Industry Profile for the Rigid Polyurethane Foam Industry-

Generic Scenario for Estimating Occupational Exposures and Environmental Releases

-Draft-

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1.0 INTRODUCTION

This document was prepared for U.S. EPA's Design for the Environment Program (DfE). In the past, DfE has worked with and researched industries that use diisocyanates, including the autorefinishing and the polyurethane foam industries, to assess potential sources of emissions and to identify best practices and controls to eliminate or reduce these emissions. Diisocyanates are skin sensitizers and are reported to be the leading cause of occupational asthma. Industries using diisocyanates may pose a health risk to workers or nearby communities if proper personal protective equipment and controls are not used. Diisocyanates are a key ingredient in the manufacturing of rigid polyurethane foam. This document profiles the rigid polyurethane foam industry, its use of diisocyanates, and its use of other chemicals of concern.

The following sections of this document describe the rigid polyurethane foam industry, the manufacturing processes of rigid polyurethane foam, the releases and associated occupational exposures from the manufacturing processes, related control technologies and personal protective equipment, and regulations governing the use and potential release of diisocyanates in the industry.

2.0 RIGID POLYURETHANE FOAM INDUSTRY BACKGROUND

Rigid polyurethane foam is mainly used for insulation and is produced via boardstock/lamination, spray, or poured methods (1). Markets for rigid polyurethane foam include (2):

- Construction;
- Appliances;
- Packaging;
- Tanks and pipes;
- Transportation;
- Marine; and
- Furniture.

2.1 SIC-NAICS Classification

The Standard Industrial Classification (SIC) System was developed in the 1930's to categorize industry into numeric groups. Throughout the years the SIC system has been updated and revised with the latest update to the classification occurring in 1987. Many U.S. economic and environmental databases have historically presented and analyzed industry data based on SIC codes.

On April 9, 1997, the Office of Management and Budget (OMB) announced its decision to adopt the North American Industry Classification System (NAICS) to replace the SIC system. The NAICS system allows for a more precise classification of industry by segmenting industry sectors into smaller components through the use of 6 - 10 digit codes as compared to the 4-digit SIC system. The smaller industry segments at the NAICS 10-digit level are termed product classes.

As a result of this greater refinement, economic and environmental data based on the NAICS system would allow for a more detailed and accurate profile of industry subsectors; in this case, rigid polyurethane foam manufacturing. Due to the fairly recent adoption of the NAICS codes, however, some economic and environmental data sets are only available based on the SIC codes rather than the more current, and more specific, NAICS codes. Consequently, data based on both classification systems is used to characterize the rigid polyurethane foam industry for this report. Specifically, this report uses the following economic and environment data sources to assist in characterizing the rigid polyurethane foam manufacturing industry:

- The U.S. Census Bureau economic industry data (such as number of workers, number of facilities, and size of the rigid polyurethane foam industry) for industry sectors according to 6-digit NAICS codes and, in some cases, according to the 10-digit level NAICS product classes.

- Data from EPA's Toxic Release Inventory (TRI), such as environmental releases of TRI chemicals and locations of facilities releasing TRI chemicals, reported by SIC codes.

A description of the SIC code and NAICS codes which capture the rigid polyurethane foam industry is provided below. This description also briefly addresses the limitations of data based on these respective classification systems and the likely impact of these limitations on the industry profile.

SIC Codes

The relevant SIC code for rigid polyurethane foam is SIC code 3086, "Plastics Foam Products". This category includes facilities that manufacture the following:

- Cups, foamed plastics;
- Cushions, carpet and rug, plastic foam;
- Foam plastic products;
- Ice chests or coolers, portable, foamed plastics;
- Insulation and cushioning, foamed plastics;
- Packaging, foamed plastics;
- Plates, foamed plastics; and
- Shipping pads, foamed plastics.

From the list above, it is expected that rigid polyurethane foam is used in the ice chests or coolers, insulation and cushioning, and packaging foamed plastics manufacturing industries. Because rigid polyurethane foam represents only a subset of industries captured under SIC 3086, and because data based on the SIC system cannot be further differentiated below the 4-digit SIC code level, the TRI data for SIC 3086 provides an overestimate of environmental releases resulting from rigid polyurethane foam manufacturers (the discussion on the *NAICS Bridge* below provides additional information on the potential magnitude of this overestimate).

NAICS Codes

The NAICS code for urethane foam product manufacturing is 326150 "Urethane and Other Foam Product (except polystyrene) Manufacturing". This industry includes the following sub-industry groups (at the 7-digit NAICS level):

- Transportation polyurethane foam products;
- Packaging polyurethane foam products;
- Building and construction polyurethane foam products;
- Furniture and furnishings polyurethane foam products;
- Consumer and institutional polyurethane foam products;
- Miscellaneous polyurethane foam products, not elsewhere classified; and
- Products made of foam other than polystyrene or polyurethane (including phenolics, vinyl and cellulose acetate, etc.)

Product classes within these sub-industry groups can be generally categorized into two sub-industries (rigid polyurethane foam and flexible polyurethane foam) allowing for easy extraction of rigid polyurethane foam industry data. Several product classes within these sub-industry groups, however, do not provide a sufficient description to determine whether the product class is in the rigid or flexible foam category. This uncertainty may result in an underestimate of the size of the rigid foam industry when evaluating the economic data based on NAICS. A more detailed evaluation of product class breakdown by rigid polyurethane foam, flexible polyurethane foam, and undetermined is provided in Section 2.2 of this report.

