology option. (A "safety margin" was applied which required expected emissions to be 10 percent greater than engineering estimates at each level of the standard in the graphs in Exhibit 4-1. In the final section of this chapter, a sensitivity analysis is presented which shows results for a larger, 25 percent, safety margin.)

EXHIBIT 4-1:

COST PER TON FOR SELECTED CONTROL TECHNOLOGIES



The shape of the control cost curves for Venturi scrubbers, electrostatic precipitators, and fabric filters applied to each plant are quite similar when expressed in cost per ton of phosphorus. The horizontal difference between the curves is accounted for by the fact that the current Po-210 emissions are 21 Ci/year for Monsanto, and 9 Ci/year for FMC.

Exhibit 4-2 shows the control cost per ton for the least-cost methods of control for each plant, as a function of the level of the standard. The exhibit also shows the weighted average control cost per ton for these two affected plants which constitute approximately one-half of the production of the industry. For this set of assumptions, control costs using the least-cost control methods remain below $17 per ton of phosphorus for all alternative standards.

Different levels of the standard affect FMC and Monsanto quite differently. At 10 Ci/year, FMC has a 10 percent safety margin given current emission levels and may choose not to adopt new controls. Monsanto, however, is forced to adopt a scaled-down version of the 15 inch pressure drop system shown in Exhibit 3-4 at a cost of $10 per ton. For standards below 10 Ci/year, electrostatic precipitators become the least-cost control option for Monsanto, while FMC may choose to remain with less than 15 inch pressure drop scrubbers down to a level of 4 Ci/year. Below 4 Ci/year, the wet electrostatic precipitator technology is cost-effective for both plants, although Monsanto must adopt a higher scale version than FMC. For a 2.5 Ci/year standard, the control costs per unit are roughly equal for both plants, approximately $14 per ton. At this standard Monsanto may adopt a 400 SCA precipitator while FMC may adopt a 250 SCA precipitator. At a 1.0 Ci/year standard, Monsanto must rely on very high energy precipitators (500 SCA or more) or choose to adopt fabric filters which have roughly the same cost-effectiveness as the precipitators. At this level FMC may choose a 400 SCA or higher precipitator or move to fabric filters which appear to be slightly more cost-effective and offer the security of a greater safety margin.

The above discussion of the graphs in Exhibits 4-1 and 4-2 is summarized in Exhibit 4-3, which presents the control technology choices and estimated capital costs for each plant under each alternative standard. Annualized unit control costs before taxes are also shown. In this table annualized capital costs were based on the assumption of a 20-year useful life and a <u>real</u> discount rate of 10 percent. The annualized capital

EXHIBIT 4-2:

LEAST-COST CONTROL STRATEGIES

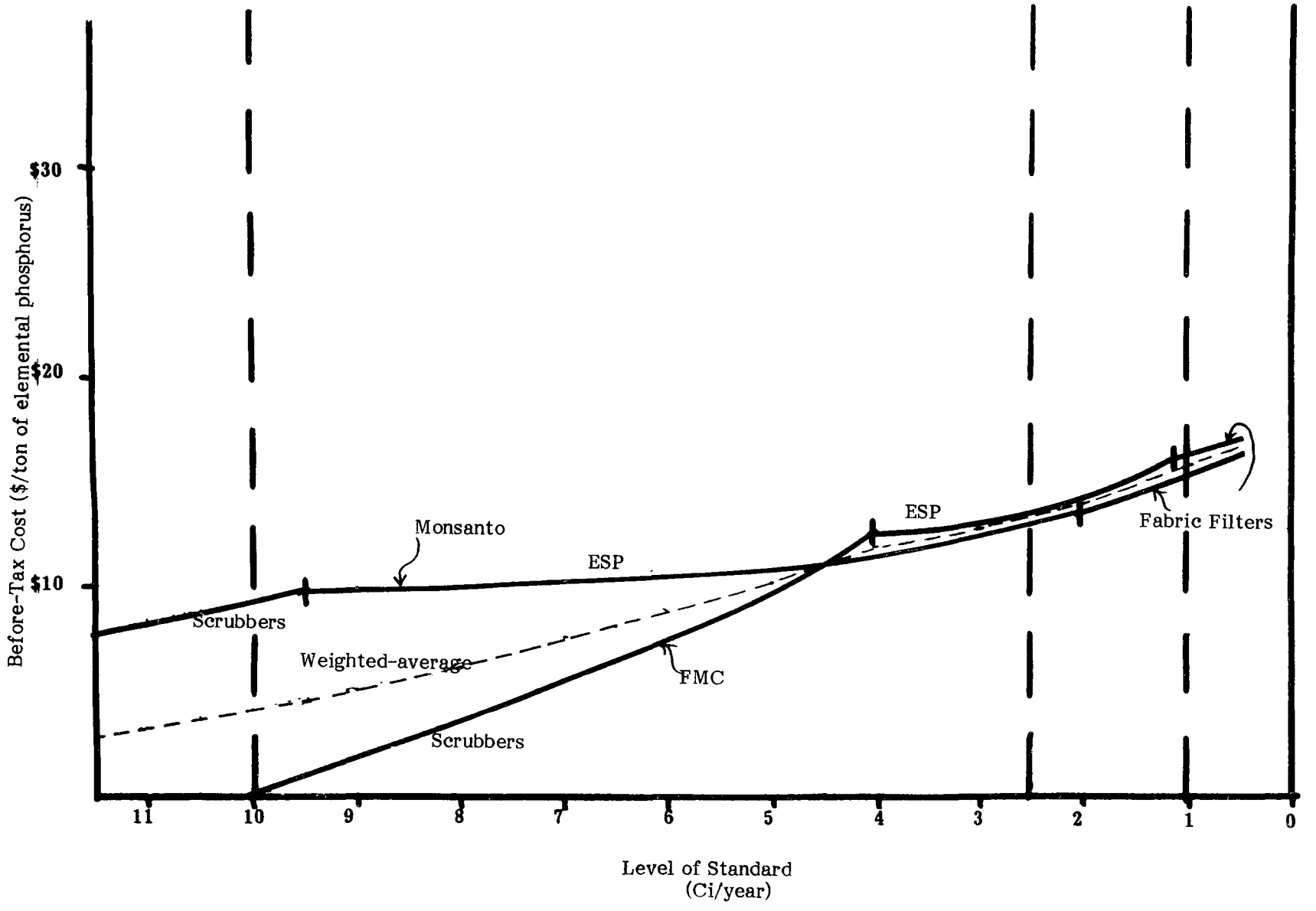


EXHIBIT 4-3:

LEAST-COST CONTROL TECHNOLOGIES BY PLANT FOR SELECTED STANDARD OPTIONS

Alternative Standard (Ci/year)	Least-Cost Technology		Capital Costs (before taxes) (mil $)			Levelized Unit Control Cost[a] (before taxes) ($/ton)		Levelized Unit Control Costs[a] (after taxes)[b] ($/ton)	
	FMC	Monsanto	FMC	Monsanto	Total	FMC	Monsanto	FMC	Monsanto
10	None	10 to 15 inch ΔP Scrubber	0	0.8	0.8	0	9.2	0	8.3
2½	250 SCA precipitators	400 SCA precipitators	5.2	4.3	9.5	13.6	13.2	10.7	11.2
1	400 SCA precipitators	Fabric Filter	6.7	3.8	10.5	16.4	15.2	13.2	12.9

[a] Annualized capital cost plus annual operating costs of control equipment, in dollars per ton of elemental phosphorus output. See Exhibit 3-4 for definition of annualized capital cost.

[b] Includes adjustment for investment tax credit and 5-year straight-line depreciation, based on 1984 tax practices.

cost also includes administrative costs, property tax and insurance, estimated at 2 percent, 1 percent, and 1 percent, respectively, based on purchase value. Tax benefits for capital investments result in after-tax unit control costs which are 10 to 20 percent lower than before-tax costs for each plant.

After-tax costs are calculated by including adjustments to the purchase cost of control equipment to account for the 10 percent investment tax credit (ITC) and for the present value of the stream of tax deductions allowed for depreciation assuming a straight-line, five-year method. The basis for the depreciation is 95 percent of the purchase value, in accordance with current tax provisions. Given these assumptions, the present value of the stream of cost savings from allowable deductions on a $1 basis is given by $z = .2u \sum_{t=1}^{5} (1 + r)^{-t}$, where u is the marginal tax rate of the firm (.46) and r is the private discount rate. If $r = .10$, then $z = \$0.349$. Hence the after-tax cost of control equipment is given by $C = (1 - .10 - .95\ z)\ C_0 = .569\ C_0$, where C_0 is the original purchase cost of the equipment. Thus the credits and deductions allowed by current tax provisions provide a 43 percent reduction in the original purchase cost of control equipment. Annualized capital costs are also reduced 43 percent. This adjustment was not applied to the 4 percent surcharge for administrative costs, property tax and insurance since the ability of the firms to deduct these costs is more uncertain.

