

EPA-600/R-96-075

June 1996

**EVALUATION OF POLLUTION PREVENTION
OPPORTUNITIES FOR MOLD RELEASE AGENTS**

Project Report

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EPA Contract No. 68-D2-0062

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Prepared for:

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

TECHNICAL REPORT DATA <i>(Please read instructions on the reverse before compl</i>				
1. REPORT NO. EPA-600/R-96-075	2.		PB96-187745	
4. TITLE AND SUBTITLE Evaluation of Pollution Prevention Opportunities for Mold Release Agents		5. REPORT DATE June 1996		
		6. PERFORMING ORGANIZATION CODE		
7. AUTHOR(S) Jeffrey S. Lanning and Kevin A. Cavender		8. PERFORMING ORGANIZATION REPORT NO.		
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southern Research Institute P. O. Box 13825 Research Triangle Park, North Carolina 27709		10. PROGRAM ELEMENT NO.		
		11. CONTRACT/GRANT NO. 68-D2-0062		
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air Pollution Prevention and Control Division Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 5/94 - 12/95		
		14. SPONSORING AGENCY CODE EPA/600/13		
15. SUPPLEMENTARY NOTES APPCD project officer is J. Kaye Whitfield, Mail Drop 61, 919/541-2509.				
16. ABSTRACT The report gives results of an assessment of the processes, materials, installation practices, and emission characteristics associated with the application of mold release agents (MRAs). Emissions were estimated based on available information on MRA composition and consumption. Volatile organic compound (VOC) emissions of MRAs were estimated to be 126,000 tons (114,000 tonnes) per year. The study also found that polyurethane molding operations accounted for a significant portion of the total MRA emissions (about 25%) and that automobile seat and other foam molding operations accounted for most of the emissions associated with the polyurethane category. Thus, the polyurethane foam manufacturing industry was selected for a pollution prevention technology demonstration. Several pollution prevention alternatives were identified for conventional MRA usage in the polyurethane foaming industry. An initial assessment of each identified technology was performed. The Solvent Emission Reduction Technology (SERT) process was selected for further evaluation. A detailed assessment of SERT was made through a demonstration at the Integram-St. Louis Seating polyurethane molding facility in Pacific, Missouri. The demonstration showed that a 60% reduction in VOC emissions is readily attainable with this process.				
17. KEY WORDS AND DOCUMENT ANALYSIS				
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Estimating	Pollution Prevention	13B	
Mold Release Agents	Organic Compounds	Stationary Sources	11G	07C
Foam Rubber	Volatility	Volatile Organic Compounds (VOCs)	11J	20M
Polyurethane Resins			11I	
Molds			13I	
Emission			14G	
18. DISTRIBUTION STATEMENT Release to Public		19. SECURITY CLASS (This Report) Unclassified		21. NO. OF PAGES 61
		20. SECURITY CLASS (This page) Unclassified		22. PRICE

NOTICE

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FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

EPA's Air Pollution Prevention and Control Division (APPCD) completed an assessment of the processes, materials, installation practices and emission characteristics associated with the application of mold release agents (MRA). Emissions estimates were developed based on available information on MRA composition and consumption. Volatile organic compound (VOC) emissions of MRA were estimated to be 126,000 tons per year. The study also found that polyurethane molding operations accounted for a significant percent of the total MRA emissions (about 25 percent) and that automobile seat and other foam molding operations accounted for most of the emissions associated with the polyurethane category. Thus, the polyurethane foam manufacturing industry was selected for a pollution prevention technology demonstration.

Several pollution prevention alternatives were identified for conventional MRA usage in the polyurethane foaming industry. An initial assessment of each of the identified technologies was performed. APPCD selected the Solvent Emission Reduction Technology™ (SERT™) process for further evaluation. A detailed assessment of SERT™ was made through a demonstration at the Integram-St. Louis Seating polyurethane molding facility in Pacific, Missouri. The demonstration evaluated the applicability and technical barriers associated with the penetration of the SERT™ process into the current MRA using infrastructure, the overall emission reduction potential, and the costs associated with switching to the SERT™ process. The demonstration showed that a 60 percent reduction in VOC emissions is readily attainable with this process and that pollution prevention, i.e., the SERT™ process, is a much more cost effective way to reduce VOC emissions as compared to conventional treatment methods.

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LIST OF ACRONYMS

ABS	Acrylonitrile, Butadiene, Styrene Polymer
ACGIH	American Conference of Governmental Industrial Hygienists
APPCD	US EPA - Air Pollution Prevention and Control Division
BCC	Business Communications Company, Inc.
CAAA	Clean Air Act Amendments of 1990
CE	Cost Effectiveness
CFC	Chlorofluorocarbons
CO ₂	Carbon Dioxide
CRC	Capital Recovery Cost
CRF	Capital Recovery Factor
DoE	US Department of Energy
DoL	US Department of Labor
ECR	Environmental Consulting and Research
EPA	US Environmental Protection Agency
FOB	Free on Board
HAP	Hazardous Air Pollutant
HR	High Resiliency
HVLP	High Volume Low Pressure
MDI	Diphenyl Methane Diisocyanate
MRA	Mold Release Agent
MSDS	Material Safety Data Sheet
MVSS	Motor Vehicle Safety Standard
NTIS	National Technical Information Service
OAQPS	US EPA - Office of Air Quality Planning and Standards
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PPA	Pollution Prevention Act of 1990
PVC	Polyvinyl Chloride
QA	Quality Assurance
RTI	Research Triangle Institute
SERT™	Solvent Emission Reduction Technology™
TAC	Total Annual Cost
TCI	Total Capital Investment
TDI	Toluene Diisocyanate
TLV	Threshold Limit Value
tpy	Tons per Year
VAC	Volts, Alternating Current
VOC	Volatile Organic Compounds

LIST OF SYMBOLS

D	Percent Reduction in VOC
i	Interest Rate
n	Payback Period (years)
N_p	Number of Units Produced

Subscripts

n	New Technology (SERT™)
s	Standard Technology (Conventional)

METRIC CONVERSIONS

Nonmetric	Times	Yields Metric
ft	0.3	m
ft ²	0.093	m ²
in	2.54	cm
in ²	6.45	cm ²
lb	0.454	kg
scfm	0.00047	sm ³ /s
ton	0.907	tonne

SECTION 1

INTRODUCTION AND BACKGROUND

Over the past several years, a new and innovative approach to reducing hazardous waste and emissions has been rapidly developing in the United States. This new approach, called "pollution prevention," has been defined by the U.S. Environmental Protection Agency (EPA) as "the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the sources. It includes practices that protect natural resources through conservation or more efficient use."

In the Pollution Prevention Act of 1990 (PPA), the U.S. Congress passed legislation to make pollution prevention a major part of national environmental policy and required the EPA to facilitate the adoption of source reduction techniques by industries. Following the PPA, the U.S. Congress passed the Clean Air Act Amendments of 1990 (CAAA) which requires the EPA to establish a basic engineering research and technology program to develop, evaluate, and demonstrate non-regulatory strategies and technologies for air pollution. In response to this legislation, the EPA published the Pollution Prevention Strategy (56 FR 7849) which outlines EPA's pollution prevention goals and sets forth a program to achieve specific objectives. A key component of the program outlined in the strategy is the establishment of a pollution prevention research program to assist in the development, evaluation and demonstration of clean products and clean technologies. One such research program required the assessment of emissions and pollution prevention options for several consumer categories, including mold release agents.

The EPA's Air Pollution Prevention and Control Division (APPCD) completed an assessment of the processes, materials, installation practices and emission characteristics associated with the application of mold release agents (MRA). Eleven categories of industrial processes were identified as consumers of MRA. Emissions estimates were developed based on available information on MRA composition and consumption for these eleven categories. While the available data were limited, total emissions from industrial mold release agent use were found to be significant. Volatile organic compound (VOC) emissions for the eleven categories of MRA processes were estimated to be 126,000 tons per year. The study also found that polyurethane molding operations accounted for a significant percent of the total MRA emissions (about 25 percent) and that automobile seat and other foam molding operations accounted for most of the emissions associated with the polyurethane category. Rubber processing and polyester manufacturing were also found to be sizable, but not as significant as polyurethane.

Initial evaluations concluded that automotive and furniture seat cushion molding operations had the greatest opportunity for pollution prevention. These operations were

identified because: (1) their activity represents a significant fraction of the total national emissions associated with MRA usage, (2) processes related to MRA usage do not vary significantly in the automotive and furniture seat molding industries, making it likely that a single pollution prevention approach could be demonstrated that would be broadly applicable, and (3) several pollution prevention technologies at various stages of development are applicable.

Several pollution prevention alternatives were identified for conventional MRA usage in the polyurethane foaming industry. An initial assessment of each of the identified technologies was performed. This initial assessment included potential to reduce emissions of VOC, technical feasibility, and cost. Based on this preliminary evaluation, the Solvent Emission Reduction Technology™ (SERT™) process was selected for further evaluation. A detailed assessment of SERT™ was made through a demonstration at the Integram-St. Louis Seating polyurethane molding facility in Pacific, Missouri. The demonstration evaluated the applicability and technical barriers associated with the penetration of the SERT™ process into the current MRA using infrastructure, the overall emission reduction potential, and the costs associated with switching to the SERT™ process. The demonstration showed that a 60 percent reduction in VOC emissions is readily attainable with this process. Additionally, the study showed that the system can be cost effective in comparison to other pollution control strategies.

This document presents a detailed account of the studies performed under this project. Section 2 provides background information on MRA types and uses. Section 3 details the development of emissions estimates for MRA using industries. Section 4 provides a description and initial evaluation of the pollution prevention options for the polyurethane foam molding industry. Section 5 provides a summary of the SERT™ demonstration. Included in Section 5 is a discussion of the demonstration approach, the results of the demonstration, and an analysis of the costs associated with the SERT™ process. Section 6 is a discussion of data quality as it relates to the demonstration. Section 7 provides a summary and conclusion for the work performed in this project. References are provided in Section 8. Finally, the appendices contain various economic definitions and calculations, and a database of information on polyurethane molding facilities in the U.S.

SECTION 2

MRA BACKGROUND

2.1 GENERAL DESCRIPTION

An MRA can be generically described as any substance used to control or eliminate the adhesion of a material to itself or to another material. The MRA prevents the molded product from sticking to the mold so that the product can easily be removed in one piece. Factors such as penetration, chemical reaction and compatibility, low surface tension, surface configuration, and differences in polarity between the two materials influence adhesion between materials (Swift, 1990). MRA may also be known as adherents, anti-blocking agents, external or surface lubricants, parting agents, and slip aids. The MRA consists of the active ingredient (the ingredient that actually prevents adhesion) and a carrier or additive that is used to apply the active ingredient. The active ingredient is most often inert, that is, it contains no VOC. The carriers and additives often contain VOC, although non-VOC carriers and additives may be used. Major industrial applications for MRA include casting, molding, forming, and materials transfer operations in a wide variety of industries, including plastic (or polymer) processing, rubber, metal processing, glass, food processing, textiles, printing, and others.

Mold release agents can be divided into three major types of agents: external MRA, internal MRA, and permanent MRA. External MRA can be further divided into single release and semi-permanent MRA. External MRA operate much in the same manner as oil, lard, and non-stick sprays operate on cookware. Adherents can be applied to a surface by standard coating methods such as spraying, brushing, dusting, dipping, electrostatic powder coating, and plasma arc coating. The product (e.g., resin, metal, rubber, glass, etc.) is injected, laid, rolled, sprayed, etc., in the mold where the product is cured. The part is then released from the mold and the MRA is reapplied to the mold. Most external MRA are designed as single use MRA. That is, the MRA must be re-applied following every mold cycle.

Semi-permanents, or multiple release products, are a relatively new concept in release agents. Semi-permanents allow a relatively large number of processing cycles to occur (approximately 10) before re-application of the MRA is needed. They are usually water- or solvent-based with the latter predominantly used in heat-cured systems. They can be used to coat the mold or can be applied to become an integral part of the mold. Advantages include low buildup, promotion of excellent part surface and finish, minimal transfer to the part, high release efficiencies, low or non-toxicity of some products, and high temperature stability (up to 375 °C).

Internal MRA, typically metallic stearates, are agents that are added to the resin itself (Swift, 1990). While there is no consensus as to how such agents work, one hypothesis is

that the MRA migrates to the surface of the resin, that is, to the part/mold interface, during the interval between the injection and the ejection. The agent then acts as an external release agent, essentially lubricating the boundary. A number of factors influence the performance of internal MRA, including solubility in the resin, rate of migration, lubricity, melting point of the additive, and extent of electrostatic inhibition (Grayson, 1985; Percell, et al., 1987).

Self-releasing molds are coated with a permanent MRA, usually Teflon, high phosphorus nickel, or tungsten disulfide. Although not truly permanent, self-releasing molds are capable of producing several hundred molded parts before the surface needs to be reapplied. Application of the permanent MRA is performed at the MRA vendor's facility, and is relatively costly. As such, the use of permanent MRA has been limited to low production operations requiring a high level of mold detail.