NAICS Bridge

A comparison of the NAICS and SIC codes (NAICS Bridge) indicates that the NAICS 326150 industry sector comprises 57 percent of the facilities covered under SIC code 3086 (the remaining 43 percent of the facilities under SIC code 3086 compose NAICS 326140, Polystyrene Foam Product Manufacturing). As discussed in Section 2.2 below, rigid polyurethane foam composes at least 15 percent of NAICS 326150, thus, as a lower bound, 9 percent (15 percent x 57 percent) of the facilities covered under SIC code 3086 are rigid polyurethane foam manufacturers. Therefore, data obtained for the SIC 3086 industry sector will represent an overestimate of environmental release data for rigid polyurethane foam manufacturers.

2.2 Industry Size

The most recent Manufacturer's Census for NAICS 326150 was published in 1997. This report provides industry information at up to the 10-digit code level (3). Table 2-1 presents the shipment values of the product classes under NAICS 326150 from the 1997 Census. Although the data presented are somewhat outdated, the qualitative and relative magnitude of the shipment values from 1997 may be used as an indicator of the current and relevant size of the sectors under NAICS 326150. More recent information from the 2002 Census report has not yet been released, but is scheduled to be published over a two-year period beginning in 2004.

Table 2-1

1997 Manufacturing Industry Series: Shipment Value Data for NAICS 326150: Urethane and other (nonpolystyrene) Foams

NAICS CODES FOR URETHANE FOAMS (NAICS 326150)					Number Companies With >$99,999	Shipment Value per NAICS ($1000)			
6-Digit	**7-Digit**	**8-Digit**	**10-Digit**	**Industry/Product Class Description**		**6-Digit**	**7-Digit**	**8-Digit**	**10-Digit**
326150				Urethane and foam products other than polystyrene	N	$6,196,664			
	3261501			Transportation polyurethane foam products	N		$1,260,730		
		32615011		Transportation polyurethane foam products	N			$1,260,730	
			3261501101	Transportation polyurethane foam products, molded seating	15				$460,348
			3261501102	Transportation polyurethane foam products, cut slabstock for seating and trim	20				$98,494
			3261501103	Transportation polyurethane foam products, other molded including headrest, armrest, etc.	30				$595,685
			3261501Y	Transportation polyurethane foam products, nsk	N				$106,203
	3261502			Packaging polyurethane foam products	N		$342,491		
		32615021		Packaging polyurethane foam products	N			$342,491	
			3261502116	Polyurethane foam protective shipping pads and shaped cushioning (peanuts, disks, etc.)	46				$97,964
			3261502196	Other polyurethane foam packaging products	33				$244,527
			3261502Y	Packaging polyurethane, nsk	N		$13,534		
	3261503			Building and construction polyurethane foam products	N		$481,221		

Table 2-1 (Continued)

NAICS CODES FOR URETHANE FOAMS (NAICS 326150)					Number Companies With >$99,999	Shipment Value per NAICS ($1000)			
6-Digit	7-Digit	8-Digit	10-Digit	Industry/Product Class Description		6-Digit	7-Digit	8-Digit	10-Digit
		32615031		Building and construction polyurethane foam products	N			$477,424	
			3261503116	Building and construction polyurethane foam insulation (including pipe and block)	24				$287,933
			3261503196	Other building and construction polyurethane foam products	19				$189,491
		3261503Y		Building and construction polyurethane foam, nsk	N			$3,797	
	3261504			Furniture and furnishings polyurethane foam products	N		$2,224,120		
		32615041		Polyurethane foam formed and slabstock for pillows, seating, and cushioning	N			$886,141	
			3261504110	Polyurethane foam formed and slabstock for pillows, seating, and cushioning	36				$886,141
		32615042		Other polyurethane foam furniture and furnishings products	N			$1,085,685	
			3261504215	Polyurethane foam carpet underlay, carpet and rug cushions, prime	12				$350,011
			3261504216	Polyurethane foam carpet underlay, carpet and rug cushions, bonded	11				$289,127
			3261504227	Polyurethane foam mattress cores (uncovered only)	11				$60,325
			3261504228	Polyurethane foam topper pads and quilting rolls	12				$77,134
			3261504237	Other furniture and furnishings polyurethane foam products	17				$309,088
		3261504Y		Furniture and furnishings polyurethane foam, nsk	N			$252,294	
	3261505			Consumer and institutional polyurethane foam products	N		$192,780		

Table 2-1 (Continued)

NAICS CODES FOR URETHANE FOAMS (NAICS 326150)					Number Companies With >$99,999	Shipment Value per NAICS ($1000)			
6-Digit	7-Digit	8-Digit	10-Digit	Industry/Product Class Description		6-Digit	7-Digit	8-Digit	10-Digit
		32615051		Consumer and institutional polyurethane foam products	N			$192,780	
			3261505100	Consumer and institutional polyurethane foam products	37				$192,780
	3261506			Miscellaneous polyurethane foam products, nec	N		$332,533		
		32615061		Miscellaneous polyurethane foam products, nec	N			$325,919	
			3261506116	Electrical and electronic polyurethane foam products	32				$182,207
			3261506196	Other polyurethane foam products, including medical, clothing, fillers, diapers, etc.	23				$143,712
		3261506Y		Miscellaneous polyurethane foam products, nec, nsk	N			$6,614	
	3261509			Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.	N		$968,036		
		32615091		Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.	N			$968,036	
			3261509100	Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.	84				$968,036
	326150W	326150W		Polyurethane and other foam products, nsk, total	N		$381,219		

N = not provided.
nec = Not elsewhere classified.
nsk = Not specified by kind.