4.2: HEALTH BENEFITS OF CONTROLLING POLONIUM-210 EMISSIONS

The health benefits which accrue to society over time from the control of Po-210 emissions at the affected elemental phosphorus plants consist largely of the reduction in expected fatal lung cancers and, to a smaller degree, the reduction in non-hazardous particulate emissions near the sites. The health benefits associated with reduction of Po-210 emissions are determined to be the major component of the total health benefits due to emission reductions at these plants. The efficiency of the particulate control technologies in terms of Po-210 control, as presented in Exhibit 3-4, are therefore of greatest importance in the the calculation of the expected health benefits under alternative control scenarios.

Examination of Exhibit 3-4 shows that the control strategies result in efficiencies of Po-210 control ranging up to 98 percent. In this section the expected benefits of the proposed alternative standards are estimated by applying proportionate reductions to the estimated health risks currently generated in the population in areas of radius 80 km around each site. This method assumes a proportionate reduction in fatal cancers

for given statutory reductions in Po-210 emissions at the sites. The proportionate reduction assumption is consistent with the AIRDOS computer code procedures for evaluating population exposures in the affected areas and with the RADRISK code for translating exposures into expected fatal cancers, based on the linear dose-response model.

The health benefits of emission reduction for each alternative standard and the risks to nearby individuals are presented in Exhibit 4-4. The estimates of fatal cancers at each alternative were generated using the proportionate reduction assumption. Although safety margin considerations in the previous section led to the selection of control technologies with design performance which exceed the standards, the calculations in Exhibit 4-4 are based on the assumption that in practice the plants will actually emit at a level equal to the standard. Risk levels for all four unaffected phosphorus plants combined are also shown for purposes of comparison. Total industry benefits amount to 0.009 avoided fatal cancers per year at the 10 Ci/year standard alternative, while 0.035 and 0.041 fatalities per year are avoided at the 2.5 and 1.0 Ci/year levels, respectively. The uncertainty of the level of these estimates may range up to a factor of 10 higher or lower.

Examination of Exhibit 4-4 shows that FMC and Monsanto, which combined produce one-half of the industry's output, account currently for 78 percent of the total population risk of the industry, 0.045 out of a total of 0.058 fatal cancers per year. Risks to nearby individuals are highest at the Monsanto plant, 0.001 lifetime risk, followed by FMC at 0.0005, then all other plants at 0.0001 or less. Control at a statutory level of 10 Ci/year affects risks only at the Monsanto plant, reducing both the lifetime risk to nearby individuals and population risk by 50 percent. At a statutory level of 2.5 Ci/year, risks for Monsanto are further reduced by 75 percent, with equivalent percentage reductions for the FMC plant. At the 2.5 Ci/year level of emissions, the risks to nearby individuals for Monsanto, FMC, and all other plants are approximately equal. Also, the regional population risk for the Monsanto and FMC plants combined are approximately equal to those for the combined total of all other plants, 0.010 as compared to 0.013 fatal cancers per year. If the standard were set at 1 Ci/year, risk to individuals living near the Idaho plants would be a factor of two below those at all other plants. The regional population risks for FMC and Monsanto combined are also significantly below those of the rest of the industry for this standard. At this

EXHIBIT 4-4:

ESTIMATED RISK LEVELS BY ALTERNATIVE STANDARD

Alternative Standard	Lifetime Risks to Nearby Individuals[a]			Regional Population Risk (80 km)[b]			
(Ci/year)	FMC	Monsanto	All Others	FMC	Monsanto	All Others	Total
None	5 E-4	1 E-3	1 E-4	.027	.018	.013	.058
10	5 E-4	5 E-4	1 E-4	.027	.009	.013	.049
2.5	1 E-4	1 E-4	1 E-4	.008	.002	.013	.023
1	5 E-5	5 E-5	1 E-4	.003	.001	.013	.017

(a) - Lifetime probability of fatal cancer for individuals living 1500 meters from plant.

(b) - Expected additional fatal cancers per year in population within 80 km radius of each plant.

level for the standard, emissions at FMC and Monsanto are respectively 90 percent and 95 percent below current levels.

4.3: BENEFIT-COST COMPARISONS

Exhibit 4-5 summarizes the benefit-cost analysis presented in this chapter. For each alternative standard, the exhibit shows the estimated levelized costs and health risk reductions (benefits) for FMC, Monsanto, and for both plants combined. Levelized costs were obtained using the before-tax unit control costs from Exhibit 4-3 and the current production estimates in Exhibit 2-2. Total annualized costs amount to $0.70 million per year at a 10 Ci/year standard, and rise to approximately $3 million per year at a 1.0 Ci/year standard. Below the 10 Ci/year standard, costs for FMC are approximately 50 percent higher than for Monsanto. This reflects the 40 percent higher production at the FMC plant and the slightly higher unit control costs shown in Exhibit 4-3.

The estimated reductions in regional population risk range from a level of 0.009 to approximately 0.041 avoided fatal cancers per year. (This range may also be interpreted as extending from 1 avoided cancer every 25 years to 1 every 110 years in the affected population of both plants). At 10 Ci/year, reductions occur only for the Monsanto plant and amount to 0.009 fatal cancers per year. At the 2.5 Ci/year statutory level, total reductions at the Monsanto and FMC sites are both approximately equal, i.e., 0.016 and 0.019 fatal cancers per year, respectively. Lowering the standard to 1 Ci/year gives a small increase in total reductions for both plants.

The cost-effectiveness of alternative standards is also shown in Exhibit 4-5. The average cost-effectiveness is defined as the ratio of the levelized annual cost to the levelized annual benefit. Calculation of this ratio is equivalent to calculating the present value of the 20 year stream of costs and benefits, assuming a constant dollar willingness-to-pay, w, to save a life in any future year, and then solving for w by setting the present values equal. (Equivalence of the levelized cost approach and the present value approach is demonstrated in section 4.5 of this chapter).

The estimated average cost per statistical death avoided is $78 million for a 10 Ci/year standard. The average cost falls to $70 million at a 2.5 Ci/year statutory level, then rises slightly to $71 million at the 1.0 Ci/year level. Given the potential errors in the

EXHIBIT 4-5:

AVERAGE AND INCREMENTAL COST-EFFECTIVENESS FOR ALTERNATIVE STANDARDS

Alternative Standard	Annualized Cost[a] (mil $/yr)			Risk Reduction[b] (fatal cancers/yr)			Average Cost Per Death Avoided (mil $/fatality)	Incremental Cost Per Death Avoided (mil $/fatality)
	FMC	Monsanto	Total	FMC	Monsanto	Total		
10	0	.70	.70	0	.009	.009	78	78
2.5	1.44	1.01	2.45	.019	.016	.035	70	67
1	1.74	1.16	2.90	.024	.017	.041	71	75

(a) Based on before-tax unit control costs shown in Exhibit 4-3.

(b) Based on estimated regional population risk for FMC and Monsanto in Exhibit 4-4.

benefits estimates presented in this analysis, the absolute level of these estimates is subject to a large degree of uncertainty.

Incremental cost-effectiveness is defined as the ratio of the additional annualized costs to the additional annual benefits which arise as the level of the standard is lowered from one alternative (10 Ci/year, for example) to a second, more stringent alternative (2.5 Ci/year, for example). The incremental cost-effectiveness of the 10 Ci/year standard is defined to be equal to the average cost-effectiveness of that standard, $78 million per statistical death avoided. The incremental cost of lowering the statutory level to 2.5 Ci/year is $1.75 million ($2.45 million at 2.5 Ci/year, less $0.7 million at 10 Ci/year). The incremental benefit is 0.026 additional avoided fatal cancers per year. The incremental cost-effectiveness of moving from a 10 Ci/year standard to 2.5 Ci/year is $1.75 million divided by 0.026, yielding $67 million per additional life saved. A similar calculation yields $75 million per life saved for shifting from a 2.5 to 1.0 Ci/year standard.