Both internal and permanent MRA have little to no associated air emissions. However, many forms of external MRA contain significant amounts of organic solvent. As such, the remainder of this section will be limited to a discussion of external MRA.

2.2 EXTERNAL MRA FORMS

External MRA can be obtained as aerosol sprays, liquids, and dusts. Almost any MRA can be applied by a spray operation using a solution, dispersion, or emulsion. In fact, most mold release products can be applied by all of these methods, depending on the individual user's needs. Liquids are often used to brush or dip molds. Many parting agents are dusted directly on to the mold surface. Topical coatings include a variety of solid parting agents (e.g., mica, talc, metallic stearates, etc.), soap solutions, waxes, silicones, and other selective, formulated chemical compounds which can be applied by spraying, dipping, brushing, or dusting. Semi-permanents are available in aerosol and bulk packaging. Determining the proper MRA and MRA delivery system for a particular process and material is complex because selection is based on a multitude of chemical and physical factors. The end selection is generally based on process and finished part compatibility. Data shows that 25.8 million pounds (48 percent) of MRA active ingredient were spray applied in 1989, while 18.4 million pounds (34 percent) were applied by dipping or brushing (Swift, 1990). Dusting and other methods of application accounted for the remaining 10.1 million pounds (18 percent) of active MRA ingredient.

2.2.1 Aerosol Sprays

Spraying with aerosols is by far the most popular MRA application. While application can be repeated as often as required, the application activity also interrupts the molding cycle. Therefore, an effective MRA must allow rapid application. Silicones offer quick-application properties, and are widely used as sprays although large amounts of other mold releases are

also applied by spraying. Despite the fact that most aerosol sprays are more expensive than an alternative application, they are projected to maintain their dominance in the market (Swift, 1990).

2.2.2 Liquids

Using liquid MRA for brushing, dipping, and spraying is usually accomplished manually and offers low-cost application. Since productivity is low with brushing and dipping, these techniques have usually been limited to batch processing of low- to medium- volume products. Approximately 34 percent of mold release active ingredient consumed in 1989 was applied by brushing and dipping. With the rising cost of propellants due to chlorofluorocarbon (CFC) regulations, this mode of application is projected to slightly increase (Swift, 1990).

2.2.3 Dusts

Dusting and related methods are primarily used to apply powders such as talc and mica, calcium stearate, calcium silicate, polyethylene powders, powdered waxes and minor amounts of other related mold releases. Dusting is also usually performed manually and offers low-cost application although productivity is low. A major application of dusting is for soft rubber products such as rubber bands, tubing, and rubber sheets. Closely related to dusting for MRA application is electrostatic powder coating and plasma arc coating. These methods feature much higher productivity, but can entail a sizable capital investment. As a result they are used primarily in high-volume applications.

2.3 MRA COMPOSITION

As mentioned earlier, an MRA consists of two chemical parts: the active ingredient and the additives, including the carrying agent(s) or carriers. The active ingredient is the actual mold release agent, i.e., the material that prevents the adhesion. The additives are the compounds, solvents, or aerosols added to the active ingredient that deliver the agent in the form that will work best for the particular molding process.

The active ingredients are generally inert, containing no, or very little, VOC. Active ingredients common to topical coatings are parting agents, soaps, waxes, silicones, and others including graphites and natural products (e.g., flour). Semi-permanent formulations are generally proprietary, because of the competitiveness of the market. The additives and carriers portion of an MRA can be solvents (e.g., mineral spirits), oils, water, or other materials. Virtually all MRA can be applied by a spray operation using a solution, dispersion, or emulsion. For example, CFCs or some other alternative propellant such as 1,1,1-trichloroethane are often used in sprays. Many parting agents such as talc, mica, and metallic stearates are dusted

directly on to the surface without being mixed with any kind of additive. A list of the active ingredients consumed in 1989 by MRA type is given in Table 2-1.

TABLE 2-1. SUMMARY OF MRA TYPES AND CONSUMPTION

MRA TYPE	ACTIVE INGREDIENT CONSUMED (million lbs)
Topical Coatings	50.0
Parting Agents	16.2
Soaps	2.2
Waxes	11.9
Silicones	17.1
Others (graphites, oils, flour, etc.)	2.6
Semi-Permanents	4.3
TOTAL	54.3

Determining the active ingredient and additives to incorporate into an MRA is based on several variables, such as the material being molded, the molding process, the configuration of the mold, the cycle time, etc. Currently, there are about 10,000 different formulations on the market, many of which are proprietary, plant and process specific MRA (Allardice, 1981).

2.4 POTENTIAL EMISSIONS SOURCES

Emissions from MRA use can occur at several points in the application process and depend primarily on the mode of application. With external MRA, VOC emissions will occur from the application of sprays and liquids. Emissions points are the applicator, the mold and the product. Emissions points for application and use of semi-permanents are similar to other external MRA. However, since these MRA are not applied as frequently as externals, their relative emissions (assuming the same VOC content as a comparable, external MRA) will be lower.

Another source of emissions from the MRA application process involves clean up activities. Mold surfaces are cleaned at regular intervals to increase the efficiency of the MRA. Many of the products used in clean up are solvents with high VOC contents (e.g., mineral spirits, trichloroethylene).

2.5 USE IN INDUSTRY

MRA are used in many industries including polymer processing, rubber, metal, glass, and food processing. In the U.S., there are 14,248 molding plants which use processes that require an MRA. Total active ingredient consumption in 1989 was 54.3 million pounds. Polyurethanes consume the greatest amount of MRA active ingredient with 12.8 million pounds. Padding/cushioning and appliance insulation are the most common uses for the finished polyurethane. Table 2-2 lists MRA usage for several industries (Swift, 1990). The manufacture of molded polyester and the processing of rubber and metal are also major consumers of MRA. Molded polyester finds a variety of uses including boat hulls, automobile body panels, and bath tubs. The processed rubber is used to make tires, hoses, and belts. Die casting and metal fabrication are the most common applications for metal processing. Table 2-3 presents a list of the types of MRA used in each industry. Most industries can use a variety of MRA formulations based on mold and product characteristics.

TABLE 2-2. MRA ACTIVE INGREDIENT CONSUMPTION BY INDUSTRY IN 1989

INDUSTRY	MRA ACTIVE INGREDIENT USE	PERCENT OF USE
Polymers - Thermosetting	23.3	42.9
Polyurethanes	12.8	23.6
Polyesters	6.7	12.3
Epoxies	1.7	3.1
Others	2.1	3.9
Polymers - Thermoplastic	8.2	15.1
PVC	3.0	5.5
Polystyrene	2.9	5.3
Others (ABS, Nylon)	2.3	4.3
Non-Polymers	22.8	42.0
Rubber Processing	8.9	16.4
Metal Processing	6.7	12.3
Glass	4.1	7.6
Others (Food)	3.1	5.7
TOTAL	54.3	100.0

TABLE 2-3. ACTIVE INGREDIENTS AND THEIR USE BY INDUSTRY

INDUSTRY	MRA TYPE	CONSUMPTION (10 ⁶ lb)
Polymers		
Thermosetting & Thermoplastic	Fine Particle Solids	1.0
	Metallic Stearates	6.3
	Polymers	4.2
	Soaps	2.2
	Waxes	8.2
	Silicones	5.7
	Semi-Permanents	3.9
	Total	31.5
Non-Polymers		
Rubber Processing	Fine Particle Solids	2.7
	Metallic Stearates	1.0
	Polymers	0.9
	Waxes	1.1
	Silicones	2.8
	Semi-Permanents	0.4
	Total	8.9
Metal Processing	Metallic Stearates	0.1
	Waxes	2.6
	Silicones	2.8
	Others	1.2
	Total	6.7
Glass	Silicones	3.0
	Other	1.1
	Total	4.1
Other	Silicones	2.0
	Other	1.1
	Total	3.1
TOTAL		54.3

SECTION 3

AIR EMISSION ESTIMATES FOR MRA USAGE

Industry-specific air emission estimates for aerosol sprays and liquids were developed based on literature data, contact with users, MRA vendors and manufacturers, and material safety data sheets (MSDS). The MRA applied as dusts are assumed to contain only active ingredient, i.e., no additives or carriers. Therefore, no VOC emissions are expected from MRA dusts. Section 3.1 summarizes the methodology used in estimating emissions from MRA use. Section 3.2 presents the industry-specific emission estimates.

3.1 METHODOLOGY

For liquids and aerosol sprays, the total weight is equal to the sum of the active ingredient and solvents. The solvents can contain both volatile organic compounds (VOC) and hazardous air pollutants (HAP). Solvents identified as HAP were typically non-VOC compounds including 1,1,1-trichloroethane and methylene chloride. MSDS representing each MRA type (aerosol spray, liquid, etc.) were utilized to determine the composition for that MRA type. The methodology used to estimate emissions from aerosol and liquid MRA are discussed in detail in the following sections.

3.1.1 Aerosol Spray-Applied MRA

Based on the literature, 25.8 million pounds of MRA active ingredients were spray applied in 1989. In addition, 75 percent of sprayed MRA active ingredients are applied by aerosol and 25 percent are liquids sprayed with compressed air (Swift, 1990). Based on this information, it is estimated that 19.4 million pounds of active ingredient are applied using an aerosol spray. Sixteen MSDS of MRA aerosols were provided by MRA vendors. These MSDS were reviewed, and average composition values for aerosol MRA were calculated. The average composition of an aerosol MRA is 4 percent active ingredient, 33.5 percent VOC, and 62.5 percent HAP by weight. Note that the average VOC and HAP contents are not representative of any one MRA formulation. Rather, individual MRA formulations are apt to contain only one solvent type, either all VOC or all HAP.

The total weight of aerosol MRA can be determined by dividing the average active ingredient percentage into the total amount of active ingredients. By dividing 19.4 million pounds of active ingredients for aerosol MRA by 4 percent, a total weight of aerosol MRA of 484 million pounds can be estimated.

To estimate the total VOC and HAP, the total weight is multiplied by the respective percent composition, as follows:

VOC	=	(484 million lb) x 33.5%
	=	162 million lb (81,000 tons)
HAP	=	(484 millions lb) x 62.5%
	=	302 million lb (151,000 tons)

3.1.2 Liquid MRA

The literature states that 18.4 million pounds of active ingredients for brushed and dipped MRA, plus 6.5 million pounds of non-aerosol spray-applied MRA are associated with liquid MRA. The total amount of liquid MRA is assumed to be 24.9 million pounds. Nine MSDS of MRA liquids were provided by MRA vendors. These MSDS were reviewed and average composition values for liquid MRA were calculated. The average MRA liquid is estimated to contain 12 percent active ingredient, 43 percent VOC, and 45 percent non-VOC by weight. No HAP compounds were identified in the MSDS reviewed for liquid MRA.

The total weight of liquid MRA was determined by dividing the average percent active ingredient into the total amount of active ingredients, as follows:

Total Weight	=	(24.9 million lb) ÷ 12%
	=	207 million lb (103,500 tons)

To estimate the total VOC, the total weight is multiplied by the respective composition percentages, as follows:

VOC	=	(207 million lb) x 43%
	=	89 million lb (44,500 tons)

Several MRA vendors were asked to comment on the liquid MRA VOC estimates. One concern was that the MRA liquid market is moving toward water-based MRA. If this is true, the estimated VOC percentage may be too high. From discussions with metal die-casting representatives, the active ingredients are diluted with 40 parts water to one part active ingredient. The additives and carriers for this particular industry are mainly water. The VOC emissions calculated above may be an overestimate due to the inclusion of the metal die-casting active ingredient with the other liquid active ingredients.

3.2 EMISSIONS ESTIMATES BY INDUSTRY

Total VOC emissions from MRA, as calculated above, are 125,600 tons. Industry-specific emissions estimates were calculated using data on the amount of active ingredient consumed and the total emissions estimated for MRA above. Total emissions were apportioned to an industry based on industry-specific active ingredient consumption, from Table 2-2. A detailed survey of each industry would be required to obtain better resolution and estimates of relative percentages than are used here. As an example, MRA VOC emissions for the polyurethane industry are calculated as follows:

$$\begin{aligned}
 \text{VOC polyurethane} &= (\text{polyurethane \% of MRA use}) \times (\text{total VOC MRA emissions}) \\
 &= (0.236) \times (125,600 \text{ tons}) \\
 &= 29,600 \text{ tons}
 \end{aligned}$$

Table 3-1 provides VOC emissions by industry. Table 3-2 presents a summary of national VOC emissions for 1990, except for miscellaneous emissions, showing the importance of MRA use relative to other major emission sources (U.S. EPA, 1995). MRA is included under the general industry category of Surface Coatings.