To better characterize the rigid polyurethane foam industry, Table 2-2 reorganizes the data presented in Table 2-1 by the two major sub-industries in NAICS 326150: rigid and flexible polyurethane foam manufacturing. A third category ("Undetermined") was added to Table 2-2 to identify those product classes for which a sub-industry could not be determined based on the NAICS description. In general, rigid polyurethane foams were considered those used in packaging, construction, and electronic/electrical applications. Flexible polyurethane foams were considered those used in furniture, mattress, and carpet applications.

According to Table 2-2, rigid foam manufacturing comprised 15 percent of the total NAICS 326150 industry by shipment value in 1997. Among the rigid foam manufacturing product classes, "building and construction polyurethane foam insulation (including pipe and block)" represents the largest shipment value, composing 31 percent of the total rigid foam shipments. Table 2-3 presents the 10-digit NAICS 326150 codes that represent the rigid polyurethane foam industry and their respective percent of the total rigid polyurethane foam shipment values.

Table 2-2

NAICS Product Classes Categorized by Assumed Sub-Industry
1997 Manufacturing Industry Census

NAICS 326150: Urethane Foams		Shipment Value per NAICS ($1000)		
NAICS Code	**Product Class Description**	**Flexible Foam**	**Rigid Foam**	**Undetermined**
3261501101	Transportation polyurethane foam products, molded seating	460,348		
3261501102	Transportation polyurethane foam products, cut slabstock for seating and trim	98,494		
3261501103	Transportation polyurethane foam products, other molded including headrest, armrest, etc.	595,685		
3261501Y	Transportation polyurethane foam products, nsk	106,203		
3261502116	Polyurethane foam protective shipping pads and shaped cushioning (peanuts, disks, etc.)	97,964		
3261502196	Other polyurethane foam packaging products		244,527	
3261502Y	Packaging polyurethane, nsk		13,534	
3261503116	Building and construction polyurethane foam insulation (including pipe and block)		287,933	

Table 2-2 (Continued)

NAICS 326150: Urethane Foams		Shipment Value per NAICS ($1000)		
NAICS Code	**Product Class Description**	**Flexible Foam**	**Rigid Foam**	**Undetermined**
3261503196	Other building and construction polyurethane foam products		189,491	
3261503Y	Building and construction polyurethane foam, nsk		3,797	
3261504110	Polyurethane foam formed and slabstock for pillows, seating, and cushioning	886,141		
3261504215	Polyurethane foam carpet underlay, carpet and rug cushions, prime	350,011		
3261504216	Polyurethane foam carpet underlay, carpet and rug cushions, bonded	289,127		
3261504227	Polyurethane foam mattress cores (uncovered only)	60,325		
3261504228	Polyurethane foam topper pads and quilting rolls	77,134		
3261504237	Other furniture and furnishings polyurethane foam products	309,088		
3261504Y	Furniture and furnishings polyurethane foam, nsk	252,294		
3261505100	Consumer and institutional polyurethane foam products			192,780
3261506116	Electrical and electronic polyurethane foam products		182,207	
3261506196	Other polyurethane foam products, including medical, clothing, fillers, diapers, etc.			143,712
3261506Y	Miscellaneous Polyurethane foam products, nec			6,614
3261509100	Products made of foam other than polystyrene or polyurethane including phenolics, vinyl and cellulose acetate, etc.			968,036
326150W	Polyurethane and other foam products, nsk, total			381,219
TOTAL SHIPMENT VALUE		**3,582,814**	**921,489**	**1,692,361**
PERCENT OF TOTAL SHIPMENT VALUE		**58%**	**15%**	**27%**

nec = Not elsewhere classified.
nsk = Not specified by kind.

Table 2-3

Distribution of Rigid Foam Sub-Industry Based on 1997 Shipment Value

NAICS Code	Product Class Description	%
3261503116	Building and construction polyurethane foam insulation (including pipe and block)	31%
3261502196	Other polyurethane foam packaging products	27%
3261503196	Other building and construction polyurethane foam products	21%
3261506116	Electrical and electronic polyurethane foam products	20%
3261502Y	Packaging polyurethane, nsk	1%
3261503Y	Building and construction polyurethane foam, nsk	>0.5%

nsk = Not specified by kind.

2.3 Number of Manufacturing Facilities

The 2001 County Business Patterns identify 610 establishments that fall under NAICS 326150 (4). From Table 2-2, based on shipment value, it can be estimated that 15 percent of the NAICS 326150 industry is rigid polyurethane foam; therefore, according to the NAICS data, approximately 92 establishments produce rigid polyurethane foam. Data provided by the Alliance for the Polyurethanes Industry (API), however, estimate that the rigid polyurethane foam industry accounts for 28 percent of the polyurethane demand, based on market demand in million pounds (2). Applying this API estimate to the total number of NAICS 326150 establishments leads to an estimate of approximately 171 establishments that produce rigid polyurethane foam.

As a more conservative estimate, the data provided by API is used in Section 4.0 of this report to make release estimates because some rigid polyurethane foam is not produced at manufacturing facilities. For example, some rigid polyurethane foam is created for in-situ applications where the foam is mixed and poured into place or spray applied at the site of the application (e.g., roofing applications, construction insulation, piping and ductwork insulation, industrial storage tank insulation). These types of rigid polyurethane foam production sites are not captured by NAICS 326150.