It is generally expected that both the incremental and average cost-effectiveness defined here will rise monotonically in numerical value at increasingly stringent standards. This relationship will generally hold true for a single type of control technology applied to a single plant. In the case of controls on the two affected elemental phosphorus plants, the incremental costs shown in Exhibit 4-5 are estimated to fall with a change in the standard from 10 Ci/year to 2.5 Ci/year, then to rise again slightly with a change from 2.5 to 1 Ci/year. This anomalous behavior is due to the summation of costs and benefits over two plants, each with different initial emission levels and requiring different control technologies to comply with the same standard. The lower total incremental cost for moving from the 10 Ci/year to the 2.5 Ci/year level is due to the small marginal cost of control (slope) of the electrostatic precipitator cost curve in this region for Monsanto, as shown in Exhibits 4-1 and 4-2. This lower incremental cost results in a lower average cost-effectiveness for the 2.5 Ci/year standard than for the other levels of the standard.

4.4: SENSITIVITY ANALYSIS

The control costs, benefits and cost-effectiveness estimates presented above are based on several key assumptions concerning the costs, efficiencies, and useful lifetime for installed control equipment. The levelized cost method for comparing costs and

benefits is also sensitive to the assumed equality of the private and social discount rates. The sensitivity of the main results in the exhibits above to these key assumptions is examined in this section.

The costs and efficiencies presented in Exhibit 3-4 for the selected examples of more efficient control technologies are based on engineering cost analysis. These technologies have not yet been applied to particulate control for the calciners in the elemental phosphorus industry. The presence of currently installed low energy scrubbers on these calciners also creates a special engineering situation which has not been encountered in practice. The current scrubbers serve a useful role in Po-210 control by removing large particulates and ensuring the condensation of the volatilized polonium onto existing particles or into new particles. The scrubbers also add additional moisture to the airstream, while lowering the temperature. This creates moisture problems in the effluent airstream, which may "clog" the add-on control equipment when precipitators or fabric filters are employed. The unique corrosive environment at the calciners also is a cause for concern.

The additional risk elements introduced into the analysis by these factors may be reflected in the benefit-cost analysis by adjusting the private discount rate to account for a risk premium and by introduction of a safety margin in the selection and design of appropriate control equipment. For the sensitivity analysis, a risk premium of 5 percent was added to the assumed 10 percent real discount rate and the useful life of the equipment was shortened from twenty years to ten years. This adjustment causes upward revisions in the annualized capital costs (excluding administrative costs, taxes and insurance).

The revised annualized costs under these assumptions are compared to the original cost estimates in Exhibit 4-6. This revision in the annualized capital cost affects the ESP's and fabric filters by a greater amount, relative to the scrubbers, due to their higher capital cost. The change in amortization rate and period increases scrubber costs by approximately 10 percent and ESP and fabric filter costs by 30 percent.

The engineering considerations above also introduce an element of uncertainty concerning the estimated efficiencies of the control equipment. This uncertainty may be modeled by the introduction of a design safety margin. In section 4.1 the safety margin was selected to be 10 percent, indicating that the expected efficiency of the designed

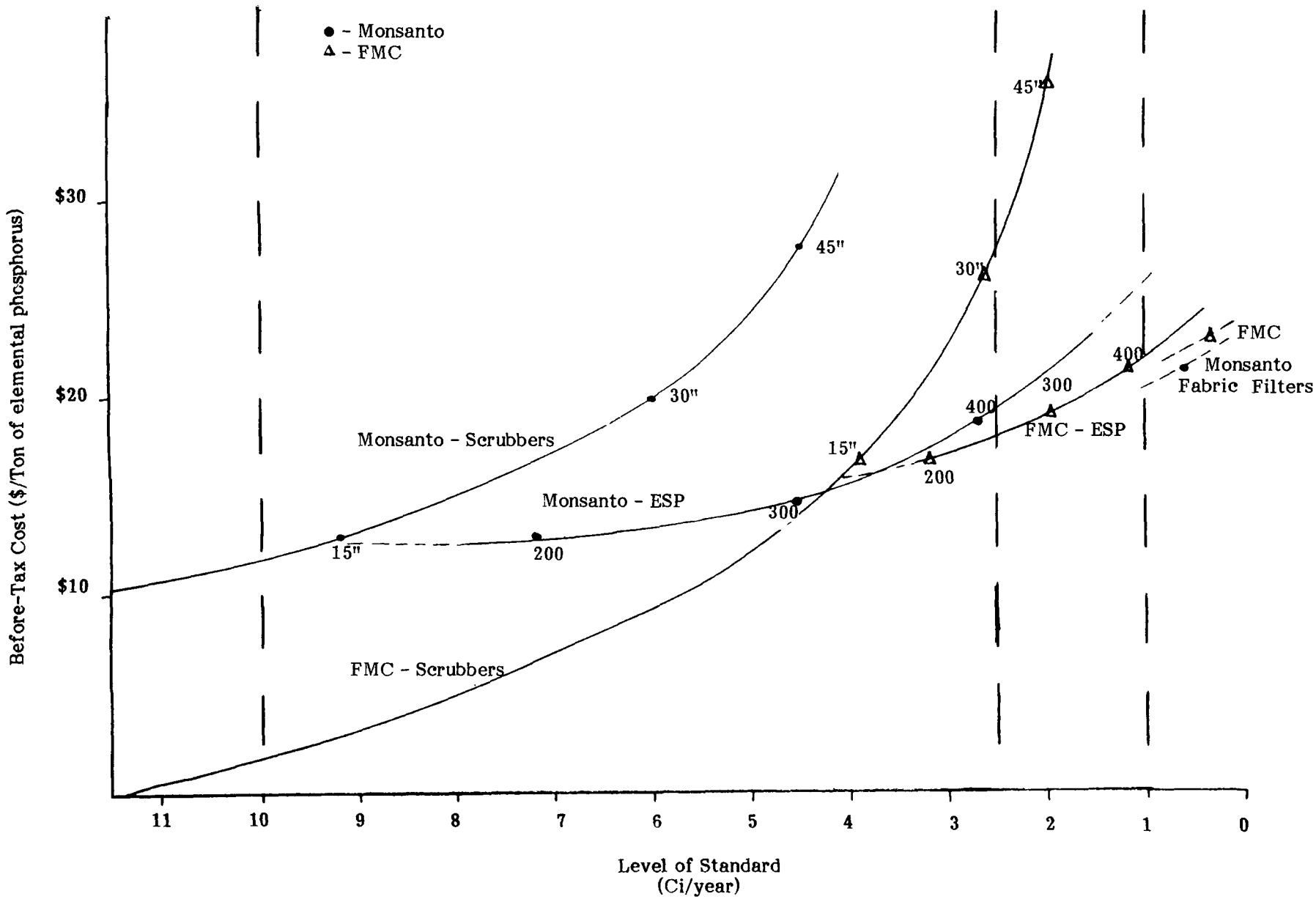
EXHIBIT 4-6
SENSITIVITY OF COSTS TO ASSUMED USEFUL LIFE AND DISCOUNT RATE

Technology		FMC			Monsanto		
Type	Scale	(a)	(b)	% Change	(a)	(b)	% Change
Scrubbers	15"	1.6	1.8	11	.9	1.0	10
	30"	2.5	2.8	9	1.4	1.5	9
	45"	3.5	3.8	8	2.0	2.1	9
ESP's	200 SCA	1.4	1.8	30	.8	1.0	29
	300 SCA	1.5	2.0	31	.9	1.1	30
	400 SCA	1.7	2.3	32	1.1	1.4	34
Fabric Filter	(c)	1.9	2.5	33	1.3	1.6	29

(a) - Capital costs amortized at 10 percent for 20 years.
(b) - Capital costs amortized at 15 percent for 10 years.
(c) - Only one scale evaluated.

EXHIBIT 4-7:

COST PER TON FOR SELECTED CONTROL TECHNOLOGIES FOR SENSITIVITY ANALYSIS



control equipment must be 10 percent below the statutory level of the standard. The engineering uncertainties discussed above may lead to larger safety margins for all control devices. The fabric filters are particularly sensitive to additional moisture and may require special pre-heating of the airstream for efficient operation. For this sensitivity analysis, the safety margins for scrubbers and ESP's were increased to 25 percent, and a safety margin of 50 percent was used for the fabric filters.

The graphs corresponding to Exhibits 4-1 and 4-2 with a revised safety margin and the higher annualized capital costs are shown in Exhibits 4-7 and 4-8. Although the revision in costs and safety margins leads to increased costs at all levels of the standard, there are no substantial changes in the choice of the least-cost technology at each alternative standard.

The least-cost technologies for each plant are shown in Exhibit 4-9 for the alternative standard. For each standard the exhibit shows the selected technology and its capital costs. Unit control costs are shown both before and after taxes. The tax adjustment was recalculated to reflect the higher private discount rate for the present value of depreciation deductions. The percentage changes in these values over the base case shown in Exhibit 4-3 are given in parentheses. Capital costs for FMC and Monsanto are only slightly higher as a result of the increase in safety margin. The changes in the capital amortization parameters increase the before-tax unit costs substantially, with cost increases ranging from 27 to 45 percent, depending on the plant and technology selected. After-tax unit costs are seen to rise approximately 30 percent for all cases, except for FMC at the 10 Ci/year standard. For this case, only slight additions to the current scrubber control equipment will enable FMC to meet the standard with the 25 percent safety margin.