TABLE 3-1. MRA VOC EMISSIONS BY INDUSTRY

INDUSTRY	VOC EMISSIONS (tons)
Polyurethanes	29,624
Polyesters	15,440
Epoxies	3,891
Other Thermosets	4,895
Polyvinyl chloride	6,904
Polystyrene	6,653
Other Thermoplastics	5,272
Rubber Processing	20,586
Metal Processing	15,440
Glass Industry	9,540
Other Non-Polymers	7,155
TOTAL	125,600

TABLE 3-2. SUMMARY OF NATIONAL VOC EMISSIONS*

CATEGORY	VOC (tons)
Highway Vehicles	6,854,000
Solvent Utilization	6,100,300
Surface Coating	2,619,000
Non-Industrial	1,900,000
Degreasing	757,000
Graphic Arts	363,000
Dry Cleaning	209,200
Mold Release Agents	125,600
Other Industrial	126,500
Waste Disposal and Recycling	2,261,800
Off Highway	2,119,500
Storage and Transport	1,758,700
Chemical and Allied Product Manufacturing	1,525,500
Fuel Combustion Electrical Utilities/Industrial/Other	919,500
Petroleum and Related	643,500
Other Industrial Processes	400,700
Metals Processing	72,300
TOTAL VOC EMISSIONS	22,655,800

* Table excludes "Miscellaneous" category

SECTION 4

POLLUTION PREVENTION OPTIONS FOR THE POLYURETHANE FOAM INDUSTRY

Polyurethane molding operations account for a significant percent of total MRA emissions (about 25 percent) as shown in the emission estimates presented in Section 3. Further review indicated that automobile seat and other foam molding operations accounted for most of the emissions associated with the polyurethane category (Southern Research, September 8, 1993). APPCD decided to identify and characterize pollution prevention opportunities for solvent-based MRA in the polyurethane foam molding industry due to the significance of this single industrial activity. This section summarizes the findings of these investigations.

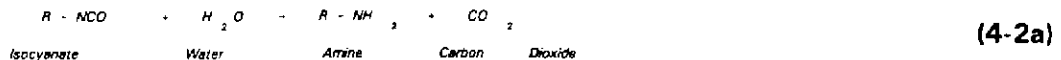
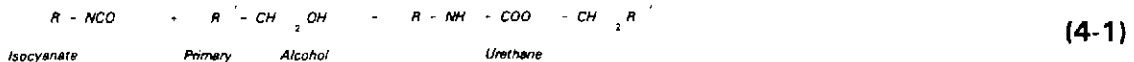
4.1 MOLDED POLYURETHANE INDUSTRY PROFILE

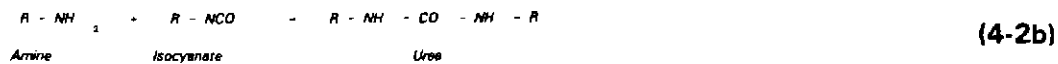
4.1.1 Process Description

Polyurethane foam molding is both a chemical process and a mechanical production process. Polyurethane foam is formed by the reaction of isocyanates with polyols and water. By running this chemical reaction inside a mold, a final product can be made in a wide variety of shapes and sizes. The following sections describe both the chemical and mechanical processes involved in the manufacturing of molded polyurethane foam.

4.1.1.1 Polyurethane Chemistry

The basic reaction in industrial polyurethane chemistry is the reaction of hydrogen from water, a hydroxyl group, or an amine with an isocyanate. Hydroxyl groups are found in alcohols. Equation 4-1 shows the reaction of a primary alcohol with an isocyanate to form a urethane, while Equations 4-2a and 4-2b show the reaction of the isocyanate with water and the subsequent reaction of the amine product with the isocyanate to form a urea (Dow, 1991).





Equation 4-2a is important because the gas (CO₂) liberated during this reaction is responsible for the foaming of the material. Primary amines, such as the one in Equation 4-2b, are much more reactive than primary hydroxyls and water toward isocyanates. Water and primary hydroxyls are equally reactive with isocyanate. Therefore, catalysts are often necessary to optimize the reaction with hydroxyls and water in order to obtain the desired products.

Two types of isocyanate are commonly used in industry. The most common type is Toluene Diisocyanate (TDI). The 2, 4 and 2, 6 isomers of TDI are often used in a mixture, 80 percent and 20 percent, respectively, (abbreviated 80:20 TDI) (Dow, 1991). However, some processes use 65:35 mixtures or a pure isomer. The second type of isocyanate used is diphenyl methane diisocyanate (MDI). Recently, some advantages to using MDI have been discovered. These advantages include: shorter cycles, lower molding temperatures, less mold waste from vents and seals, and a higher rate of cure. The most common MDI mixtures are polymeric MDI and a prepolymer, a partially reacted, not fully polymerized urethane, or polymeric MDI with pure 2, 4'- or 4, 4'-MDI. Pure 2, 4' and 4, 4'-MDI react too quickly to be used alone. Polyurethane foam recipes usually specify isocyanate concentration as an index. This index is a percentage of the amount determined by stoichiometry. Therefore, 105 index means that 105 percent of the stoichiometric amount of isocyanate is used. Commonly, the index is between 90 and 120.

Polyols are polyether compounds that contain more than one hydroxyl group (Dow, 1991). These compounds take the place of the alcohol in Equation 4-1. The polymers used here vary from formulation to formulation, but most have molecular weights between 2000 and 7000. Polyols are the polymerization product of an initiator and an alkylene oxide. Common initiators include ethylene glycol, propylene glycol, glycerine, and ethylene diamine. The two most common oxides used in polyol preparation are ethylene oxide and propylene oxide. The ethylene oxide polymer will have primary hydroxyl reaction sites, while the propylene oxide polymer will have secondary hydroxyl reaction sites. The use of a secondary hydroxyl polyol imparts different characteristics to the polymer. In industrial practice, the use of primary and secondary hydroxyl polyols does not significantly change the processing time since all foaming reactions are run in the presence of several catalysts.

Catalysts play an important role in foam production, as most foam recipes include several catalysts. Different catalysts are used to increase the rate of foam production, and to increase the rate of gas production from the reactions in Equations 4-2a and 4-2b. The most common types of catalysts are tertiary amines and organometallics (Dow, 1991). The tertiary amines have a free electron pair on the nitrogen atom which aides in the formation of highly reactive complexes. Tin based compounds are the most used organometallic catalysts. The tin is usually held to the organic part of the molecule by ester linkages. Organometallics are

generally thought of as gelation catalysts while the tertiary amines are used more as blowing catalysts. The rates of the two reactions (polymer gelling and blowing) must be balanced so that gas is efficiently trapped in the foam and the cell walls develop sufficient strength to maintain their structure.

Other compounds that are added to the foam mixture are surfactants, cross-linkers, blowing agents, and flame retardants. The surfactants are nonionic and silicone based. They are used to lower bulk surface tension, emulsify incompatible formulation ingredients, promote nucleation of bubbles during mixing, reduce stress concentrations in cell walls, and counteract the defoaming effect of solids. The cross linkers are short-chain polyfunctional polyols. They join the polymer chains together, thus adding load bearing capabilities and increasing stability. If the water present in the system cannot generate enough gas to promote foaming, an additional blowing agent will be introduced. Previously, blowing agents were chlorofluorocarbons (CFCs), however, industry is currently looking at new compounds for use as blowing agents. The last major component added to foams is a flame retardant. Flame retardants are important since many foam products are required to meet state and federal regulations regarding flammability. The most common types of flame retardant used today are chlorinated phosphate esters.

4.1.1.2 Foam Processing

There are several ways to manufacture polyurethane foam. Generally, foams are molded or made into large slab stocks. The molded foams can then be broken down into two types: hot cure and high resiliency (HR) foam. The high resiliency foam is very common in North America because it uses much less energy than hot cure foams. In automobile seat processing, roughly 45,000 Btu are used to process one hot cure cushion, which is enough energy to process six high resiliency cushions. The following paragraphs describe an industrial HR foam molding operation (Dow, 1991). Figure 4-1 provides a simplified process flow diagram of a typical high resiliency polyurethane molding line.

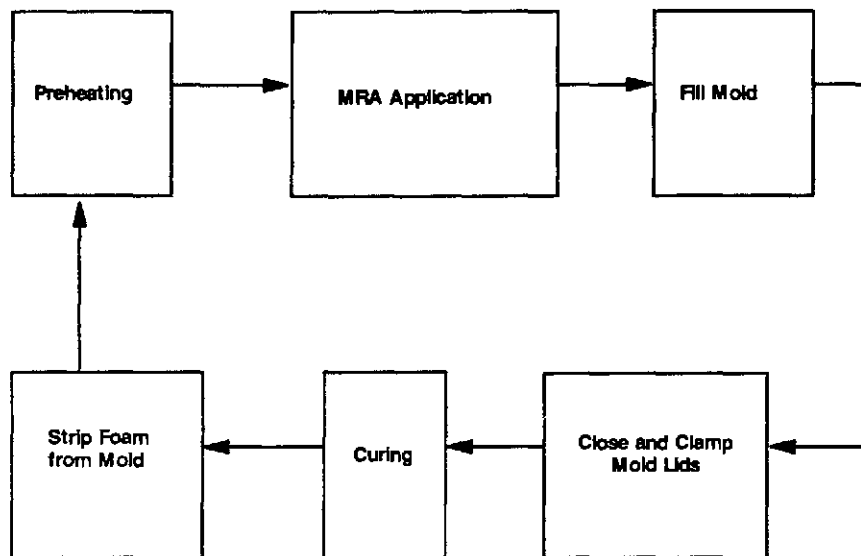


Figure 4-1. Schematic of foam molding process.

Industrial polyurethane foam molding operations are highly automated processes. The molds typically revolve on a carousel or around a "racetrack". The carousel style is becoming increasingly popular because it requires less space. Additionally, changes to the foaming process have led to significantly shorter residence times within the mold, therefore allowing for a smaller process with greater production capacity.

The first step in the process is to preheat the molds. The use of a preheated mold helps to evenly dissipate the heat generated by the polymerization reaction. This, in turn, gives a uniform skin density and helps to complete the reaction at the skin. Next, the mold is sprayed with a release agent. Urethanes are good adhesives, and without a release agent it would be impossible to remove the molded piece intact. The preheating of the mold also aids in the release agent process. Preheated molds flash off the solvent carriers used in the MRA. At this point, the necessary foam ingredients are added to the mold. The polyol and isocyanate are fed into a mixing head from local storage tanks. The mixing heads can be low pressure, which require solvent cleaning, or high pressure impingement mixers, which are self-cleaning. The mixing head is attached to a robot, which aids in evenly distributing the foam system within the mold. Since the mixing/distribution system is used discontinuously, recirculation pumps have been added to return unmixed reactants to their storage tanks for later use.

The molds are generally made of cast aluminum. In high resiliency molding, the molds have few vents, and therefore, must be able to withstand pressures of up to 30 psig. All seals

must be tightly clamped to allow pressure of that magnitude. The molding surface has an unpolished finish to allow for better coating of the mold release agent. The lids are mechanically opened and closed. After the mold has been closed and locked, it proceeds through a curing oven if more than ambient temperatures are needed to cure the foam. Generally, these ovens heat the molds to a range of 170°F to 200°F. If no additional heat is required, the mold simply continues around.

The product is now ready to be removed. There are processes for removing the part mechanically and by hand. Care must be taken when removing the part, so that it is not damaged. The effect of the MRA is seen here. After the part is stripped from the mold, it is placed on a conveyor that leads to a storage area. The mold is then cleaned if necessary. At this point, the process can begin again with the application of the mold release agent or preheating if necessary.

4.1.2 Molded Polyurethane Facilities

APPCD obtained and reviewed a database of polyurethane foam molders created by Environmental Consulting and Research (ECR). Appendix B summarizes the data pertaining to mold release agents collected on the foam molding facilities. It appears that the database of facilities may be incomplete. The total annual production represented in the database is just under 100,000 tons per year (tpy). Two literature sources estimate the nationwide molded polyurethane demand at roughly 1,600,000 tpy (Swift, 1990; Polyurethane Foam Association, 1991). It is also possible that the literature estimates include slab stock polyurethane foam. While the database may be incomplete, several observations can be made assuming the database provides a representative sample of polyurethane foam molding facilities.

The molded polyurethane foam industry's primary products include automotive seating (70 percent) and furniture cushions (20 percent). Other products include molded dashboards, arm rests, packaging, toys, and miscellaneous molded foam parts.

Facility size varies greatly within the polyurethane foam molding industry, from less than 5 tpy to as high as 15,000 tpy of polyurethane. The average facility size is estimated to be 2,300 tpy of polyurethane, with nearly 50 percent of the facilities having a capacity less than 500 tpy of polyurethane. However, the majority of production (roughly 65 percent) is accounted for by facilities with a production capacity greater than 5,000 tpy of polyurethane.