Employment size class distribution information for facilities under NAICS 326150 was obtained from the 2001 County Business Patterns (4) and is presented in Table 2-4.

Employment size distribution information was not available below the 6-digit NAICS level; therefore, Table 2-4 presents data at the NAICS 326150 level and includes flexible, rigid, and other undetermined urethane foam manufacturers. According to the 2001 County Business Patterns, most of the NAICS 326150 facilities have an employment size class of 20-99.

Table 2-4

Classification of Establishments by Employment Class Size for NAICS 326150

NAICS	Industry	Establishments	Total Employment Size Class			
			1-19	20-99	100-499	>499
326150	Urethane and Foam Products Other than Polystyrene	610	229	276	103	3
			38%	45%	17%	<0.5%

The 2001 County Business Patterns reports a total of 35,635 employees under NAICS 326150 (4). From the analysis in Section 2.1, it may be assumed that the rigid polyurethane foam sub-industry comprises 28 percent of the NAICS 326150 industry, based on rigid foam demand, therefore, 9,978 workers (35,635 workers × 28 percent) are estimated to work in the rigid polyurethane foam sub-industry. If the representation of employees and facilities parallels the rigid polyurethane foam demand, an average of 58 employees per facility (9,978 employees ÷ 171 establishments) is estimated. This estimate falls within the 20-99 worker size class that accounts for the largest fraction of NAICS 326150.

2.4 Geographic Distribution

EPA's Toxic Release Inventory (TRI) collects geographic information for all facilities reporting releases. The TRI data, however, are collected by SIC code rather than the NAICS code. Since the SIC code 3086 groups all foamed plastics together, the geographic data contained in TRI does not distinguish between rigid polyurethane foam facilities and facilities manufacturing other plastic foam products. Despite this limitation, the TRI data represents the only identified source of geographic data available for this analysis, and thus, are assumed to be representative of the rigid polyurethane foam industry for the purpose of this report. The distribution of the 224 SIC 3086, foamed plastics facilities reporting TRI releases in 2001 is presented in Figure 2-1.

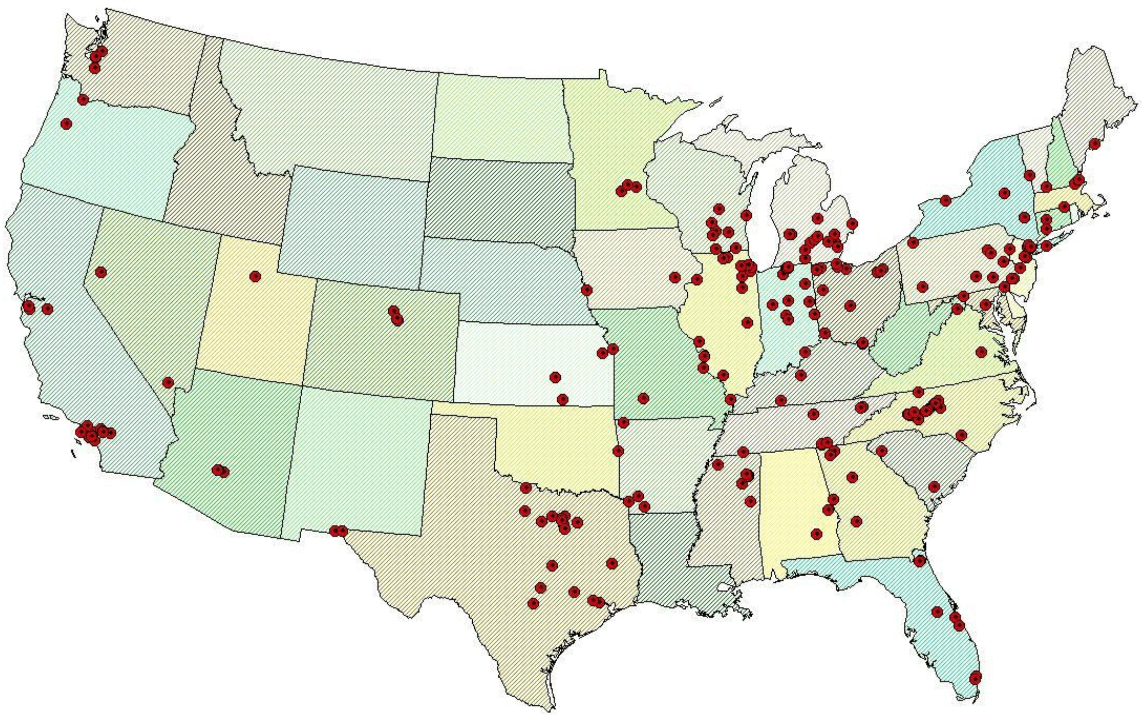


Figure 2-1. Geographic Distribution of Foam Manufacturers

The TRI data are further limited due to reporting thresholds associated with the Superfund Amendments and Reauthorization Act (SARA) Title III Section 313. Facilities are required to report releases of TRI chemicals only if they manufacture or process the chemical in excess of 25,000 pounds per year or if they "otherwise use" the chemical (e.g., as a solvent) in excess of 10,000 pounds per year.[1] Therefore, TRI data may not include releases associated with very small facilities. In addition, some of the rigid polyurethane foam is made on the site of application and not actually in a rigid foam manufacturing facility. These sites are not captured under SIC 3086, and data is not currently available to accurately characterize the geographic distribution of this portion of the rigid polyurethane foam industry.