The revised average and incremental cost per statistical death avoided for the revised cost estimates may be calculated using the estimated risk reductions in Exhibit 4-4 and the revised cost estimates in Exhibit 4-9. Although the private discount rate was increased from 10 percent to 15 percent for this sensitivity analysis, the appropriateness of making a corresponding adjustment to the social discount rate used for discounting the benefits is questionable. The levelized cost method of comparing costs and benefits can be derived from the present value method when the private and social rate of time preference are the same (See section 4.5). Hence, for a 15 percent social rate of discount, the average cost per statistical life saved may be calculated by

EXHIBIT 4-8:

LEAST-CONTROL COST STRATEGIES FOR SENSITIVITY ANALYSIS

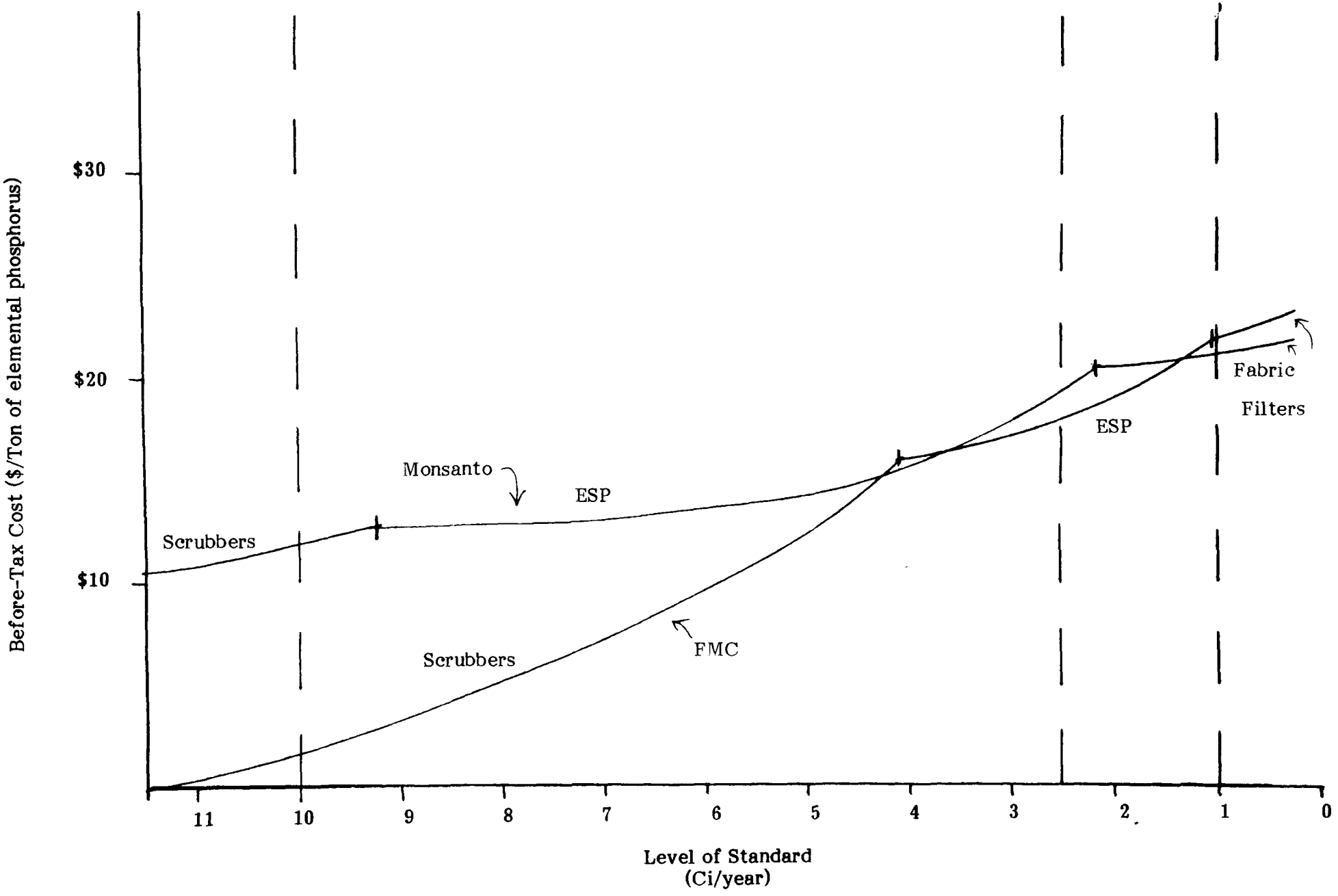


EXHIBIT 4-9:

SENSITIVITY OF THE COST OF LEAST-COST CONTROL TECHNOLOGIES FOR ALTERNATIVE STANDARDS

Alternative Standard (Ci/year)	Least-Cost Technology		Capital Costs (before taxes) (mil $)			Levelized Unit Control Cost[a] (before taxes) ($/ton)		Levelized Unit Control Costs[a] (after taxes)[b] ($/ton)	
	FMC	Monsanto	FMC	Monsanto	Total	FMC	Monsanto	FMC	Monsanto
10	Slight	15" P	.02	1.0	1.0	0.1	11.7	0.1	10.7
	Additional Scrubbing	Scrubbers	(—)[c]	(19)[d]	(20)	(—)	(27)	(—)	(29)
2½	250 SCA	425-450 SCA	5.5	4.5	10	17.7	19.1	13.7	14.5
	Precipitators	Precipitators	(6)	(5)	(5)	(30)	(45)	(28)	(29)
1	425-450 SCA Precipitators	Fabric Filter	6.9	4.1	11	22.3	20.9	17.2	16.7
			(3)	(8)	(5)	(36)	(38)	(30)	(29)

[a] Annualized capital cost plus annual operating cost of control equipment, in dollars per ton of elemental phosphorus. See Exhibit 3-4 for definition of annualized capital cost.

[b] Includes adjustment for investment tax credit and 5-year straight-line depreciation, based on 1984 tax practices.

[c] Base-case costs were zero; new safety margin implies small additional scrubbing costs.

[d] Percent increase over base-case estimate shown in parentheses.

dividing the levelized annual costs by the expected annual number of statistical deaths avoided. These results are shown in Exhibit 4-10. The exhibit shows the average and incremental cost per statistical death avoided based on the higher control costs of the sensitivity analysis case and an implicit 15 percent social rate of discount for the benefits. Percent increases in the average and incremental costs over the base case shown in Exhibit 4-5 are given in parentheses. The increases in cost per life saved range from 28 to 40 percent.

The right-hand column of Exhibit 4-10 shows the effect of restricting the social rate of discount applied to the benefit stream at the original value of 10 percent, while costs are discounted at the risk-adjusted private rate of 15 percent. The necessary corrections to the levelized cost approach to account for different rates of discount for benefits and costs are presented in the addendum to this chapter. Estimated costs per statistical death avoided are lower under these assumptions, due to the larger present value of society's willingness-to-pay for each death avoided in future years. In this case, the percent increases in cost per death avoided range from 5 to 15 percent higher than those for the base case.

4.5 ADDENDUM ON PRESENT VALUE AND ANNUALIZED COSTS

It is generally agreed that benefit-cost analysis is to be conducted by comparing the present value of the achieved benefits to the present value of the real-resource costs of alternative actions. The methodology of this chapter was based on the annualized cost approach. The annualized cost is defined as the stream of constant yearly payments which has the same present value as the actual cost stream. In this addendum the method of annualized costs and benefits is shown to lead to identical conclusions to those of the present value method under the assumptions that the rate of time preference for benefits is the same as the rate of time preference for costs. When these two rates differ, a simple correction to the annualized cost method is required to correspond to the present value approach. Consider the following example:

> Plant A is required to invest C_o dollars in control equipment at time zero. This equipment is expected to control emissions for T years. For simplicity, assume that annual operating costs, F, are constant over the time period, expressed in real dollars. The annualized cost is given by $a_{r,T}C_o+F$, where $a_{r,T}$ is an annualization factor which is defined in equation (1) below.