4.2 POLLUTION PREVENTION OPTIONS

Several potential pollution prevention technologies for reducing VOC and HAP emissions from the use of MRA at polyurethane molding operations have been identified. Potentially feasible technologies examined here include the following:

- (1) High Volume Low Pressure (HVLP) spray guns,

- (2) Solvent Emissions Reduction Technology™ (SERT™),
- (3) Water-based MRA,
- (4) High solids MRA,
- (5) Powder Mold Release System,
- (6) Permanent MRA, and
- (7) Semi-permanent MRA.

4.2.1 High Volume Low Pressure Spray Guns

HVLP spray guns are currently used in several coating industries, including polyurethane foam molding. The use of HVLP spray guns minimizes the effect of overspray, the fraction of coating which does not adhere, by producing a more uniform aerosol size distribution. The performance of HVLP has been well documented and has been shown to potentially reduce coating usage and emissions by 30 to 50 percent over conventional spray gun technology. While the capital cost of HVLP is higher than conventional spray guns, the savings in annual coating costs can more than offset the initial capital cost differential. A cost effectiveness of -\$1200 per ton of VOC reduced was estimated over conventional spray technology with solvent-based MRA. HVLP can be used in conjunction with conventional, water-based, and high-solids MRA.

4.2.2 Solvent Emission Reduction Technology™

SERT™ was developed by Union Carbide specifically for the polyurethane foam molding industry. This technology has been under development since 1989, and is now commercially available from OSI Specialties*. In SERT™, supercritical carbon dioxide (CO₂) is used as the solvent carrier to deliver a specially formulated MRA to the mold using spray guns. SERT™ is an offshoot of Union Carbide's UNICARB™, a system that uses supercritical CO₂ to apply paints. The critical point of CO₂ is 88 °F and 1,070 psi. Above these conditions, CO₂ acts as a solvent. When sprayed the CO₂ flashes off almost instantaneously upon leaving the spray nozzle. Only a fine spray remains, consisting mostly of MRA active ingredient and a small amount of solvent. The solvent is required to assist in good film formation on the mold surface (i.e. even, complete coverage of the mold with MRA). This results in good release characteristics with minimal MRA buildup.

Discussion with the vendor indicated that results of limited tests have been encouraging. With SERT™, the VOC content of the MRA is low, as is the usage rate, resulting in high VOC reductions compared to the use of solvent-based MRA. Emission reductions of 70 to 80 percent are being achieved now in limited demonstrations, but reductions of 90 to 95 percent may be possible with incorporation of higher solids MRA. OSI plans to begin the research necessary to extend the use of SERT™ into other molding operations.

*OSI Specialties, Box 38015, 3200/3300 Kanawha Turnpike, South Charleston, WV 25303-3815

Based on the information supplied by the vendor, SERT™ provides as good or better performance as conventional MRA (Dan Blakemore, OSI Specialties, Teleconference, June 1994). Only the carrier solvent is replaced with super-critical CO₂ and standard active ingredients are used. However, some concerns exist regarding the initial capital investment required to adopt SERT™ at the plant level. The equipment cost for the SERT™ process is on the order of \$60,000 per line (Dan Blakemore, OSI Specialties, Teleconference, June 1994). Discussions with the vendor indicate that the market they are targeting is automotive seat manufacturers who, the vendor believes, could accept the SERT™ capital expense. A substantial emission reduction could be achieved even if only the largest plants adopted SERT™. A review of the industry shows that nearly 70 percent of all molded foam is produced by companies with capacities greater than 5,000 tpy of polyurethane.

The cost of the reformulated MRA on a per gallon basis is higher than solvent- and water-based MRA. However, since SERT™ MRA is more concentrated, less MRA is used resulting in an actual cost between that of solvent-based and water-based MRA. Based on information supplied by the vendor, a preliminary cost effectiveness estimate of \$1,000 per ton of VOC reduced was made. In addition to incremental MRA costs, this estimate includes an annualized capital cost for SERT™ based on a 10 year life and a 10 percent cost of capital.

4.2.3 Water-Based MRA

Water-based release agents use water as the primary carrier, have low VOC contents ranging from 0 to 10 percent, and generally have usage rates that are about 50 percent higher than solvent-

based MRA. Although solvent-based MRA typically have lower usage rates than water-based MRA, the VOC contents range from 43 to 99 percent. The solvent content of a conventional spray-applied MRA is typically 95 percent or higher. For a typical molding operation using 100 gallons of solvent-based MRA, the VOC content would be 95 gallons. For the same operation, up to 150 gallons of water-based MRA may be used, with a VOC content of between 0 and 15 gallons, representing an emission reduction of between 84 and 100 percent.

Water-based MRA have been used in automotive seat molding facilities with mixed results. A review of the facility database indicates that at least eight facilities are currently using water-based MRA. Correspondence with two car seat molding plants that use water-based MRA indicated that water-based MRA can be successfully integrated into the seat molding process, but time and effort are required to successfully make the transition from solvent-based to water-based MRA (Doug McClain, Douglas and Lomason, Teleconference, September 1993; Anant Shah, Johnson Controls, Teleconference, September 1993). Successful transitions have occurred in both cases without a decrease in the production rate. However, according to plant personnel, problems still exist with the increased number of defects and the elevated price of the release agent.

Technical issues associated with the use of water-based MRA include potential for increased defects, difficulties in application, and MRA cost. Isocyanate, one of the primary

ingredients in polyurethane foam, reacts with water to form carbon dioxide. The presence of residual water on the mold surface can lead to the formation of carbon dioxide at the mold surface which can cause surface defects. One vendor claims to have developed a water-based MRA which creates a "barrier" between any residual water and the polyurethane foam (John Robinson, Air Products, Teleconference, June 1994).

Water-based MRA could be integrated into most existing polyurethane foam molding facilities since the application technology, spray guns, is the same as for conventional solvent-based MRA. However, according to the industry, water-based MRA do not apply as evenly as solvent-based MRA because it is more difficult to achieve a fine mist spray that coats all surfaces of the mold. The water-based MRA is, therefore, subject to overspraying and as a result, there is increased build-up in the mold. Plant personnel also reported excessive build-up in the molds caused by the isocyanate/water reaction mentioned above. In an attempt to reduce the problems with overspray, one facility has evaluated different spray technology, and has found that HVLP spray guns help control MRA buildup when using water-based MRA.

In addition to the technical difficulties, there may be a cost penalty associated with water-based solvents. Based on information supplied by one of the facilities using a water-based MRA, the cost differential between water-based and solvent-based MRA is approximately \$4 per gallon (Doug McClain, Douglas and Lomason, Teleconference, September 1993). Southern Research estimated an increase in MRA cost for a 2,000 tpy polyurethane facility would be on the order of \$85,000 per year, with cost effectiveness estimated at approximately \$1700 per ton VOC reduced. Increased defect rates or reduced production rates may increase the cost further.

4.2.4 High-Solids MRA

High-solids MRA formulations are under development. Typical active ingredient content for conventional solvent-based MRA is less than 5 percent. The remaining 95 percent is composed of solvents used as a carrier fluid and for proper film formation. By increasing the active ingredient content, less solvent is used for the same amount of active ingredient applied. For the flexible polyurethane foam molding industry, high solid MRA have active ingredient concentrations ranging from 6 to 12 percent (Paul Gavin, Chem-Trend, Teleconference, June 1994). For example, for an application of 5 gallons of active ingredient using conventional solvent-based MRA containing 5 percent solids, 100 gallons of total MRA would be used consisting of 95 gallons of VOC. For a high-solid MRA with an active ingredient content of 10 percent, only 50 gallons of total MRA would be needed with a total VOC content of 45 gallons. This corresponds to a 53 percent reduction in VOC emissions.

Limited operating experience exists for high-solid MRA. Based on discussions with the vendor, high-solid coatings are difficult to apply using conventional spray technologies and HVLP spray guns would be needed to achieve good results. MRA buildup could also be a problem due to difficulties achieving a uniform coat, and a tendency for workers familiar with

conventional MRA to over apply the high solids MRA. No facilities were identified that are currently using high-solid MRA.

An estimate of the cost effectiveness of high-solids MRA was made based on the information supplied by the vendor (Paul Gavin, Chem-Trend, Teleconference, June 1994). The cost of high-solid MRA is much higher on a per gallon basis than solvent-based MRA. This is only partially offset by the lower usage rate. High-solids MRA are estimated to result in a cost effectiveness of \$3,000 per ton of VOC reduced.

4.2.5 Powder-Based MRA

Polymerit began development of a powder-based MRA in 1987. The technology has been tested by the vendor at several polyurethane molding facilities (Bror Hanson, Polymerit, Teleconference, June 1994). However, there are currently no polyurethane molding facilities using the Polymerit system. Polymerit uses a dry powder release agent instead of other conventional agents (e.g., waxes or silicones). The powder contains no VOC resulting in a 100 percent emission reduction over conventional solvent-based MRA. Prior to service, each mold must be pre-conditioned with a coat of Polymerit base coat. According to the vendor, this conditioning is only required once during the lifetime of the mold. A coating of powder is then applied prior to each molding. Several different powders are used depending on the type of foam to be molded and the surface desired on the part. Currently, the powder is applied with a powder-impregnated urethane sponge. Alternative application strategies are being evaluated by the vendor to decrease the application time required.

Limited demonstrations of the Polymerit system have been performed for the industry. Although full sized parts have been produced, these tests have generally been limited to non-production scale demonstrations (i.e. one mold used to produce 100 to 1000 parts). Companies who have participated in these demonstrations include Dow Chemical, Johnson Controls, Lear Seating, Woodbridge Foam, and Michigan Seat. Southern Research contacted the representatives from these companies to determine the success of the demonstrations. All companies contacted said the powder-based MRA produced excellent parts and had several advantages over water-based MRA. The powder-based MRA eliminated waxy MRA carryover often occurring with both conventional and water-based MRA. Also, the powder-based MRA system is reported to result in much less mold cleaning. One group who had evaluated the powder-based MRA noted that the "skin" on the foam produced had an open pore structure, which allows the foam to "breathe", a desirable quality for seat cushions (Douglas Hunter, Dow Chemicals USA, Teleconference, June 1994).

The biggest factor keeping the Polymerit powder-based MRA from entering the market place is the need for a better application method. The current system cannot keep up with the high production rate of large polyurethane molding operations. A representative of the Woodbridge Corporation said that the MRA application time is roughly six seconds at their automotive seating facilities (Erny Gatto, Woodbridge Group, Teleconference, June 1994). In comparison, the Polymerit application time is currently on the order of 25 seconds. As

mentioned above, Polymerit is continuing to evaluate alternative methods for applying the powder.

Based on information supplied by the vendor, the powder-based MRA is approximately 30-50 percent more costly on a per part basis than conventional solvent-based MRA. In comparison, water-based MRA are estimated to cost nearly twice as much as conventional solvent-based MRA on a per part basis. In addition, the vendor is currently charging \$500/mold for pre-conditioning. This cost would be lower for a licensed facility. Based on information supplied by the vendor, a cost effectiveness estimate of \$830 per ton of VOC reduced was estimated. This includes the cost of pre-conditioning the mold, but does not include any developmental costs associated with making a more "production oriented" MRA delivery system.

4.2.6 Permanent MRA

Self-releasing molds are coated with a permanent MRA, usually Teflon, high phosphorus nickel, or tungsten disulfide. No polyurethane foam molding facilities have been identified as using permanent MRA. Based on discussions with one Teflon applicator, permanent MRA have several technical problems (Tom Sloan, Plas-Tech Coating, Teleconference, June 1994). The primary problem is that teflon-based MRA are not permanent. According to the above vendor, for a polyurethane foam molding operation, no more than 300 to 400 cycles could be expected before the coating would need to be reapplied. Based on a cycle rate of 1 part every 10 minutes, it is estimated that a mold would need to be recoated every 2 to 4 days. The molds would need to be taken out of service as the coating can not be applied on site, necessitating extra sets of molds. A second problem with permanent MRA is that they do not have the best release characteristics. This could lead to increased defects due to rips or tears caused by sticking. In addition, as the mold gets dirty the problems with sticking become worse. As a result, to get good performance, the molds would need cleaning approximately every 10 cycles. In addition, since teflon is non-wetting, conventional MRA cannot be used in conjunction with permanent MRA as the conventional MRA would bead-up and not leave a uniform coat.

The initial cost of preparing a teflon coated self-releasing tool is estimated at \$4 to \$6 per square foot of mold surface (Tom Sloan, Plas-Tech Coating, Teleconference, June 1994). For a simple 1.5' by 1.5' by 0.33' rectangular mold, the surface area would be 6.5 square feet, and the cost to prepare the mold would be roughly \$30. No attempt was made at estimating a cost effectiveness value for permanent MRA due to the high loss of production that would be incurred.

4.2.7 Semi-Permanent MRA

Semi-permanent MRA are more durable than conventional MRA. The solvent content of semi-permanent MRA can be comparable to conventional solvent-based MRA, however, several moldings can be performed before the MRA needs to be reapplied. A theoretical

emission reduction of 90 percent could be achieved with an application rate of once per 10 moldings. Water-based semi-permanent MRA are also being developed which could increase the emission reduction to nearly 100 percent.