[1] Note: There are exceptions to these thresholds for 20 chemicals designated to be persistent, bioaccumulative, and toxic. These chemicals have significantly smaller thresholds. However, diisocyanates and other commonly used chemicals in polyurethane foam manufacturing are not designated as persistent, bioaccumulative, and toxic.

3.0 RIGID POLYURETHANE FOAM MANUFACTURING PROCESS DESCRIPTION

Rigid polyurethane foam is unique in that the configuration of the product determines the method of production. Rigid polyurethane foam can be boardstock/laminate, poured into place, or spray applied depending upon the application (2). Each process is described in more detail in the subsections that follow. Industry markets for rigid polyurethane foam include construction, appliances, packaging, tanks and pipes, transportation, marine, and furniture. The most common use of rigid polyurethane foam is insulation in construction. Table 3-1 presents the rigid polyurethane foam market production for each industry use (2). As shown in Table 3-1, 56 percent of the rigid polyurethane foam production is boardstock/laminate, with construction as the dominant industry use.

Table 3-1

Rigid Polyurethane Foam Consumption Per Use

Industry Use	Rigid Polyurethane Foam Consumption (millions of pounds)			
	Total	**Board & Laminate**	**Pour-in-Place**	**Spray**
Construction	731	636	25	70
Appliances	240	11	229	0
Packaging	88	19	69	0
Tanks & Pipes	76	21	31	24
Transportation	73	20	53	0
Marine	35	0	32	3
Furniture	11	1	10	0
Other	13	6	3	4
All Uses	**1267**	**714**	**452**	**101**
Percent of Total	**100%**	**56%**	**36%**	**8%**

Raw materials used in the manufacture of rigid polyurethane foam include polyols, diisocyanates, catalysts, blowing agents, stabilizers, and flame retardants. Each of the above mentioned manufacturing processes begins in the same fashion by metering of the liquid chemical raw materials; the polyol mixture, which contains the polyol and all the necessary additives, and the diisocyanate, into a single mixing head. The reaction mixture remains free-flowing until the final phase of the foaming process, which results in foam that can be used in boardstock lamination, pour-in-place, spray, and other minor applications (e.g., slabstock, described below).

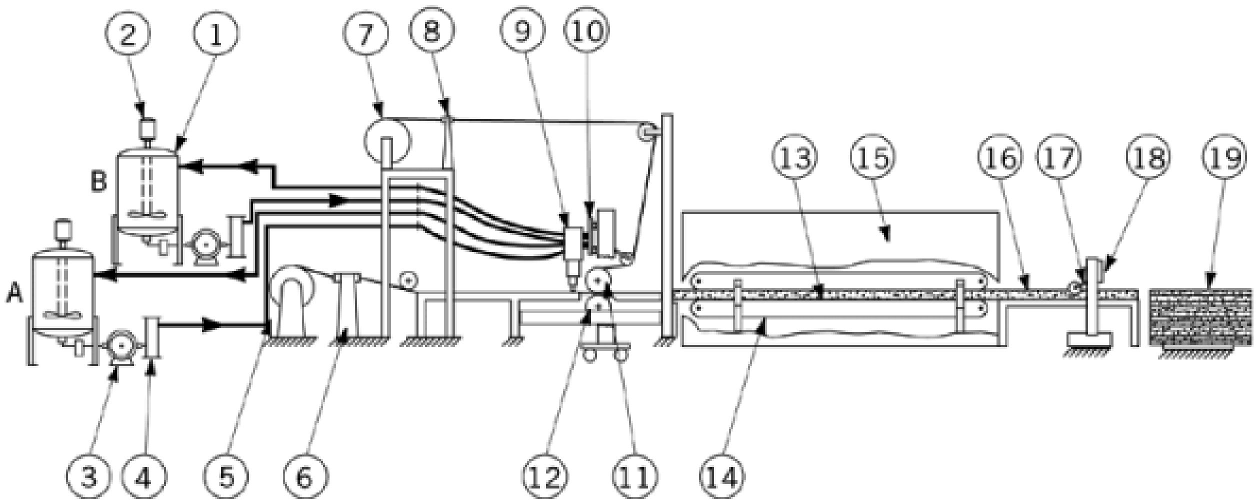
3.1 Boardstock/Laminate Rigid Foam

Boardstock/laminate foam applications represent approximately 56 percent of the rigid polyurethane foam industry (2). There are two primary means of manufacturing boardstock/laminate rigid foam: a continuous horizontal laminate or a sandwich panel. In both processes, the rigid polyurethane foam is continuously laminated between various facing materials including asphalt, tar paper, aluminum, steel, fiberboard, or gypsum facings. Both processes are described below.

3.1.1 Continuous Horizontal Lamination

The principle type of rigid foam laminate is manufactured using a continuous horizontal laminator. This type of laminator is used to produce rigid foam between two flexible facers (6). The products from this process are primarily used as insulation in buildings and in some cases used as tank and solar collector insulation. The density of a typical rigid foam between flexible facings is 30 to 36 kg/m^3 (15).

In a continuous horizontal laminator, the reaction mix is distributed uniformly on a lower facing, which then enters the laminator on a conveyor. The conveyor is enclosed and ventilated to remove gases that are produced in the foam reaction. A pressure zone exists inside the laminator to cause the lower facing with the foam to adhere to the upper facing to form a laminate (5). A diagram of a typical horizontal laminator is presented in Figure 3-1.