EXHIBIT 4-10:
SENSITIVITY OF AVERAGE AND INCREMENTAL COST PER STATISTICAL DEATH AVOIDED

Alternative Standard (Ci/year)	Annualized Cost[a] (mil $/year)			Risk Reduction[b] (Fatal cancers/yr)	Cost per Death Avoided[c] (15% rate for costs; 15% rate for benefits) (mil $/fatality)		Cost per Death Avoided[d] (15% rate for costs; 10% rate for benefits) (mil $/fatality)	
	FMC	Monsanto	Total	Total	Average Cost	Incremental Cost	Average Cost	Incremental Cost
10	.01 (—)	.89 (27)	.90 (29)	.009	100 (28)	100 (28)	82 (5)	82 (5)
$2\frac{1}{2}$	1.87 (30)	1.46 (45)	3.33 (36)	.035	95 (36)	93 (39)	78 (11)	76 (13)
1	2.36 936)	1.60 (38)	3.96 (37)	.041	97 (37)	105 (40)	79 (11)	86 (15)

[a] Based on before-tax unit control costs shown in Exhibit 4-9. Percent change over base-case shown in Exhibit 4-5 are given in parentheses.

[b] Based on regional population risk for FMC and Monsanto plants shown in Exhibit 4-4.

[c] Levelized cost per statistical death avoided based on assumed 15 percent discount rate for both costs and benefits.

[d] Levelized cost per statistical death avoided based on a 15 percent risk-adjusted discount rate for private costs and a 10 percent social discount rate for benefits.

It is also assumed that installation of the control equipment is expected to avoid an estimated number n of premature fatalities per year during the operation of the plant. Rather than assign a value to each premature death avoided, it is sufficient to define the symbol w as our willingness-to-pay (in real dollars in year t) to avoid a premature death in year t. The principle of equity across generations requires that w be constant, when expressed in real dollars. If n deaths are avoided in each year, then the annual benefit stream is $n \cdot w$ dollars per year for each year of operation of the plant with control equipment in place.

The present value approach may be stated in the following way. If society is willing to adopt a control method, then the present value of the control costs must be equal to or less than the present value of the benefit stream. Rather than assign a single value to w, one may set the present value of costs equal to the present value of the benefits and then solve for the corresponding value of w from each alternative. This gives the smallest value of the willingness-to-pay for which the present value of the benefits of this alternative exceeds the present value of the costs.

To demonstrate that the annualized cost approach and the present value approach lead to the same value of the willingness-to-pay to avoid a premature death w, the present values of all costs and benefits are calculated over the appropriate time period:

(a) Capital costs, C_o, are expended at time zero; and hence the present value is C_o.

(b) Operating costs must be discounted to the present time. We assume a social rate of time preference, r, for the discount rate. Then:

$$PV = F \sum_{t=1}^{T} \left(\frac{1}{1+r} \right)^t = F/a_{r,T}, \qquad (1)$$

where: $a_{r,T} = r/\ [1 - (1+r)^{-T}]$ is the appropriate discount factor.[1]

[1] Equation (1) relies on the identity:

$$\sum_{k=1}^{N} x^k = \frac{x}{1-x} \left(1-x^N \right).$$ Letting $x = 1/(1+r)$, gives the desired result.

(c) In a similar fashion to (b), the present value of the benefit stream is:

$$PV = nw/a_{r,T} \tag{2}$$

The value of the willingness-to-pay is then calculated by equating the present value of costs and benefits. The subscripts on the discount factor may be dropped for convenience of notation. Then calculations (a) through (c) imply that

$$nw/a = C_o + F/a$$

$$w = (aC_o + F)/n, \tag{3}$$

which is simply the ratio of the levelized annual cost, $aC_o + F$, to the annual benefit, expressed in deaths avoided per year.

A table of the discount factors for several discount rates and time periods is shown in Exhibit 4-11. For the base-case scenario $a_{.10,20}$ was used to annualize the capital costs. (Four percent of the purchase value was then added each year to account for administrative costs, property tax and insurance).

Risk Premiums

When the control methods are unproven, the generally accepted procedure is to add a risk premium to the social rate of time preference when calculating levelized annual capital costs. The risk-adjusted rate of discount for the cost stream then is defined as $\bar{r}$. It is inappropriate to also apply the risk premium to calculate the present value of the benefit stream, however, and benefits continue to be discounted at the social discount rate r. In this case a simple correction must be made to the levelized cost approach when estimating the willingness-to-pay, w.

In this case, the present value of the cost of control is:

$$PV(costs) = C_o + F/a_{\bar{r},T} \tag{4}$$

while the present value of the benefit stream is given by equation (2). Then the value of w is obtained by setting the present values of costs and benefits equal:

EXHIBIT 4-11:
ANNUALIZATION FACTORS

$$a_{r,t} = r/[1 - (1 + r)^{-t}]$$

r \ t	5	10	20 years
.05	.23098	.12950	.08024
.10	.26380	.16275	.11746[a]
.15	.29832	.19926[b]	.15976
.20	.33438	.23492	.20535

(a) Factor for annualizing capital costs in base case.

(b) Factor for annualizing capital costs in sensitivity analysis.

$$\frac{nw}{a_{r,T}} = C_o + \frac{F}{a_{\bar{r},T}}$$

$$w = \frac{a_{r,T}}{a_{\bar{r},T}} \cdot \frac{a_{\bar{r},T}C_o + F}{n} . \qquad (5)$$

Comparison of equations (3) and (5) shows, in this case, that the ratio of the levelized costs to the annual benefit must be multiplied by the factor $a_{r,T}/a_{\bar{r},T}$ to obtain the appropriate willingness-to-pay.

CHAPTER 5

ECONOMIC IMPACT ANALYSIS

5.0. INTRODUCTION

Economic impacts occur when regulations alter the costs of production. Changes in the cost of production may lead to a change in product price and demand, thus altering the structure of the market in which the product is sold. The impacts on producers, consumers, workers and communities may be positive or negative, may depend on the overall state of the economy, and may be transitional or permanent. The impacts may represent losses in economic efficiency or they may be distributional, indicating shifts among economic entities (e.g., among firms or among groups of workers).

Government regulations generally occur when the market fails to meet all of the objectives of society. Regulations are designed to mend the market imperfections by, for example, internalizing to a polluter the cost of environmental damage caused by that pollution. In the case of the elemental phosphorus industry, the market has provided no incentive for two high volume western manufacturers to reduce their particulate emissions since other producers, utilizing phosphate inputs of different quality and quantity and generally producing less elemental phosphorus, do not emit the same volume of hazardous particulates, and have no need to incur costs for pollution control equipment.

As shown in the previous chapters of this report, limiting the allowable emissions of polonium 210 at various alternative levels would require one or two of the six plants operating in 1984 to install and operate pollution control equipment designed to reduce their particulate emissions. The technology selected by the affected plants would depend on the level of standards and individual firm preferences. Varying levels and proportions of capital and operating expenses would be incurred by each plant based on the technology selected. These costs would result in an increase in the unit production cost of the affected facilities. The total of these pollution control expenditures is referred to as the private real resource cost.

When a regulation imposes real resource costs on firms that change the unit cost of production, manufacturers will attempt to minimize the effect on profitability. This

may result in attempts to reduce input costs including raw materials and wages, or to increase prices. If there is an increase in price, demand for the product may be reduced, and demand for competitors' output or substitute products may increase. These changes can lead to layoffs at the affected plant, reduced income in the community where the plant is located, and effects on the structure of the market. These effects on market structure include shifts in the price elasticity for the product, decreases in overall demand, and redistribution of market positions for each competitor and producer of substitute products.

The extent to which a regulated manufacturer may effectively pass on increases in cost will depend on the competitive environment in which the products are produced and sold and on the elasticity of demand. The elasticity of demand is a measure of the sensitivity of the consumers to changes in price. In some markets a small change in price could lead to a large reduction in volume sold, while in other markets large price changes may have only marginal effects on volume. As a regulated manufacturer increases prices, demand for the products will usually fall. The rate at which volume falls will determine the change in total revenues that results from a change in price. If the market price of the product changes (all manufacturers incur higher costs), consumers use less of the product and some of the utility associated with consumption of the product will be lost. Consumers who continue to use the same amount of the product at higher prices will have to allocate a larger portion of their budget to this consumption, thus reducing savings or consumption of other goods and services.

The control of Po-210 emissions through the setting of a Ci/year standard will result in changes in the cost of producing elemental phosphorus at some plants. The structure of this industry and the nature of the markets in which the output is utilized adds significant uncertainty to the measurement and allocation of expected economic impacts. Some of these characteristics include the following:

- The industry has contracted substantially over the past two decades, closing over half the plants and reducing capacity by almost 40 percent.

- Elemental phosphorus is an intermediate product utilized to produce chemical compounds used in consumer goods that are sold in highly competitive markets (detergents, soft drinks, etc.).