Semi-permanent MRA are currently used in several molding industries. However, none of the polyurethane foam molding facilities are believed to be using semi-permanent MRA at this time. According to vendors, due to the longer curing time required (approximately 1 hour), semi-permanent MRA are best suited for long, low cycle operations (molding of airplane wings was given as an example) (Dave Martin, Dexter Freco, Teleconference, June 1994). Polyurethane foam molding has a very high cycle rate, roughly 1 part every 10 minutes, which make semi-permanent MRA undesirable. Taking the molds out of production for 1 hour every 10 parts would result in a potential production decrease of 37 percent when compared to conventional MRA. For comparison, a process with a 2 hour cycle time would only experience a five percent decrease in production. No attempt was made at estimating a cost effectiveness value for semi-permanent MRA due to the high loss of production that would be incurred.

4.3 SELECTING AN OPTION FOR DEMONSTRATION

The first step in selecting an option is to summarize the information available for each option. Table 4-1 summarizes the cost effectiveness values for each option. The cost effectiveness is a combination of the costs associated with an option and an option's potential to reduce emissions. Other information to be considered is technical feasibility. The last three options presented (powder-based, permanent, and semi-permanent MRA) are currently not suitable for large high-output polyurethane production lines. The other four options have been used on large, production lines in testing or actual production. HVLP spray guns offer a cost savings but are already widely used to apply MRA as well as a number of other coatings. HVLP spray guns were, therefore, not selected for this demonstration. From the three remaining candidates, the SERT™ system was selected for the demonstration based on two factors: (1) the SERT™ system is more cost effective than the high solids system, and (2) installing the SERT™ system for the demonstration would require far fewer changes to the equipment and foam formulation than the water-based system, thus, minimizing the impact on the industrial site selected for the demonstration.

TABLE 4-1. COMPARISON OF POLLUTION PREVENTION OPTIONS

TECHNOLOGY	EMISSIONS REDUCTION (%)	ESTIMATED COST EFFECTIVENESS¹ (\$/ton)
HVLP Spray Guns	30-50	-1,200
SERT™	70-95	1,000 ²
Water-based MRA	84-100	1,700
High Solids MRA	53	3,000
Powder System ³	100	830
Permanent MRA ⁴	100	---
Semi-Permanent MRA ⁴	90-100	---

¹These cost effectiveness values are approximations based on available information. They were arranged to help determine which process to evaluate further. Actual costs associated with these technologies may differ.

²Not feasible for use in high production polyurethane plant.

³Preliminary estimate. Refined estimates based on demonstration results are presented in later sections.

SECTION 5

DEMONSTRATION OF SOLVENT EMISSION REDUCTION TECHNOLOGY™

APPCD decided to perform a demonstration of the SERT™ process at a polyurethane foam molding facility based on the analysis summarized in Section 4-3. The site selected for the demonstration was Integram's St. Louis Seating plant in Pacific, Missouri. This plant has a capacity of roughly 4,000 tons per year of molded polyurethane, and its main product is a high resiliency foam automobile seat for the Chrysler Corporation. The Integram facility uses a patented "foam in place" molding technology in which an upholstered lining is inserted into the mold, and the mold is charged to allow the polyurethane to expand and fill the mold. The foam adheres to the lining and produces a finished upholstered seat cushion. This foam in place technology greatly reduces the mold surface area which comes in contact with the polyurethane. Currently, a solvent-based MRA is applied with HVLP spray guns to those areas where the lining does not cover the mold. Each mold proceeds around the carousel style molding line, stopping at each "station". Figure 5-1 is a schematic of a carousel line as set up for the demonstration. Mold release is applied at three stations. Station 1 accounts for only 10 percent of the MRA applied on the line. This station is located in such a way that including it in the SERT™ test would have greatly increased the set-up time, and required the rearrangement of the operating line, therefore, it was not included in the testing. During the testing of the conventional MRA, two operators sprayed mold release from a pressure pot system using HVLP spray guns at stations 2 and 3 in Figure 5-1. During the testing of the

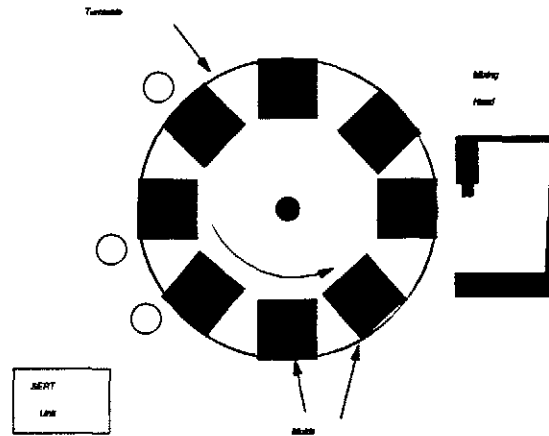


Figure 5-1: Schematic of Demonstration Setup

Note: (1) 1, 2, and 3 are the MRA spraying stations. Spray station 1 was not used in any of the tests, but accounts for only 10 percent of the MRA sprayed. (2) Stations 2 and 3 were used in the test of the conventional MRA. All of the parts coated with MRA from stations 2 and 3 in the test of the conventional MRA were sprayed from station 3 in the test of the SERT™ station.

SERT™ process, the spraying duties of stations 2 and 3 were combined and performed from station 3.

The goal of the demonstration was to evaluate the SERT™ process as a method of reducing VOC emissions from the application of mold release agents in polyurethane foam molding. Section 5.1 summarizes the approach used as described in the quality assurance and test plan for this project. Additionally, the data collected during the demonstration is presented in Section 5.1. Section 5.2 presents a feasibility cost analysis for retrofitting the Integram facility with the SERT™ process.

5.1 MEASUREMENTS DATA

The demonstration approach was designed to gather data to allow a direct comparison of SERT MRA to conventional MRA in four areas:

- VOC emission reductions,
- Effect on production rate,
- Effect on product quality, and
- Cost impacts.

The demonstration was carried out over a period of four days. Each technology was tested during ten lots of approximately 100 parts each. During each lot, approximately 1 hour of running time, data was collected to allow the comparison of the SERT™ technology to the conventional MRA. Section 6 examines the quality of the data collected.

Product surface quality data was collected to help determine if the process can be easily integrated into a processing facility. Foams with poor surface quality or ones that are flammable will be difficult or impossible for the manufacturer to sell, thus making surface

quality and flammability key factors in this technology assessment. Factors such as production rate and downtime were also examined to determine their impact on the economics of the process.

5.1.1 MRA Usage Rate and VOC Emissions

Alternative MRA technologies (e.g., SERT™) are of interest due to their ability to reduce VOC emissions. It is assumed that all of the VOC in the MRA will be volatilized either during the molding process or during product storage and usage. As such, the VOC emission rate is a function of the MRA use rate and the VOC content of the MRA.

The quantity of MRA used at the stations in the test was determined by weighing the MRA storage container before and after each production lot. A lot size of 100 parts was chosen to allow for an appreciable weight change in the MRA storage container and for a sample size adequate for testing differences in VOC emissions rates and product surface quality. Table 5-1 summarizes the data collected on MRA usage rate. The SERT™ process resulted in a decrease in MRA usage of 60 percent.

Samples of the MRA were taken before and after each lot, so that an average VOC content could be determined. The MRA samples were analyzed for VOC content and density using EPA Reference Method 24 (CFR, 1986). The conventional MRA contained 96 percent VOC on average, and had an average density of 6.4 lb/gal (0.77 g/ml). The SERT™ MRA, which is applied in lower quantities, averaged 87 percent VOC, with a density of 6.5 lb/gal (0.78 g/ml).

The VOC emissions per 100 molded parts were then calculated for each technology based on the average MRA usage rate and VOC content. The estimated emissions are also presented in Table 5-1. The conventional MRA system is estimated to result in VOC emissions of 4.8 lb/100 molded parts. The VOC emission rate estimated for the SERT process is 1.8 lb/100 molded parts. Based on these estimates, the SERT™ process was able to reduce VOC emissions by 63 percent during the demonstration.

Two factors should be considered when evaluating these results. First, the standard MRA system, which the SERT™ system was compared against, uses high volume low pressure HVLP spray guns. The VOC reduction when compared to standard spray gun equipment would be considerably higher (VOC reductions of 75 to 80 percent). Second, to avoid a lengthy set-up during the demonstration, the SERT™ MRA was applied at only one station (Figure 5-1). This station had a greater than optimum spraying distance for coating some parts of the mold. This condition likely resulted in the need to spray additional MRA. The conventional MRA data was gathered using two spray stations. Upon installation, VOC reductions could be higher than those seen during the demonstration by moving the operator closer to the part being sprayed.

5.1.2 Production Rate

The use of an alternative MRA can effect the production rate in two ways. First, production rate could be negatively impacted if the alternative MRA has a longer application time than the current MRA. Second, the production rate can be impacted if the alternative MRA has either a greater or lesser amount of downtime due to malfunctions or maintenance. Both the SERT™ and conventional MRA were spray applied taking only a few seconds per part. The MRA application step was not a limiting factor with either technology. Downtime was also

TABLE 5-1. SUMMARY OF MRA USAGE AND VOC EMISSIONS MEASURED DURING SERT™ DEMONSTRATION

MRA TYPE	RUN NUMBER	MRA USAGE* (lb/100 parts)	VOC EMISSIONS* (lb/100 parts)
Conventional	1	6.1	5.9
	2	6.0	5.7
	3	4.0	3.8
	4	8.3	8.0
	5	6.8	6.5
	6	4.9	4.7
	7	2.9	2.7
	8	4.4	4.2
	9	3.5	3.4
	10	3.4	3.2
	Average	5.0	4.8
SERT™ High Solids	1	1.9	1.7
	2	2.3	2.0
	3	1.6	1.3
	4	2.1	1.8
	5	1.6	1.4
	6	1.6	1.4
	7	2.5	2.2
	8	2.0	1.7
	9	2.2	1.9
	10	2.3	2.0
	Average	2.0	1.8
Estimated Percent Reduction (%)		60	63

*MRA usage estimates does not include station 1 in Figure 5-1. Based on historical information supplied by the test facility, station 1 is estimated to contribute an additional 10% to the total MRA usage.

monitored during the demonstration. The cause for each downtime was determined to identify if the MRA were at fault. Downtime averaged less than 10 percent (5 minutes per hour) for both the conventional and SERT™ processes. No MRA related downtime was observed during the demonstration for either technology. Additionally, the number of parts molded per hour per number of active molds was determined for each lot. The difference in the values for the SERT™ and conventional processes was insignificant (less than two percent). The production rate for the conventional process during testing was typical of normal operations (about 95 parts per hour). Based on these observations, it can be concluded that the SERT™ process did not result in any significant impact on production rate.

5.1.3 Product Quality

As in most industries, molded polyurethane foam must meet specific surface qualities to ensure that the foam will be adequate for its intended use. Poor surface quality foams are often shredded for other uses, such as carpet backing, thus lowering the value to the manufacturer. During the demonstration, surface quality was evaluated by Integram's trained inspectors. Each molded part was initially inspected following demolding. The foam was allowed to finish curing, and was then evaluated by a final inspector. The inspectors examined the foam for defects (i.e., tears, surface bubbles, and pore structure defects) and rated the pieces of foam on a pass/fail basis. There were no MRA related defects for parts made by either process. Based on the results of the demonstration, it is concluded that the SERT™ process would have no negative impacts on the quality of the molded foam.

5.1.4 Worker Acceptance

A key issue in implementing any new process is worker acceptance. If the workers are uncomfortable with a process or piece of equipment, overall performance and quality may suffer. During the test, the operators were asked for their opinion of the SERT™ system. Half of the operators were completely satisfied with the system in its present state. The others recommended minor changes to the system. The most common recommendation was the use of lighter, more flexible hoses and a swivel at the base of the spray gun. This would allow the operator more maneuverability, and could potentially reduce overspray by giving the worker better access to the part that needs to be sprayed. The only other complaint voiced by the workers was the "cloud" the system produced. This was simply the vaporization of the CO₂. By increasing the maneuverability of the worker, worker exposure to this "nuisance cloud" could be avoided. From these interviews, the workers appeared receptive to the SERT™ process.

5.1.5 Health & Safety

Worker comfort and safety are major concerns at any manufacturing facility, and thus any process that would improve working conditions needs to be considered. Reducing the VOC usage will likely reduce worker exposure to the solvent vapor. Most facilities are able to meet OSHA standards, however, future process modifications may increase MRA use. This may, in turn, push the solvent concentration over the permissible limit if no other actions are taken. Stoddard solvent has a permissible exposure limit (PEL) of 100 ppm (525 mg/m³). Many workers exposed to permissible levels of solvent vapor develop minor health problems such as nose bleeds, headaches and increased mucous production. Reducing solvent use by switching to the SERT™ could lead to a decrease in the number of these incidents, thus improving worker satisfaction and health, and decreasing absenteeism. Additionally, the American Conference of Governmental Industrial Hygienists, ACGIH, is reviewing the threshold limit values (TLV) for petroleum solvents. The TLV is not the legal limit, but in many cases, a change in the TLV has led to a change in the PEL.