1. material tank 2. agitator 3. metering pump 4. heat exchanger 5. bottom facer roll	6. bottom facer alignment device 7. top facer roll 8. top facer alignment device 9. mixing head 10. traverse assembly	11. top nip roll 12. bottom nip roll 13. take-up conveyor top belt 14. take-up conveyor bottom belt 15. curing oven	16. laminate 17. side trim saws 18. cut-off saw 19. laminated panel-stack and packaging

Source: Kirk-Othmer Encyclopedia of Chemical Technology, Copyright 2004.

Figure 3-1. Rigid Foam Laminating Line

3.1.2 Sandwich Panels

The sandwich panel production process is another variation of rigid polyurethane foam boardstock lamination. Sandwich panels have foam cores between rigid facings. Facings for sandwich panels are typically steel, aluminum, or glass fiber reinforced sheets. Applications for sandwich panels include cold stores for food storage, entrance and garage doors, and factories where controlled environments are required such as in electronics, pharmaceuticals, and food processing (6). There are two types of processes used to create rigid foam sandwich panels: continuous and discontinuous processes.

The continuous process uses a horizontal laminator, much like those used to create flexible-faced laminates. The raw material of the rigid facing is supplied in a coil and is first fed into an un-coiler to form the outside panels. If corrugated or profiled panels are required, a roll-forming machine will press the plates to fit the product specifications. The foam chemicals are fed in between the plates and the entire product is then sent through the laminator. The laminator presses the foam between the two rigid facings, ensuring the foam is tightly adhered to the upper and lower facings, and then the laminator continues to compresses the panel to the appropriate thickness (20).

The discontinuous process requires flat facings, with appropriate spacers, in a single or multi-daylight or oyster press. The facings are fixed in a support mold on a frame. The cavity between the flat facings is filled with rigid polyurethane foam injected at multiple ports (6). Sandwich panels used for buildings are produced in lengths of up to 15 meters (5).

3.2 Pour-in-Place

Pour-in-place foam applications represent 36 percent of the rigid polyurethane foam market (2). Pour-in-place foam applications include insulation in appliances, ships, cold stores, and containers. In this process, the liquid raw materials are injected between the outer shell and the interior liner of the application. As the foam reaction occurs, the foam flows and expands throughout the cavity. Fixtures are required to support the walls of the application, which are under pressure from the expanding foam. During the foaming process, a small portion of the blowing agent escapes and is usually vented directly into the atmosphere, thus, the in-situ production process does not lend to the easy recovery of the blowing agent (6).

Froth foams, or one component foams, are considered to be pour-in-place. This process is used by the “do-it-yourself” home improvers and the building industry, in applications such as draft proofing around pipes, doors, windows, joining of insulating panels, and roofing boards. Froth foams contain the blowing agent CFC-12. This blowing agent has such a low boiling point that the foam acts as a propellant. CFC is usable in this application because the reaction prevents the material from flowing away from the site of the application and does not produce enough heat to volatilize the CFC (6). The foam is supplied in pressurized cylinders fitted with a nozzle. A thin strip of foam is extruded onto the surface of the application where it expands at room temperature. Curing occurs as the foam reacts with moisture in the air. The total time needed for foam to cure is dependent upon the surrounding temperature and relative humidity (6). The density of froth foams ranges from 27 kg/m^3 (1.7 lb/ft^3) to 64 kg/m^3 (4 lb/ft^3) (21,22).

3.3 Spray Rigid Foam

Spray foam applications represent 8 percent of the rigid polyurethane foam market (2). The major use for spray foam is in-situ application of rigid thermal insulation, especially in roofing applications. Other areas where spray foam is commonly applied are residential and commercial buildings, industrial storage tanks, piping and ductwork, and refrigerated transport tanks (6). The density of spray applied foam usually ranges from 21 kg/m^3 to 48 kg/m^3 (1).

Five equipment elements are necessary to spray polyurethane foam; a system for storage and handling, a material feed system, a proportioner pumping and heating system, a delivery hose, and a spray gun (18). Spray foam is directly applied using the hand-held pressurized spray gun. In this spray gun, separate polyol (with appropriate additives) and isocyanate liquids are metered, mixed, and dispersed. Spray foam is especially beneficial because the operator has the ability to control formulations through processing parameters, and thus, can control specific foam properties (6).

The foam is sprayed directly from the mixing head onto the medium, allowing for the coverage of large complicated surfaces. Insulating layers of up to 15 millimeters thick can be produced in one spray application, and a thick layer of foam can be produced via application of several thin layers (5, 6).