- All plants are owned by large, highly integrated Fortune 500 firms that consume virtually all of the elemental phosphorus output in company-owned chemical plants.

- The owners of the elemental phosphorus plants own or have extraction leases for phosphate rock, an exhaustible resource that is the principle input to production.

- The two plants most likely to require new emissions control equipment are the two largest plants, accounting for about half the industry capacity.

- The affected plants have the lowest production costs due to scale economies and regional differences in input prices.

- One of the potentially regulated low cost plants is owned by a firm that also owns and operates one of the non-regulated plants.

- The long range prospects for current elemental phosphorus markets are uncertain, and extensive industry R&D efforts over the past decade have failed to develop any significant new markets.

- Substitutes for phosphorus compounds are available at reasonable prices.

- Bans or restrictions on phosphate use in detergents have been imposed in some states.

These and other factors make it difficult to predict the ability or desirability of the regulated plants to pass on all or part of these pollution control costs to consumers through price increases. In the next section the costs of producing elemental phosphorus at the currently operating plants are compared. A subsequent section presents some methods for bounding the potential economic impacts of the proposed alternatives and the final section reviews the Regulatory Flexibility Act implications of these regulations.

5.1: PRODUCTION COSTS

The primary components of the cost of producing elemental phosphorus are phosphate rock, coke, electricity, and labor. Together, these account for 80 to 88 percent of the cost of producing a ton of phosphorus. Prices of these materials for each producer and plant vary, with the western plants having a significant cost advantage compared to Tennessee plants. The components of cost for elemental phosphorus and estimated costs for each plant are described in the following section.

Components of Cost

The inputs to elemental phosphorus production have been investigated for a hypothetical Tennessee plant by Arthur D. Little,[1] and for FMC by EPA in 1984.[2] Additional data on costs are published in SRI's Chemical Economics Handbook. The ranges in the amounts and prices of each input needed to produce a ton of phosphorus seen in these studies are provided in Exhibit 5-1.

As the exhibit shows, the total cost per ton could range from $955 to $1,811; however, it is unlikely that the variation in costs is this broad. The primary inputs to production and estimates of their cost for each plant are discussed below.

Phosphate Rock

Phosphate rock costs from $11.48 to $25.84 per ton, delivered. At the high end of the range is the washed and/or beneficiated rock used by Tennessee plants. When this higher quality rock is used, less rock may be required (10 tons per ton of phosphorus compared to 12.5 tons).[3] Lower grade material is usually less expensive, but the proximity and convenience of transporting the rock to the plant is the most important cost factor. FMC and Monsanto's Idaho rock is relatively low cost because it is obtained from captive mines close to elemental phosphorus plants. Stauffer's phosphate rock costs for its Montana plant are relatively higher because of greater transportation

---

[1] Arthur D. Little, Economic Analysis of Proposed Effluent Guidelines for the Industrial Phosphate Industry. Prepared for the Environmental Protection Agency, August, 1973.

[2] "Preliminary Analysis of Potential Impacts of $20 Million Compliance Cost at FMC Plant," Memorandum from Rod Lorang and Barry Galif, Sobotka, Inc., to Byron Bunger, Environmental Protection Agency, February 6, 1984, p.B-3.

[3] Arthur D. Little, op.cit.; and Lorang and Galif, op. cit., p. B-3.

EXHIBIT 5-1

COST OF ELEMENTAL PHOSPHORUS

Cost Item	Units	Units/Ton of Phosphorus	Cost/Unit	Cost/Ton of Phosphorus
RAW MATERIALS				
Phosphate Rock	tons	10-12.5[1]	$11.48-$25.84[2]	$114.80-$323.00
Silica	tons	0.79[3]	12.29[4]	9.71
Coke	tons	1.4-1.5[2]	113.00[5]	158.20-169.50
Electrodes	lbs	0.42[1]	0.73[6]	0.31
UTILITIES				
Electricity	kwh	13,000-15,200[2]	0.0160-0.0461[7]	208.00-700.70
Water	Mgal	20.00[1]	0.13[8]	2.60
Fuel	MSCF	12.00[1]	1.30[9]	15.57
OTHER				
Labor	n.a.	n.a.	n.a.	190.25-256.32[10]
Operating Supplies	n.a.	n.a.	n.a.	12.72[11]
Maintenance	n.a.	n.a.	n.a.	127.31[11]
Taxes	n.a.	n.a.	n.a.	28.64[11]
Subtotal				868.11-1646.38
GS&A (10%)	n.a.	n.a.	n.a.	86.81-164.64
TOTAL COSTS	n.a.	n.a.	n.a.	954.92-1811.02

[1] Arthur D. Little, op.cit.; and unpublished EPA data.

[2] SRI, Chemical Economics Handbook, January 1983. Updated to 1984 prices using index for phosphate rock in Bureau of Labor Statistics, Producer Prices and Price Indexes, June 1984, p.11.

[3] Unpublished EPA data.

[4] Unpublished EPA data, updated from 1982 to 1984 using index for "other industrial inorganic chemicals" in Bureau of Labor Statistics, op.cit., p.101.

[5] Energy Information Administration, Quarterly Coal Report, April 1984, p.55.

[6] Unpublished EPA data, updated to 1984 using index for arc welding electrodes in Bureau of Labor Statistics, op.cit., June 1982, p.75.

[7] SRI, op.cit., January 1983, and JFA estimates.

[8] Unpublished EPA data, updated to 1984 using index for water and sewerage maintenance in Bureau of labor Statistics, CPI Detailed Report, June 1984, p.20; and June 1982, p.22.

[9] Unpublished EPA data, updated to 1984 using index for fuels in CPI, op.cit., June 1984, p.11; and June 1982, p.13.

[10] Industry information for 1983 updated to 1984 using GNP deflator in "Economic Indicators," op.cit., p.2.

[11] Unpublished EPA data updated to 1984 using GNP deflator in "Economic Indicators," op.cit., p.2.

costs.[1] Additional information on the phosphate rock resources of each producer are provided in Chapter 2. The estimated costs of phosphate rock for each plant and producer are summarized in Exhibit 5-2.

Coke

For each ton of phosphorus produced, 1.4 to 1.5 tons of coke are required, depending on quality. The cost of the coke per ton to the producer depends on its quality, grade, and value at which it is transferred when captively produced. The cost of coke per ton of phosphorus is levelled across producers by this cost and input structure: lower quality coke is lower priced but more is required, while higher quality coke is higher priced and less is required.[2] The cost of coke per ton of phosphorus used for this analysis was $160.46. This cost assumes 1.42 tons of coke are used per ton of phosphorus[3] and that the price per ton is $113.00, the national average market price of coke.[4]

Electricity

Production of a ton of phosphorus requires 13,000 to 15,200 kwh of electricity. Estimates of the cost of this electricity range from 0.0160 to 0.0408 per kwh.[5]

Plants served by TVA have witnessed steadily increasing rates since 1976, as rates have been more and more dependent on coal purchase commitments. Power rates in Idaho were stable until the last part of the 1970's, and for the Montana plant until 1980. Rates are expected to continue to grow for FMC and Monsanto in Idaho because of increasing reliance on coal-fired electricity. Stauffer, which was previously purchasing power from Bonneville, changed sources in late 1982 in an effort to control its costs.[6] The estimated cost of electricity for each plant and producer is shown in Exhibit 5-3.

---

[1] SRI, op.cit., January 1983.

[2] Ibid.

[3] Unpublished EPA data and Arthur D. Little, op.cit., p. 17.

[4] Energy Information Administration, Quarterly Coal Report, April 1984, p. 55.

[5] SRI, op.cit., January 1983 and Energy Information Administration, Financial Statistics of Selected Electric Utilities: 1982, February 1984.

[6] SRI, op.cit., January 1983.

EXHIBIT 5-2

PHOSPHATE ROCK

Producer	Location	$/Ton[1]	Tons of Phosphate Rock Mined/ Ton of Phosphorus	$/Ton of Phosphorus ($)
Monsanto	Columbia, TN	25.75	10.00[2]	257.50
	Soda Springs, ID	17.80	12.50[3]	222.50
FMC	Pocatello, ID	17.80	12.50[3]	222.50
Stauffer	Mt. Pleasant, TN	25.75	10.00[2]	257.50[4]
	Silver Bow, MT	17.80	12.50[3]	222.50
Occidental	Columbia, TN	25.75	10.00[2]	257.50

[1]Source: William Stowasser, Bureau of Mines. Prices shown for Idaho and Montano plants are the prices of domestically consumed phosphate rock in the western states. Prices are average prices for January - June, 1984.