5.2 COST ANALYSIS FOR SERT™ PROCESS

Cost is a key factor in the evaluation of any technology. Two cost impacts are commonly considered when evaluating alternative technologies - total capital investment (TCI) and total annual cost (TAC). The total capital investment represents the amount of money that must be invested in order to implement the new technology, and includes equipment costs, engineering design costs, and installation expenses. The total annual cost represents the annual operating costs such as raw materials and labor, as well as indirect operating costs such as overhead and capital recovery. Pollution abatement systems are also evaluated based on "Cost Effectiveness", which is the annual cost of a system divided by the total annual pollution abated. The remainder of this section presents the methodology used to estimate TCI and TAC, as well as the results of the analysis. Additionally, the sensitivity of the costs to design and operating factors are also evaluated and discussed.

The costs presented in this section will be based on a four carousel operation with annual production of 2.1 million parts, and MRA consumption equal to the values observed during the demonstration. The costs information (electricity, MRA, etc.) will be determined from industry and national standards, not site specific values. The base case for comparison will be a plant of the same layout using conventional MRA with HVLP spray guns.

5.2.1 Total Capital Investment

The total capital investment in technology is often far more than the purchase price of the equipment. The capital investment can be broken down into the following smaller groups: purchased equipment, direct installation, site preparation/buildings, and indirect installation costs. The first three are often combined and referred to as the total direct cost (Peters &

Timmerhaus, 1991). The purchased equipment cost includes the primary device, plus ancillary equipment and instrumentation. Often these prices are quoted free on board (FOB), and thus sales tax and freight must be added. For the SERT™ process, instrumentation is included in the price of the primary device, and no ancillary equipment is necessary; therefore, the purchased equipment price was assigned the price of the primary device, sales tax, and freight.

The equipment cost for the SERT™ equipment was obtained from the manufacturer. Each SERT™ station is estimated to cost \$60,000. A four carousel facility would need four stations to fully implement the SERT™ technology. A liquid CO₂ distribution system would also need to be purchased. Based on the use rates obtained during testing, two large (384 lb, 174 kg) dewars of CO₂ could be coupled together for use with the SERT™ system. Two other dewars would be coupled together and connected to the same system. An automatic switching device would need to be purchased to switch from an empty manifold to the full one. The purchase of the manifolds and switching device would cost \$3,000 (Shawn Smyth, Liquid Carbonic, Teleconference, April 1995.). The dewars could be rented, thus their costs are incorporated into the operating costs. The total equipment purchase price is, therefore, \$243,000.

The costs due to sales tax and freight are typically estimated using average values which appear in the OAQPS Control Cost Manual (Vatavuk, 1990) and other cost estimating manuals. For this study, sales tax was set at 3 percent, and freight at 5 percent of the equipment purchase price (Vatavuk, 1990; Peters and Timmerhaus, 1991). The direct installation costs were assumed to be minimal since the SERT™ process does not require painting, insulation, or a separate foundation/support. This leaves only costs for handling and erecting the system and supplying electricity to the system. The indirect installation costs include engineering, construction, contractor, start-up, and contingency costs. No construction or start-up costs were deemed necessary for the SERT™ process. The TCI for the SERT™ process is estimated at \$290,000. Table 5-2a summarizes the estimated costs leading to the TCI.

The capital costs associated with the conventional system would include the purchase of 12 HVLP spray guns and an agitator. Since conventional MRA can be purchased in large totes that accommodate mixing arms, a tank does not need to be purchased. A price quote of \$385 per HVLP guns was obtained from a vendor. The cost of the agitator was estimated at \$3000. The total purchased equipment cost is \$7,620. Sales tax was estimated in the same manner as the SERT™ costs. Freight was taken as 5 percent of the purchased equipment price. Piping was estimated at 20 percent of the agitator cost. Installation was estimated at 10 percent of the purchased equipment cost, and engineering at 25 percent of the purchased equipment price. Contingency was estimated at 5 percent of the purchased equipment cost. The TCI is simply the sum of these values. For the conventional process, the TCI is \$11,900. Table 5-2b summarizes the cost estimate made for the conventional process.

5.2.2 Operating Costs

The TAC of both the SERT™ process and the conventional MRA system were estimated. Table 5-3 summarizes the estimated annual costs for the two MRA technologies. Annual costs can be broken down to direct costs, indirect costs, and recovery credits. Recovery credits represent savings in raw material or energy costs due to recovered materials or energy. The SERT™ process does not recover either materials or energy, so recovery credits do not apply. Direct costs include raw materials, utilities, waste disposal, labor, and maintenance. Raw material costs include MRA and the CO₂ carrier gas (SERT™ only). The raw material cost were estimated from vendor price data and the measured use rates. Utilities were limited to electricity since neither process require fuel, water, or steam. Electricity costs were determined from use rates provided by the vendor and national average electricity costs to industrial users from the *Monthly Energy Review* (USDoE, 1994).

TABLE 5-2a. ESTIMATE OF TOTAL CAPITAL INVESTMENT FOR SERT™ PROCESS

ITEM	BASIS	COST ESTIMATE(\$)
SERT™ Units (4)	OSI	240,000
CO ₂ Manifold	Liquid Carbonic Inc.	3,000
Electrical Improvements	5% of 1 Unit (Handbook)*	3,000
Painting	OSI	0
Insulation	OSI	0
Support/Foundation	OSI	0
Piping	20% of Manifold (Handbook)	600
Sales Tax	3% of Equipment (Handbook)	7,300
Freight	Vendor Estimate	3,000
Installation	13% of 1 Unit (Handbook)	7,800
Engineering	25% of 1 Unit (Handbook)	15,000
Construction	OSI	0
Start-Up	OSI	0
Contingency	4% of Equipment Cost (Handbook)	10,000
Total Capital Investment		\$290,000

*Handbook values were taken from the OAQPS Control Cost Manual (Vatavuk, 1990) and Plant Design and Economics for Chemical Engineers by Peters & Timmerhaus.

**TABLE 5-2b. ESTIMATE OF TOTAL CAPITAL INVESTMENT FOR
CONVENTIONAL PROCESS**

ITEM	BASIS	COST ESTIMATE (\$)
HVLP Spray Guns (12)	Vendor	4,620
Agitator	Estimate (Handbook)*	3,000
Piping	20% of Agitator (Handbook)	600
Sales Tax	3% of Equipment (Handbook)	230
Freight	5% of Equipment Cost (Handbook)	380
Installation	10% of Equipment Cost (Handbook)	760
Engineering	25% of Equipment Cost (Handbook)	1,900
Contingency	5% of Equipment Cost (Handbook)	380
Total Capital Investment		\$11,900

*Handbook values were taken from the OAQPS Control Cost Manual (Vatavuk,1990) and Plant Design and Economics for Chemical Engineers by Peters & Timmerhaus.

Three types of labor costs are typically accounted for: operating, supervisory, and maintenance. Due to the additional equipment involved, it was estimated that the SERT process would require one additional hour per day to operate the process. The supervisory requirements are estimated at 15 percent of the operating labor. Labor rates for the motor vehicle manufacturing industry were obtained from the *Monthly Labor Review* (USDOL, 1994). The total maintenance costs can be estimated at 3 percent of the total capital investment (Peters and Timmerhaus, 1991). The OAQPS control cost manual suggests that maintenance materials costs are equal to maintenance labor costs, so each was estimated at 1.5 percent of the total capital investment (Vatavuk, 1990).

The total indirect costs are far less tangible. Overhead, property tax, insurance, and administrative costs make up the indirect costs. The property tax, insurance, and administrative costs were estimated at 4 percent of the total capital investment (Vatavuk,

1990). The overhead can be estimated in terms of the labor costs. Cost estimating manuals suggest 60 percent of the total labor cost for overhead. The total labor costs include maintenance, operating, and supervisory labor. Changes in production rate and product quality need to be considered when evaluating alternative processes or technologies. However, no changes in production rate or product quality were realized during the demonstration. Therefore, no losses were included. Annual operating costs total \$117,000 for the SERT™ system and \$96,700 for the conventional process.

TABLE 5-3. ESTIMATE OF CHANGE IN ANNUAL MRA COST WITH SERT™ PROCESS

ITEM	CONVENTIONAL MRA		SERT™ PROCESS	
	Basis	Cost Estimate (\$)	Basis	Cost Estimate (\$)
Mold Release	18,200 gal @\$5/gal	91,000	7,200 gal @\$12/gal	86,400
CO ₂	N/A	N/A	39,000 lb @\$0.16/lb	6,200
CO ₂ Tank Rental	N/A	N/A	4 tanks @\$35/month	1,680
Electricity	9,500 kw/yr @4.9¢/kw-hr	470	34,700 kw/yr @4.9¢/kw-hr	1,700
Operator Labor	150 hr @\$16.91/hr	2,500	300 hr @\$16.91/hr	5,100
Supervisory Labor	22 hr @\$19.45/hr	430	45 hr @\$19.45/hr	880
Maintenance Labor	1.5% of TCI	180	1.5% of TCI	4,300
Maintenance Materials	1.5% of TCI	180	1.5% of TCI	4,300
Overhead	60% of Labor	1,890	60% of Labor	6,200
Capital Recovery	10yr life, 10% interest	1,940	10yr life, 10% interest	47,150
Total		98,600		164,000
Net Increase				65,400
Cost Effectiveness (35 tons VOC not released)				1,870

5.2.3 Total Annual Cost

Capital recovery is added to the annual operating costs to determine a total annual cost. The fraction of the total capital investment that is added to the annual operating cost is based on equal yearly payments to cover principle and interest. This value is known as the capital recovery cost, CRC. The CRC is determined from the capital recovery factor (CRF) and the TCI. The CRF is calculated in Equation 5-1:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (5-1)$$

Where:

i = interest rate

n = useful life of the equipment

Standard OAQPS assumptions set i at 10 percent and n at 10 years. Using these assumptions, the CRF is 0.163. The CRC is then \$47,000 for 10 years, based on the SERT™ process, thus giving a pre-tax TAC of \$164,000. For the conventional process, the CRC is \$1940. The TAC is then \$98,600.

5.2.4 Cost Effectiveness

Cost effectiveness is a useful tool in comparing pollution prevention options as well as pollution control devices. Cost effectiveness can be calculated from the TAC and VOC emissions rates. For a production rate of 2,100,000 parts per year, the VOC emission reduction obtainable with the SERT™ process, as compared to the base case, is estimated at 35 tons per year. Therefore, the cost effectiveness of the SERT™ process using four units at the base MRA use rates will be \$1,870 per ton of VOC not released.

5.2.5 Sensitivity Analysis

A number of alternative costing scenarios were performed to evaluate the cost sensitivity of the SERT™ process to alternative conditions. Variation in raw material prices, MRA use rate, and capital investment were examined. Each of these categories will be discussed in the following subsections. Tables A-1 to A-5 in Appendix A derive TAC for various usage rates and capital investment. From this analysis, it was determined that the cost effectiveness of the SERT™ process is highly sensitive to the number of SERT™ stations required, and the cost of the conventional MRA. Three probable scenarios are discussed below along with the change in TAC and cost effectiveness.

Scenario 1. Reduced SERT™ MRA Usage Rates

Since the SERT™ process involves the use of new equipment, and a new MRA, the operators were uncertain how much MRA needed to be sprayed, so it is possible that they sprayed an excess amount of the SERT™ MRA. Analysis of the amount of solids sprayed showed that the operators were using roughly 30 percent more solids with the SERT™ process than with the conventional MRA. Therefore, it is possible that SERT™ MRA use would decline as the operators learned more about the SERT™ MRA and process. An optimized SERT™ MRA use scenario was made where the SERT™ use rate was set to provide the same solids usage rate as the current system. The SERT™ MRA use rate was set at 1.7 lb/100 parts (0.77 kg/100 parts). For the optimized case, annual MRA usage would be 5,500 gallons (21,000 liters) with a net emission reduction of 40 tons per year. The TAC for this case would be \$142,000, leading to a cost effectiveness of \$1,090 per ton of VOC reduced.

Scenario 2. Higher and Lower Conventional MRA Costs

A higher and lower conventional MRA cost were also examined. Conventional MRA costs of \$4 per gallon and \$6 per gallon were used. These led to annual MRA costs of \$72,800 and \$109,200 for each of the alternate cost estimates. The cost effectiveness (after taxes) associated with each of these alternate cost estimates would be \$2,390 and \$1,350 per ton of VOC reduced, respectively.