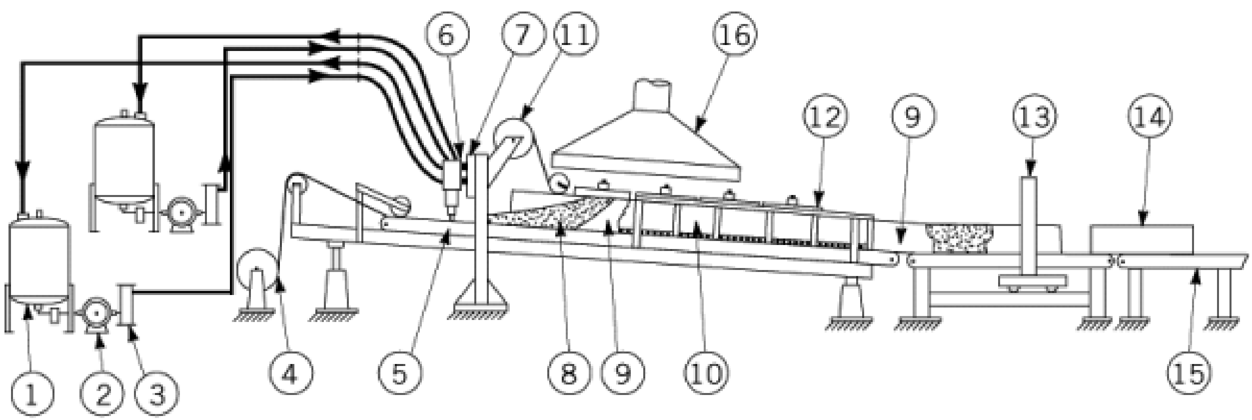
Spray polyurethane foam applicators are most likely installed in self-contained trailers or trucks, where auxiliary equipment such as air compressors, coating spray equipment, and electrical generators, can also be mounted. These self-contained units are typically heated and insulated to keep the polyol and isocyanate liquids at the necessary storage or feed temperatures (18).

3.4 Slabstock Rigid Foam

Slabstock is a minor process used to produce rigid polyurethane foam. Rigid slabstock foam is used as insulation for pipes, storage tanks, and boards in construction. Slabstock rigid foam can be produced using either a continuous or discontinuous manufacturing process. For both production processes, after three to five days of storage, the finished slabstock can be cut or milled into slabs and molded parts (5).

Discontinuous production of rigid slabstock foam is the more simple of the two methods for producing slabstock rigid foam. Chemical components are weighed, mixed, and poured into a wooden or cardboard mold. The mold is outfitted with a floating lid, which rises as the foam expands. This serves to level the top surface of the foam block (6).

In continuous production of rigid slabstock foam, the chemical components are mixed and dispersed continuously into a trough on a conveyor belt lined with paper or polyethylene film. The foam expands as it moves across the conveyor belt (6). Figure 3-2 is a diagram of a typical rigid bun foam line.



1. material tank with agitators	5. conveyor	9. side paper	13. cut-off saw
2. metering pump	6. mixing head	10. adjustable side panels	14. cut foam bun
3. heat exchanger	7. traverse assembly	11. top paper roll	15. roller conveyor
4. bottom paper roll	8. rising foam	12.top panels with adjustable height	16.exhaust hood

Source: Kirk-Othmer Encyclopedia of Chemical Technology, Copyright 2004.

Figure 3-2. Rigid Bun Foam Line

3.5 Chemicals Used to Manufacture Rigid Polyurethane Foam

Polyurethane foam is produced during the reaction of a polyol and a diisocyanate. The first reaction of the isocyanate and polyol is exothermic and forms a polymer chain and releases heat. The second reaction, known as blowing, incorporates some combination of a low boiling liquid blowing agent (e.g., HCFC, HFC, pentane), plus the isocyanate and water. The heat from the polyol isocyanate reaction causes the blowing agent to evaporate. The gas produced is responsible for the insulating properties of the foam. As the gas evaporates, the foam expands, trapping the gas in millions of tightly enclosed voids. The foam mix expands up to 30 to 50 times its original volume (5). A catalyst is used to speed up and control the reaction rate. The liquid foam mixture is then released onto the appropriate medium.

The polyol, isocyanate, and blowing agent are the main components in rigid polyurethane foam, but many other chemicals are added to control the course of the reaction and to obtain specific foam characteristics. Table 3-2 lists the types of chemicals used to manufacture rigid polyurethane foam and their specific function.

Table 3-2

Chemicals Used to Manufacture Rigid Polyurethane Foam

Type of Chemical	Purpose	Estimated Fraction in Foam
Polyols	The type of polyol selected influences foam properties Polyols can be either polyester or polyether based (polyether is more common)	35% by wt (1)
Diisocyanate	Raw material for polyurethane foam (polymeric methyl diphenyl and toluene diisocyanates)	50% by wt (15)
Tertiary Amines	Help to control the speed of the foam reaction (catalyst)	NA
Alkali Carboxylate Salts	Used for forming polyisocyanurate structures	NA
Blowing Agents	In addition to the water-isocyanate reaction which produces CO_2, auxiliary blowing agents produce gas responsible for foam expansion and determine the insulation value	7% by wt (15)
Stabilizers	Polyether-polysiloxanes prevent collapse of foaming mix and act as emulsifiers to regulate cell structure and size	NA

Table 3-2 (Continued)

Type of Chemical	Purpose	Estimated Fraction in Foam
Flame Retardants	Reduce flammability of foam	0.05 to 0.4 (16-17)*
Pigment Pastes	Colorant may be (not commonly) added to rigid polyurethane foam	0.005 to 0.03 (16)*

* These fractions are representative of loading rates in all plastic materials. Fractions of additives used in rigid foam may fall within the reported range.
NA-Not Available

3.5.1 Diisocyanates

Diisocyanates are a main component in the production or rigid polyurethane foam and are a class of low molecular weight aromatic and aliphatic compounds. The two main types of diisocyanates used to manufacture rigid polyurethane foam are toluene diisocyanate (TDI) and polymeric methyl diphenyl diisocyanates (MDI). Table 3-3 presents data on TDI and MDI use in rigid polyurethane foam. Approximately 98 percent of the rigid polyurethane foam produced uses MDI. MDI produces less gas than TDI, thus, the foam is more dense. The higher density of foam creates a suitable niche for rigid foam as insulation. Diisocyanates (MDI and TDI) have been linked to occupational asthma through inhalation of aerosols and vapors, and skin sensitization through dermal contact.