[2]Arthur D. Little, op.cit., p.17. Phosphate rock required per ton of phosphorus in sample Tennessee plant was assumed to apply to all Tennessee plants.

[3]Unpublished EPA data for FMC. Phosphate rock required per ton of phosphorus at FMC plant was assumed to apply to all Idaho and Montana plants.

[4]Stauffer's Montana plant is believed to have higher costs for phosphate rock than FMC and Monsanto's Idaho plants because of high transportation costs. In the absence of plant specific data however, the Bureau of Mines "western states" price was assumed to apply.

EXHIBIT 5-3

ELECTRICITY COSTS

Producer	Location	kwh/Ton Phosphorus[1]	$/kwh[2]	$/Ton of Phosphorus
Monsanto	Columbia, TN	13,000	.0461	599.70
	Soda Springs, ID	13,000	.0220	286.60
FMC	Pocatello, ID	13,000	.0220	286.60
Stauffer	Mt. Pleasant, TN	13,000	.0461	599.70
	Silver Bow, MT	13,000	.0220	286.60
Occidental	Columbia, TN	13,000	.0461	599.70

[1] Unpublished EPA data for FMC. Applied to all plants.

[2] Energy Information Administration, Financial Statistics of Selected Electric Utilities, 1982, February 1984.

Labor

The fourth major cost of producing phosphorus is labor. Average labor cost in the industry are estimated to range from $33,465 to $40,158 per year[1] per worker and labor costs per ton of phosphorus from $189.75 to $255.65.[2] Labor costs for each producer and plant are detailed in Exhibit 5-4.

Total Costs by Plant

The cost of producing a ton of phosphorus is estimated to range from approximately $1,180 in Montana and Idaho plants, to over $1,600 in the Tennessee plants. These estimates are comparable to the estimates provide by SRI in the Chemical Economics Handbook (January 1983) of $1,070 to $1,180 per ton of phosphorus in the western states and $1,315 to $1,555 in Tennessee.[3] Costs by plant are summarized in Exhibit 5-5.

5.2 MEASURING ECONOMIC IMPACTS

The degree to which the elemental phosphorus industry will be affected by pollution control costs, and the ability of producers to mitigate these impacts through price changes will be determined by the market structure of the industry. As noted in Chapter 2 and in section 5.1, several alternative theories could be used to describe this market. First, the output of each plant in this industry is almost totally consumed by other plants owned by the parent corporation. The downstream plants process this elemental phosphorus into various compounds of phosphorus that are mostly sold as inputs to the production of highly competitive consumer goods such as detergents and soft drinks. Substitute inputs for the phosphorus are available and widely utilized. Thus the demand for elemental phosphorus is derived from the demand for products in highly competitive markets that are price sensitive. Therefore, phosphorus producers may face a flat demand curve, as in a competitive market, even though there are only four manufacturers. A flat or nearly flat demand curve suggests that the manufacturer would have little opportunity to pass on increases in unit costs through price increases.

---

[1] Industry information for 1983, updated to 1984 using GNP Implicit Price Deflator in Council of Economic Advisors, op.cit., p. 2.

[2] JFA estimates.

[3] SRI, Chemical Economics Handbook, January 1983. 1982 estimates updated to 1984 using GNP implicit price deflator in Council of Economic Advisors, op.cit., p. 2.

EXHIBIT 5-4

LABOR COSTS

Plant	Location	Employees[1]	$/Manyear[1]	$(million)	Production (tons)[2]	$/Ton Phosphorus
Monsanto	Columbia, TN	440	37,069	16.31	63,800	255.65
	Soda Springs, ID	397	40,158	15.94	76,500	208.40
FMC	Pocatello, ID	600	37,069	22.24	106,300	209.24
Stauffer	Mt. Pleasant, TN	305	33,465	10.20	42,500	240.15
	Silver Bow, MT	185	37,069	6.86	34,000	201.70
Occidental	Columbia, TN	275	33,465	9.20	48,500	189.75

[1]Source: Industry estimates of 1983 salaries and employees, updated to 1984 using GNP Implicit Price Deflator in Council of Economic Advisors, op.cit., p.2.

[2]Production is estimated 1984 production.

EXHIBIT 5-5

SUMMARY OF COST ESTIMATES, BY PLANT

Producer	Location	Phosphate Rock	Electricity	Labor	Coke	Subtotal	Other Costs	Total Excluding GS&A	Total Including GS&A at 10%
Monsanto	Columbia, TN	257.50	599.70	255.65	160.46	1,273.31	196.86	1,470.17	1,617.19
	Soda Springs, ID	222.50	286.60	208.40	160.46	877.96	196.86	1,074.82	1,182.30
FMC	Pocatello, ID	222.50	286.60	209.24	160.46	878.80	196.86	1,075.66	1,183.23
Stauffer	Mt. Pleasant, TN	257.50	599.70	240.15	160.46	1,257.81	196.86	1,454.67	1,600.14
	Silver Bow, MT	222.50[1]	286.60	201.70	160.46	871.26	196.86	1,068.12	1,174.93[1]
Occidental	Columbia, TN	257.50	599.70	189.75	160.46	1,207.41	196.86	1,404.27	1,544.70

[1]Stauffer costs of phosphate rock per ton of phosphorus are probably higher than this average phosphate rock price in western states provided by the Bureau of Mines. Stauffer's phosphate rock costs are adversely affected by high transportation expenses.

An alternative description of the elemental phosphorus industry is that it is an oligopoly with strong price leadership. There are only four manufacturers and production costs at the western plants are lower than at plants elsewhere. The low cost manufacturers have the ability to set the market price at a profit maximizing production level. The higher cost manufacturers would thus be price takers because, if market price were set at the marginal cost of the low cost producers, the higher cost producers would have to sell their product at this price, even if it meant losing money on each unit sold, or leave the industry. As seven higher cost plants have been closed over the past two decades it would appear that the cost of closing these plants was less than the cost of selling products below their individual marginal cost of production.

A collusive oligopoly will attempt to operate as a monopoly, setting industry marginal revenue equal to industry marginal cost to determine output. The price is then established by the demand curve at a level above that which would exist in a competitive market. Thus industry maximizes its profit. Output and revenue for each manufacturer are determined by the manufacturer's marginal costs and the price level. While it may not be possible in the absence of collusion for the oligopoly to operate in this fashion, firms in such an industry would likely be able to maintain price above marginal cost (the competitive price) and thus earn excess profits.

Firms in any market will determine their level of output based on their marginal cost. By definition, fixed costs do not vary with the level of output. Therefore, they do not enter into the production rate decision since firms in general will continue to produce as long as marginal revenue is greater than or equal to marginal cost. The cost of regulatory compliance presents a special case. While the expenditures for pollution control capital equipment are clearly fixed costs, operating costs for this equipment are not so clearly categorized. Usually operating cost is thought of as a variable cost. That is, if no production occurs, no operating costs are accrued. However, in the case of these particular regulations of the elemental phosphorus industry, the capital and operating costs vary little with output. The two regulated plants are the most profitable operating facilities, a fact which will not change with the additional pollution control expenditures. It is unlikely that either facility would consider stopping operation or significantly reducing output in place of purchasing and operating control equipment sufficient to meet the standards. In addition, the operating cost for these systems will not vary significantly over a wide range (50-90 percent) of capacity

utilization. Thus, almost all of the costs required to meet these standards may be viewed as fixed costs, suggesting that no changes in output or price would be expected as a result of the compliance with the standards. In this case, all the impacts will be born by the affected manufacturers in the form of lower profits.

The fact that phosphate rock is an exhaustible resource owned by the regulated industry requires some special consideration. The resource stock is an asset held by its owner, the value of which is determined by the size of the asset and the present value of the difference between market price and extraction cost in any period. The rate of extraction selected by the owner of the resource will depend on the structure of the market in which the resource is sold, forecasts of the future prices of the product, and forecasts of interest rates. If, for example, the resource owner expected the rate of growth in the net price (market price less extraction cost) to be less than the interest rate, he would extract the resource as quickly as possible and convert it to a new asset which would return at least the market rate of interest. In general, we would expect a monopolist to establish prices high enough that the extraction rate would be slower than that of a producer in a competitive market. In an oligopoly the resource would be extracted faster than in the monopoly, but slower than in the competitive market, with the price and extraction rates approaching the competitive case as the number of firms in the industry became larger. In this case several stocks of the exhaustible resource are available with each plant being fed by a specific mine. The potentially regulated plants, as the lower cost producers, are able to earn a higher return from their resource than are the other plants. This higher return allows these producers to earn an economic rent on their stocks of phosphate rock. By imposing a new environmental cost that is mostly a fixed cost, as discussed above, the available rent that could be earned by these producers is reduced by the amount of the pollution abatement costs.