Scenario 3. Two SERT™ Stations

The number of SERT™ stations needed at a facility directly affects the capital investment, maintenance, and labor costs and indirectly affects overhead costs. It is likely that some facilities may be able to use fewer SERT™ stations due to differences in their design. In this scenario, a racetrack molding line is modeled. According to OSI personnel, a racetrack design could obtain the same production rate using only two SERT™ stations. TCI for this case is estimated at \$161,000. Additionally, the maintenance costs, labor and materials, are based on the TCI, and therefore, these values also decrease. This decrease in operating costs also effects overhead, which is based on total labor requirements. The cost effectiveness of this arrangement would be \$1,110 per ton of VOC reduced.

Scenario 4. Two SERT™ Stations and Optimized MRA Usage Rates

This Scenario is a combination of Scenarios 1 and 3 in that reduced MRA usage is examined for a facility that would only need two SERT™ stations (racetrack layout). For this scenario, a cost effectiveness value of \$440 is estimated using the optimized usage rate, reduced capital, labor, maintenance, and electricity costs.

5.2.6 SERT™ versus Add-On Control Devices

A comparison of costs associated with the base-case SERT™ process to costs for thermal and fixed bed incinerators was conducted. Incinerators were chosen as a likely add-on control device since foam molding facilities may not have the steam capacity necessary to regenerate spent carbon adsorbers. Additionally, air flow rates at such facilities would be too large to be processed by disposable carbon canisters. For this simulation, a plant air flow of 13,000 cfm (370 m³/min) was chosen. The capture efficiency of the ventilation system was estimated at 50 percent, thus 6,500 cfm (190 m³/min) of gas are to be processed by the add-on pollution control equipment. The concentration of the pollutant (Stoddard solvent) in the plant is estimated to be 76 ppm. Table 5-4 summarizes the information used to compare the various options. It can be seen that the SERT™ system is much less expensive than either of these add-control technologies. The add-on control system could be improved by increasing the capture efficiency of the exhaust system, however, this would increase the necessary size of the control device as well as the price. The incinerators were designed and the costs estimated based on information found in the OAQPS control cost manual (Vatavuk, 1990).

TABLE 5-4: COMPARISON OF SERT™ PROCESS WITH INCINERATORS

	THERMAL INCINERATOR†	FIXED BED CATALYTIC INCINERATOR†	SERT™ PROCESS
Purchased Equipment Costs	\$226,800	\$218,900	\$253,300
Direct Installation Costs	\$76,900	\$74,200	\$11,400
Indirect Costs	\$70,300	\$67,800	\$25,000
Total Capital Investment	\$374,000	\$360,900	\$290,000
Direct Annual Costs	\$146,900	\$103,300	\$110,600
Indirect Annual Costs	\$25,300	\$24,800	\$6,200
Capital Recovery Cost	\$60,900	\$58,800	\$47,150
Total Annual Cost	\$233,100	\$186,900	\$164,000
VOC Reduction	29 tons	29 tons	35 tons
COST EFFECTIVENESS	\$8,040	\$6,440	\$1,870

†Estimate for comparison purposes only.

Costs shown are increases over the use of conventional mold release.

70 percent energy recovery assumed for both incinerators.

98 percent VOC reduction for both incinerators.

SECTION 6

DATA QUALITY

Sampling, analytical, and quality control procedures were carried out as specified in the QAPjP. The QAPjP was prepared and approved for this APPCD QA Category III project. Overall the data quality was good. Completeness was not an issue, as 100 percent of all measurements were collected and accepted for use. The following section will outline the data quality measurements that were made.

The precision and accuracy of the primary measurements was very good. Table 6-1 lists the primary measurements, and their associated values for precision and accuracy. The accuracy and precision of the scale used to weigh the MRA container was checked daily using two calibration weights (25 and 50 pounds). An internal performance audit of the EPA Method 24 procedure was conducted to verify the precision and accuracy of the VOC content data. This consisted of duplicate analyses and comparisons of method results against standard mixtures. The VOC content results in Table 6-1 show the results of this audit. An internal systems audit was also conducted to verify adherence to the QAPjP, completeness and consistency of field documentation, and calculations and summary statistics. No external audit was conducted.

Table 6-1. Precision and Accuracy for Key Values

Measurement	Precision (%)		Accuracy (%)	
	Objective	Measured	Objective	Measured
Conventional Process				
MRA Use	---	4.5	---	4.5
VOC Content	---	0.4	---	0.4
VOC Emissions	15	4.2	15	5
SERT™ Process				
MRA Use	---	11.6	---	11.6
VOC Content	---	0.2	---	0.4
VOC Emissions	15	11.6	15	12
VOC Reduction	---	6.0	---	6.0
Production Rate				
Conventional	5	1.7	5	>1
SERT™	5	1.7	5	>1

The product quality is not shown in Table 6-1 since no parts were rated as defective due to the MRA. All products were examined multiple times and graded acceptable in regards to MRA performance. No flammability data was collected during the demonstration. However, Integram personnel felt that the MRA active ingredients were so similar that these tests would be unnecessary.

The last data quality objective was cost effectiveness. The cost effectiveness is a combination of the VOC reduction and the cost estimate. Table 6-1 shows that the accuracy in the VOC reduction is 6.0 percent. Therefore, the accuracy of the cost estimate must be discussed. The cost estimate was a "study" estimate (accuracy ± 30 percent) as defined in the OAQPS Control Cost Manual (Vatavuk, 1990). However, the accuracy of the estimate was improved by obtaining actual vendor cost information. The costs of all equipment and raw materials was obtained from vendors and therefore can be considered exact (accuracy equals zero). The exact costs represent 93 percent of the total annual cost for the conventional MRA system and 81 percent of the SERT™ process total annual cost. Assuming a 30 percent accuracy for the remaining costs, the overall accuracy values would be 2.1 percent for the conventional process, and 5.7 percent for the SERT™ process. From these values it is easy to see that the accuracy is well within the 25 percent specified in the QAPjP.

SECTION 7

SUMMARY AND CONCLUSIONS

The manufacture of many molded products, such as polyurethane, requires the use of mold release agents. These agents facilitate the separation of the mold and the product. VOC emissions from MRA use has been estimated at 126,000 tons per year, thus making MRA use a significant source of VOC emissions. Data was collected to identify the industries most responsible for MRA use and emissions. The polyurethane foam industry was found to be responsible for the consumption of 23 percent of the MRA active ingredients (12.8 million lb). From this, the VOC emissions from polyurethane foam were estimated at 29,600 tpy. Further examination of the polyurethane industry showed that most of the foam produced and the MRA used are associated with the manufacture of automobile seating. A list of pollution prevention options for the automobile seating industry was created. These options were ranked based on cost, potential to reduce emissions, feasibility for use at a large production facility, current use in production facilities, and impact on the demonstration host facility's production. SERT™ was selected from a number of options as the best candidate for the execution of a pollution prevention demonstration.

The SERT™ process was found to be effective at reducing VOC emissions during the demonstration. MRA usage was reduced from 4.8 lb/100 parts (2.27kg/100 parts) to 1.8 lb/100 parts (0.91 kg/100 parts). This corresponds to a decrease in VOC emissions of 3 lb/100 parts (1.36 kg/100 parts), representing a 63 percent reduction in VOC emissions. For a plant producing 2,100,000 parts per year, the VOC reduction would be over 35 tpy. From the ECR database, it can be determined that 57 percent of the VOC emissions are due to plants with annual foam production greater than 4,000 tpy. If SERT™ was installed at polyurethane plants using solvent based MRA and 63 percent reductions were seen, VOC emissions from mold release agents could potentially decrease by 10,700 tpy.

Production rate and product quality were examined during the demonstration to ensure that the SERT™ process had not adversely affected the production line. The production rates for the conventional and SERT™ processes were the same. Additionally, no MRA related product defects occurred during the study. The workers were questioned to determine if they would be comfortable using the new system. Half of the workers that used the system were satisfied with the system in its current state. The other half recommended minor changes to the system. These changes would reduce the weight and increase the maneuverability of the system. The OSI staff felt that these changes could be worked into the design of the system with minimal effort.

Optimization of the system and training of the sprayers would lead to even greater reductions in VOC emissions. During the study, it was determined that workers using the SERT™ system were spraying 30 percent more solids than the workers using the conventional MRA. Experience using this system will help the workers determine the proper amount of MRA

to use, thus reducing the amount of overspray. The two spraying stations used in the study of the conventional process were combined into one for testing the SERT™ system. One section of the mold was being sprayed from beyond the optimum distance. This may have led to additional overspray in an attempt to compensate for the MRA that was not reaching the mold. If the system were optimized to equal the amount of solids sprayed by the conventional system, emissions reductions may exceed 70 percent. This would correspond to a 40 tpy reduction in VOC emissions from a plant such as the one in the demonstration.

The costs associated with implementing the new system were broken up into two groups, capital and annual. The total capital investment for four SERT™ stations including freight, engineering, electrical improvements, and installation would be \$290,000. The total annual cost is \$164,000 (including operating costs of \$117,000 and capital recovery costs of \$47,000). The total annual cost for the conventional MRA is equal to \$98,600. From the total annual costs for the new and conventional systems and the VOC reduction, a cost effectiveness value can be calculated. The cost effectiveness for the SERT™ system is \$1,870 per ton of VOC reduced. Several scenarios were generated by manipulating conventional MRA price, number of SERT™ stations required, and SERT™ MRA use rate. The cost effectiveness for scenarios involving four SERT™ stations ranged from \$1,090 to \$2,390, while it ranged from \$440 to \$1,110 if only two stations were required.

The cost effectiveness value obtained for the SERT™ process with four stations was compared to standard add-on VOC control measures. Thermal and catalytic incinerators were chosen as the control methods, since many polyurethane facilities may not have the steam necessary to regenerate carbon adsorbers. The incinerators were designed and costs determined by the methods described in the OAQPS Control Cost Manual (Vatavuk, 1990). The cost effectiveness value for a thermal incinerator was estimated at \$8,040 per ton of VOC reduced, while the cost effectiveness for the fixed bed catalytic incinerator was estimated at \$6,440 per ton of VOC reduced. From these values, it is clear that pollution prevention, i.e., the SERT™ process, is a much more cost effective way to reduce VOC emissions as compared to conventional treatment methods.

SECTION 8

REFERENCES

Allardice, J, The Perfect '10' in Mold Release Agents, Rubber World, October 1981.

CFR, "Determination of Volatile Matter Content, Water Content, Density, Volume Solids, and Weight Solids of Surface Coatings," Code of Federal Regulations, Title 40, Part 60, Appendix A, Method 24, July 1986.

Dow Chemical Company, Flexible Polyurethane Foams, Dow, Midland, Michigan, 1991.

Grayson, H, Kirk-Othmer Encyclopedia of Chemical Technology, Wiley & Sons, New York, 1985.

Percell, KS; Tomlinson, HH; and Walp, LE; Selective Fatty Chemicals as Mold Release Agents, Plastics Engineering, September 1987.

Peters, M and Timmerhaus, K, Plant Design and Economics for Chemical Engineers, McGraw-Hill, New York, 1991.

Polyurethane Foam Association. 1991 U.S. Foamed Plastics Markets and Directory, Technomic Publishing Co., Lancaster, Pennsylvania, 1991.

Swift, K, Mold Release Agents, Business Communications Company, Inc., Norwalk, Connecticut, May 1990.

U.S. Department of Energy -- Energy Information Administration, Monthly Energy Review, Washington, D.C., May 1994.

U.S. Department of Labor -- Bureau of Labor Statistics, Monthly Labor Review, Washington, D.C., May 1994.

U. S. Environmental Protection Agency, National Air Pollutant Emission Trends, 1900-1994, EPA-454/R-95-011(NTIS PB96-135678), Research Triangle Park, North Carolina, October 1995.

Vatavuk, WM, OAQPS Control Cost Manual, 4th Edition, EPA-450/3-90-006 (NTIS PB90-169954), Research Triangle Park, NC, January 1990.

TELECONFERENCES

Telecons. Jill Webster, Southern Research Institute, Research Triangle Park, North Carolina with Doug McClain, Douglas and Lomason, Milan, Tennessee, September 1993.

Telecons. Jill Webster, Southern Research Institute, Research Triangle Park, North Carolina with Anant Shah, Johnson Controls, Belcamp, Maryland, September 1993.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with Dan Blakemore, OSI Specialties, Danbury, Connecticut, June 1994.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with John Robinson, Air Products, Allentown, Pennsylvania, June 1994.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with Paul Gavin, Chem-Trend, Howell, Michigan, June 1994.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with Bror Hanson, Polymerit, New Baltimore, Michigan, June 1994.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with Douglas Hunter, Dow Chemicals USA, Midland, Michigan, June 1994.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with Erny Gatto, Woodbridge Group, Troy, Michigan, June 1994.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with Tom Sloan, Plas-Tech Coating, West Palm Beach, Florida, June 1994.

Telecons. Kevin Cavender, Southern Research Institute, Research Triangle Park, North Carolina with Dave Martin, Dexter Freco, Seabrooke, New Hampshire, June 1994.

Telecons. Jeffrey Lanning, Southern Research Institute, Research Triangle Park, North Carolina with Shawn Smyth, Liquid Carbonic, Shelbyville, Indiana, April 1995.

APPENDIX A
COST INFORMATION & ESTIMATES

CAPITAL COSTS

Purchased Equipment - SERT™ Units, CO₂ Manifold Switching System

Installation - Includes labor, supports, and other expenses related to installation.

Electrical Improvements - Labor and materials to provide 460 VAC to the units.

Engineering & Supervision - Includes engineering, drafting, purchasing, accounting, cost engineering, travel, communications, and home office expenses.

Piping - Pipes, valves, and fittings to deliver liquid CO₂ to the SERT™ Units.

Start-Up & Contingency - Accounts for unforeseen expenses, strikes, price changes, design changes, errors in estimation, and lost production (downtime or limited capacity).

OPERATING COSTS

Raw Materials - MRA, CO₂, CO₂ Dewar rental

Electricity - Needed to run the SERT™ Units.

Labor - Worker to check on SERT™ units and CO₂ system. Clerical and supervisory labor needed to order more raw materials, and assist with problems.

Maintenance - Materials and labor to repair damaged or malfunctioning equipment.

Overhead - Helps to offset costs associated with general engineering, safety services, cafeteria facilities, payroll overhead (employee benefits), plant maintenance, QA laboratories, plant security, custodial services, lighting, climate control, machine shop, and shipping and receiving facilities.

**TABLE A-1. SENSITIVITY ANALYSIS - SCENARIO 1
OPTIMIZED SERT™ MRA USAGE RATE**

Item	Conventional MRA		SERT™ Process	
	Basis	Cost Estimate (\$)	Basis	Cost Estimate (\$)
Mold Release	18,200 gal @\$5/gal	91,000	5,500 gal @\$12/gal	66,000
CO ₂	na	na	30,000 lb @\$0.16/lb	4,800
CO ₂ Tank Rental	na	na	4 tanks @\$35/month	1,680
Electricity	9,500 kw/yr @4.9¢/kw-hr	470	34,700 kw/yr @4.9¢/kw-hr	1,700
Operator Labor	150 hr @\$16.91/hr	2,500	300 hr @\$16.91/hr	5,100
Supervisory Labor	22 hr @\$19.45/hr	430	45 hr @\$19.45/hr	880
Maintenance Labor	1.5% of TCI	180	1.5% of TCI	4,300
Maintenance Materials	1.5% of TCI	180	1.5% of TCI	4,300
Overhead	60% of Labor	1,890	60% of Labor	6,200
Capital Recovery	10yr life, 10% interest	1,940	10yr life, 10% interest	47,150
Total		98,600		142,000
Net Increase				44,000
Cost Effectiveness (40 tons of VOC not released)				1,090

**TABLE A-2. SENSITIVITY ANALYSIS - SCENARIO 2A
REDUCED CONVENTIONAL MRA COST**

Item	Conventional MRA		SERT™ Process	
	Basis	Cost Estimate (\$)	Basis	Cost Estimate (\$)
Mold Release	18,200 gal @\$4/gal	72,800	7,200 gal @\$12/gal	86,400
CO ₂	na	na	39,000 lb @\$0.16/lb	6,200
CO ₂ Tank Rental	na	na	4 tanks @\$35/month	1,680
Electricity	9,500 kw/yr @4.9¢/kw-hr	470	34,700 kw/yr @4.9¢/kw-hr	1,700
Operator Labor	150 hr @\$16.91/hr	2,500	300 hr @\$16.91/hr	5,100
Supervisory Labor	22 hr @\$19.45/hr	430	45 hr @\$19.45/hr	880
Maintenance Labor	1.5% of TCI	180	1.5% of TCI	4,300
Maintenance Materials	1.5% of TCI	180	1.5% of TCI	4,300
Overhead	60% of Labor	1,890	60% of Labor	6,200
Capital Recovery	10yr life, 10% interest	1,940	10yr life, 10% interest	47,150
Total		80,400		164,000
Net Increase				83,600
Cost Effectiveness (35 tons VOC not released)				2,390

**TABLE A-3. SENSITIVITY ANALYSIS - SCENARIO 2B
INCREASED CONVENTIONAL MRA COST**

Item	Conventional MRA		SERT™ Process	
	Base	Cost Estimate (\$)	Base	Cost Estimate (\$)
Mold Release	18,200 gal @\$6/gal	109,200	7,200 gal @\$12/gal	86,400
CO ₂	na	na	39,000 lb @\$0.16/lb	6,200
CO ₂ Tank Rental	na	na	4 tanks @\$35/month	1,680
Electricity	9,500 kw/yr @4.9¢/kw-hr	470	34,700 kw/yr @4.9¢/kw-hr	1,700
Operator Labor	150 hr @\$16.91/hr	2,500	300 hr @\$16.91/hr	5,100
Supervisory Labor	22 hr @\$19.45/hr	430	45 hr @\$19.45/hr	880
Maintenance Labor	1.5% of TCI	180	1.5% of TCI	4,300
Maintenance Materials	1.5% of TCI	180	1.5% of TCI	4,300
Overhead	60% of Labor	1,780	60% of Labor	6,200
Capital Recovery	10yr life, 10% interest	1,940	10yr life, 10% interest	47,150
Total		116,700		164,000
Net Increase				47,300
Cost Effectiveness (35 tons of VOC not released)				1,350

**TABLE A-4. SENSITIVITY ANALYSIS - SCENARIO 3
TWO SERT™ STATIONS**

Item	Conventional MRA		SERT™ Process	
	Basis	Cost Estimate (\$)	Basis	Cost Estimate (\$)
Mold Release	18,200 gal @\$5/gal	91,000	7,200 gal @\$12/gal	86,400
CO ₂	na	na	39,000 lb @\$0.16/lb	6,200
CO ₂ Tank Rental	na	na	4 tanks @\$35/month	1,680
Electricity	9,5000 kw/yr @4.9¢/kw-hr	470	17,500 kw/yr @4.9¢/kw-hr	860
Operator Labor	150 hr @\$16.91/hr	2,500	300 hr @\$16.91/hr	5,100
Supervisory Labor	22 hr @\$19.45/hr	430	45 hr @\$19.45/hr	880
Maintenance Labor	1.5% of TCI	130	1.5% of TCI	2,400
Maintenance Materials	1.5% of TCI	130	1.5% of TCI	2,400
Overhead	60% of Labor	1,860	60% of Labor	5,000
Capital Recovery	10yr life, 10% interest	1,380	10yr life, 10% interest	26,200
Total		97,900		136,900
Net Increase				39,000
Cost Effectiveness (35 tons of VOC not released)				1,110

**TABLE A-5. SENSITIVITY ANALYSIS - SCENARIO 4
TWO SERT™ STATIONS WITH OPTIMIZED SERT™ MRA USAGE RATE**

Item	Conventional MRA		SERT™ Process	
	Basis	Cost Estimate (\$)	Basis	Cost Estimate (\$)
Mold Release	18,200 gal @\$5/gal	91,000	5,500 gal @\$12/gal	66,000
CO ₂	na	na	30,000 lb @\$0.16/lb	4,800
CO ₂ Tank Rental	na	na	4 tanks @\$35/month	1,680
Electricity	9,500 kw/yr @4.9¢/kw-hr	470	17,500 kw/yr @4.9¢/kw-hr	860
Operator Labor	150 hr @\$16.91/hr	2,500	300 hr @\$16.91/hr	5,100
Supervisory Labor	22 hr @\$19.45/hr	430	45 hr @\$19.45/hr	880
Maintenance Labor	1.5% of TCI	130	1.5% of TCI	2,400
Maintenance Materials	1.5% of TCI	130	1.5% of TCI	2,400
Overhead	60% of Labor	1,860	60% of Labor	5,000
Capital Recovery	10yr life, 10% interest	1,380	10yr life, 10% interest	26,200
Total		97,900		115,300
Net Increase				17,400
Cost Effectiveness (40 tons of VOC not released)				440

APPENDIX B
ECR DATABASE INFORMATION

Polyurethane Foam Industry Database

FACILITY	LOCATION	MAJOR PRODUCT	OTHER PRODUCT	CAPACITY (tons)	MRA TYPE	MRA USE (est) (lb/yr)	VOC EMISSIONS (tpy)
Johnson Controls - Greenfield Plant	Greenfield, OH	molded foam		15,000	NON	1,726,000	368.8
Woodbridge Corporation - Brodhead Plant	Brodhead, WI	molded automotive seating		9,738	NON	1,121,818	252.4
Johnson Controls - Jefferson City Plant	Jefferson City, MO	molded foam		8,400	NON	1,082,880	243.6
Woodbridge Foam - Whitmore Lake Facility	Whitmore Lake, MI	molded foam		7,300	NON	840,960	189.2
Johnson Controls - Puleski Plant	Pulaski, TN	molded foam		7,250	WATER	836,200	20.9
Woodbridge Corporation - St. Peters Facility	St. Peters, MO	molded foam seats		5,841	WATER	672,883	18.8
Ford Motor Company - Utica Plant	Utica, MI	molded auto seat pads	molded auto headrests	5,750	NON	662,400	149.0
Johnson Controls, Inc. - Belcamp Plant	Belcamp, MD	molded foam		4,500	WATER	518,400	13.0
Intagram - St. Louis Seating, Foam	Pacific, MO	molded auto foam		4,100	NON	472,320	106.3
Johnson Controls - Livermore Plant	Livermore, CA	molded auto foam		3,500	WATER	403,200	10.1
Fanwell Plant, Renosci Corporation	Fanwell, MI	molded foam seating	molded head and armrests	2,800	NON	322,560	72.6
H.L. Blackford - Troy Plant	Troy, MI	cast-in-place foam		2,165	NON	249,408	56.1
Douglas & Lomson Company	Milan, TN	automotive seats	FIP headrests	1,965	NON	226,368	50.9
Goodyear Tire & Rubber Company - Logan Plant	Logan, OH	automotive instr. panels		1,600	NON	184,320	41.5
Johnson Controls Inc. - Ossian Plant	Ossian, IN	molded foam		1,400	NON	161,280	36.3
Douglas & Lomson Company	Havre de Grace, MD	automotive seats		1,302	WATER	149,980	3.7
Automotive Industries, Inc., Plants 2,3 & Visor Foam Bldg.	Strasburg, VA	auto interior armrests	peeled foam for sunvisors	1,018	NON	117,274	26.4
Herman Miller - Holland Operations	Holland, MI	molded chair parts	molded arm pads	795	NON	91,584	20.6
Johnson Controls - Prototype Laboratory	Plymouth, MI	molded foam		675	WATER	77,760	1.9
H.L. Blackford - West Chicago	West Chicago, IL	cast in place foam		640	WATER	73,728	1.8
Foam Design, Incorporated	Lexington, KY	foam-in-place PU packaging	PU deer targets	553	NON	63,708	14.3
Swenson Company	Redgranite, WI	foam-in-place cushions	integral skin armrests	490	NON	58,448	12.7
Universal Urethane, Inc.	North Las Vegas, NV	IS auto interior parts	IS portable spa headrests	471	NON	54,259	12.2
Kem Foam Products Corporation	S. Plainfield, NJ	molded seating foam	molded foam for packaging	309	NON	35,597	8.0
Scott-Port-A-Fold	Archbold, OH	molded foam for toys	molded foam for insulation	230	NON	26,496	6.0
Pureforms, Inc.	Portland, OR	integral skin foam		207	NON	23,848	5.4
Conway Industries, Incorporated	Hamilton, OH	molded polyurethane foam		98	NON	11,059	2.5
American Seating Company	Grand Rapids, MI	molded foam		80	NON	8,216	2.1
Perry Chemical & Manufacturing Company, Inc.	Lafayette, IN	surface preparation pads	scrap foam	62	NON	7,142	1.6
Kustom Foam Manufacturing	Modesto, CA	IS foam	other molded foam	38	HAP	4,378	1.0
Flexible Industries Company	Burlington, IA	molded expansion joints		32	NON	3,686	0.8
Stephenson & Lawyer Incorporated	Grand Rapids, MI	integral skin products		19	NON	2,189	0.5
Foam Molders and Specialties	Cerritos, CA	molded aerospace products	molded auto products	12	HAP	1,382	0.3
E-A-R Specialty Composites/Indianapolis	Indianapolis, IN	molded foam		3	HAP	346	0.1
Aero Specialties Corporation	Deer Park, NY	molded foam		1	HAP	115	0.0
American Poly-Therm Company, Inc.	Lincoln, CA	seat cushions & crash pad		1	NON	115	0.0
Furon Company	Seattle, WA	integral skin		1	HAP	115	0.0
Kalamazoo Plastic Company	Kalamazoo, MI	integral skin foam		1	WATER	115	0.0
Flextron Industries	Aston, PA	packages and mats		0	NON	0	0.0
				Totals From ECR Survey		89,345	1,770
				Totals From Literature		1,600,000	31,680