While it is uncertain to what extent product prices and demand for elemental phosphorus will be affected by these standards, the available information indicates that there would be relatively little change in production levels at the regulated facilities. Thus, for the purpose of this analysis, we will assume that product price is unchanged; therefore, there are no consumer impacts, no change in employment levels and no community impacts. The entire impact of the standards is thus calculated as a reduction in profits for the impacted firms. Exhibit 5-6 presents the estimated value of elemental phosphorus production, the total revenue of the parent corporation, and the

EXHIBIT 5-6:

REVENUES FROM ELEMENTAL PHOSPHORUS PRODUCTION
AND
TOTAL CORPORATE REVENUES
(1983)

Producer	Elemental Phosphorus Revenue (in millions)	Total Corporate Revenue (in millions)	Elemental Phosphorus as a Percent of Total Revenue
Monsanto	$ 266.5	$ 6,299.0	4.2%
FMC	$ 201.9	$ 3,572.0	5.7%
Stauffer	$ 145.4	$ 1,339.9	10.9%
Occidental	$ 92.1	$ 19,709.9	0.5%

Source: 1983 annual reports, for total corporate revenue. Stauffer revenues are for the fiscal year ending September 30, 1983. JFA estimates for elemental phosphorus production revenues (Exhibit 5-1).

percent of total revenues accounted for by elemental phosphorus. Monsanto and FMC, the two potentially impacted firms under current output and production conditions, have 4.2 and 5.7 percent of their revenues associated with elemental phosphorus production. As Monsanto operates a plant that will not be affected by these standards, the portion of its revenues and profits affected by the standard should be about 40 percent lower than shown in Exhibit 5-6. Exhibit 5-7 shows the level of capital expenditures normally undertaken by these firms, required capital expenditures under different regulatory alternatives and the percentage of total capital expenditures represented by the pollution control capital expenditures.

Exhibit 5-8 summarizes the analysis of impacts on profits, showing the effect of the required after-tax pollution control expenditures for each plant and the effect on the profits of each firm under three alternate standards. The 1983 present value of the stream of profit reductions for Ci/year standards of 10, 2.5 and 1 for Monsanto were $5.4, $7.3 and $8.4 million respectively. FMC incurs no cost or profit loss at a 10 Ci/year standard. At 2.5 and 1 Ci/year standards, the present value of FMC losses would be an estimated $9.7 and $11.9 million, respectively.

5.3 REGULATORY FLEXIBILITY ANALYSIS

The Regulatory Flexibility Act (RFA) requires regulators to determine whether proposed regulations would have a significant economic impact on a substantial number of small businesses or other small entities. If such impacts exist, they are required to consider specific alternative regulatory structures to minimize the small entity impacts without compromising the objective of the statute under which the rule is enacted. Alternatives specified for consideration by the RFA are tiering regulations, performance rather than design standards, and small firm exemptions.

The four firms operating plants in this industry are major diversified corporations, the smallest of which was ranked 213 on the Fortune list of the 500 largest manufacturing firms in 1983. The three emission control levels evaluated affect, at most, two of these plants. The two potentially affected plants are the largest operating plants in the industry and enjoy the lowest cost structure due to economies of scale and regional cost differences. These two plants account for approximately half of the annual production of elemental phosphorus and are probably the most profitable units. This profitability rank will not be affected by any of the proposed alternatives.

EXHIBIT 5-7:

IMPACT ON CAPITAL EXPENDITURES

Producer	Capital Expenditures, 1983 (in millions)	Standard Option (Ci/year)	Estimated Capital Costs of Emissions Control	Emissions Costs as a Percent of 1983 Capital Costs
Monsanto	$ 560.0	10	0.8	.14
		2.5	4.3	.77
		1	3.8	.68
FMC	$ 173.6	10	0	0
		2.5	5.2	3.00
		1	6.7	3.86
Stauffer	$ 170.0	10	0	0
		2.5	0	0
		1	0	0
Occidental	$ 951.0	10	0	0
		2.5	0	0
		1	0	0

Source: 1983 annual reports for Monsanto, FMC, and Occidental. Projection of 1983 expenditures in 1982 annual report for Stauffer. (1982 expenditures by Stauffer were $176.9 million).

EXHIBIT 5-8:

IMPACT ON AFTER TAX PROFITS

Producer	Profits After Taxes, 1983[1] (in millions)	Standard Option (Ci/year)	Annualized Costs of Emissions Control[2] (mil $/year)	Estimated Reduction in Profits After Taxes[3]	
				Percent	Present Value of Profit Reduction[5] (in millions)
Monsanto	$ 369.0	10	.63	.17	5.4
		2.5	.86	.23	7.3
		1	.99	.27	8.4
FMC	$ 168.8	10	0	0	0
		2.5	1.14	.68	9.7
		1	1.40	.83	11.9
Stauffer	$ (12.4)[4]	10	0	0	0
		2.5	0	0	0
		1	0	0	0
Occidental	$ 566.7	10	0	0	0
		2.5	0	0	0
		1	0	0	0

[1] Parentheses are used to indicate a loss.

[2] Costs of emissions control are detailed in Exhibit 4-3.

[3] The elemental phosphorus industry is highly competitive and prices are essentially uniform for all producers. FMC and Monsanto, the lowest marginal cost producers, will not raise the market price of phosphorus. If prices do not change, demand (and hence, revenue) will also be unaffected by the regulation. Thus, the increase in costs translates directly into a decrease in profits.

[4] Profits after taxes for Stauffer are for the fiscal year ending September 30, 1983.

[5] Present value of 20 years of profit loss discounted at 10 percent per year.

Source: 1983 annual reports and JFA estimates.

In light of the fact that the four smallest plants in this industry are expected to incur no compliance costs as a result of any of the regulatory alternatives under consideration, no significant small business impact will occur.

REFERENCES

Annual Reports for 1983 for Monsanto Company, FMC Corporation, Occidental Petroleum Corporation, and Stauffer Chemical Company.

Bureau of the Census, U.S. Department of Commerce, Current Industrial Reports: Inorganic Chemicals, May 1984 and annuals, 1968-1982.

Bureau of Labor Statistics, U.S. Department of Labor, Producer Prices and Price Indexes, April 1984 and June 1984.

"Chemical Profile: Phosphorus," Chemical Marketing Reporter, 1964-1981.

Council of Economic Advisors, "Economic Indicators," July 1984.

Dasgupta, P.S. and Heal, G.M., Economic Theory and Exhaustible Resources. Cambridge: Cambridge University Press, 1979.

Energy Information Administration, U.S. Department of Energy, Financial Statistics of Selected Electric Utilities: 1982, February 1984.

Energy Information Administration, U.S. Department of Energy, Quarterly Coal Report, April 1984.

Friedman, Milton, Price Theory: A Provisional Text. Chicago: Aldine Publishing Company, 1962.

GARD, Inc., Capital and Operating Costs of Selected Air Pollution Control Systems. Prepared for U.S. Environmental Protection Agency, Publication No. EPA-4515-80-002.

"Key Chemicals: Phosphorus," Chemical and Engineering News, July 30, 1984; July 11, 1983; March 23, 1981; April 24, 1979; April 24, 1978.

Arthur D. Little, Economic Analysis of Proposed Effluent Guidelines for the Industrial Phosphate Industry. Prepared for the Environmental Protection Agency, August 1973.

Midwest Research Institute, Analysis of Achievable Po-210 Emission Reductions and Associated Costs for FMC's Pocatello, Idaho, Plant. Prepared for the Office of Radiation Programs, U.S. Environmental Protection Agency, August 1984.

Midwest Research Institute, Analysis of Achievable Po-210 Emission Reductions and Associated Costs for Monsanto's Elemental Phosphorus Plant at Soda Springs, Idaho. Prepared for the Office of Radiation Programs, U.S. Environmental Protection Agency, August 1984.

"National Emission Standards for Hazardous Air Pollutants, Standards for Radionuclides: Proposed Rules and Announcement of Public Hearing," Federal Register, April 6, 1983.

"Preliminary Analysis of Potential Impacts of $20 Million Compliance Cost at FMC Plant," Memorandum from Rod Lorang and Barry Galif, Sobotka, Inc., to Byron Bunger, Environmental Protection Agency, February 6, 1984.

SRI, Chemical Economics Handbook, Menlo Park, California, January 1983 and March 1980.

Stowasser, William, "Phosphate Rock," Minerals Yearbook, Volume 1, 1982.

U.S. Environmental Protection Agency, Draft Background Information Document: Proposed Standards for Radionuclides, March 1983.