Table 3-3

Diisocyanate Use in Rigid Polyurethane Foam

Diisocyanate	Annual Use in Rigid Polyurethane Foam (millions of pounds DI per year)
TDI	10
MDI	606
Total	616

In 2001, Eurotech Ltd. announced a patented hybrid non-isocyanate polyurethane (HNIPU). Eurotech claimed that rigid foam made with this polyurethane has improved performance properties over isocyanate foam, while the health and safety concerns associated with the release of diisocyanates during the production of rigid foam is eliminated (19). Attempts to contact Eurotech were unsuccessful, therefore, additional information on HNIPU rigid foam is not available.

3.5.2 Flame Retardants

Because rigid polyurethane foam is used as thermal insulation in buildings and transportation, there are many instances where flammability and smoke regulations must be met. Favorable behavior of rigid foam in a fire can be influenced and enhanced by the selection of suitable polyols, the choice of basic foam structure, and by the addition of flame retardants. The following are some flame retardants commonly added to rigid polyurethane foam (1,7).

- Halogenated phosphate esters (tris(chloroethyl) phosphate and tris(chlorisopropyl) phosphate);
- Chlorendic anhydride-derived diols;
- Tetrabromophthalate ester diols;
- Phosphonates;
- Halogenated aromatic compounds;
- Borax;
- Melamine;
- Brominated diols; and
- Non-halogenated polyols.

The quantity and type of flame retardant added to polyurethane foam is dependent upon the foam type, product specifications, and manufacturing concerns. Since most rigid polyurethane foam is made with MDI and is higher density, “scorching” concerns are not as significant, thus, in general, dense foams require less flame retardant. However some rigid foams are being manufactured using low boiling liquid blowing agents such as pentane that are highly flammable, and require a greater amount of flame retardant. Currently tris(chloroethyl) phosphate and tris(chloroisopropyl) phosphate are the leading flame retardant additives in rigid polyurethane foam (7).

3.5.3 Blowing Agents

During the process of foam blowing, foam is created by forming gas bubbles in the polymerizing mixture. The cells of the foam filled with gas are produced by two methods, which usually occur simultaneously; the chemical blowing process, and the physical blowing process. During the chemical blowing process, the diisocyanate and water react to form carbon dioxide. In the physical blowing process, a low boiling liquid is added to the reaction mixture and as the reaction generates heat, the liquid evaporates to form the cells of the foam in the process (5).

Rigid polyurethane foams were originally produced using CFC based blowing agents. A mandatory phase out of CFCs by January 1996 created the need to develop blowing agents that would not damage the ozone layer. Two classes of blowing agents are considered as a short-term solution: hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). Longer-term solutions have lead to the use of CO_2 and hydrocarbons such as pentane; however, rigid foams produced with alternatives to CFC-based blowing agents provide less efficient insulating properties (1). Table 3-4 presents current and expected use of CFC-alternative blowing agents (6).

Currently, most rigid foam is blown with HCFCs, but because HCFCs contain chlorine, these chemicals are still a threat to the depletion of the ozone layer, but to a much lesser extent than CFCs. All developed countries that are parties to the Montreal Protocol are subject to a HCFC cap. In the United States, the implementation of restrictions on the production and consumption of HCFCs is conducted through the Clean Air Act (40CFR, Part 82, subpart A). Restriction of the production and import of HCFC 141-b began in January of 2003, with a final phase out of all HCFCs scheduled for 2030 (8).

Table 3-4

Alternatives to CFC Blowing Agents in Rigid Polyurethane Foam

Rigid Polyurethane Foam Application	CFC Alternatives		
	Currently in Use (2000-2001)	Anticipated Use (2005-2010)	
		Developed Countries	Developing Countries
Domestic Refrigerators and Freezers	HCFC-141b, HCFC-141b/22, HCFC-141b/22 blends, hydrocarbons, HFC-134a	HFC-245a, HFC-134a, hydrocarbons	HCFC-141b, hydrocarbons
Other Appliances	HCFC-141b, HCFC-22, HCFC-22/HCFC-142b	CO_2 (water), HFC-134a, hydrocarbons, HFC-245fa, HFC-365mfc/HFC-227ea	HCFC-141b, CO_2 (water), hydrocarbons
Reefers and Transport	HCFC-141b, HCFC-141b/-22	HFC-245fa, HFC-365mfc/HFC-227ea	HCFC-141b
Boardstock	HCFC-141b, HCFC 141b/-22	Hydrocarbons, HFC-245fa, HFC-365/HFC 227ea	N/A
Panels	HFC-141b	HFC-134a, hydrocarbons, HFC-365/HFC 227ea, HFC-245fa	HCFC-141b
Spray	HCFC-141b	CO_2 (water), HFC-365/HFC 227ea, HFC-245fa	HCFC-141b
Blocks	HCFC-141b	Hydrocarbons, HFC-365/HFC 227ea, HFC-245fa	HCFC-141b
Pipe	HCFC-141b	CO_2 (water), cyclopentane	HCFC-141b
One Component Foam	HCFC-22	HFC-134a or HFC-152a/dimethylether/propane /butane	HFC-134a or HFC-152a/dimethylether/propane /butane

3.5.4 Chemicals of Concern

TRI chemicals reported under SIC code 3086 and other selected chemicals expected to be used in the foam manufacturing process were compared to regulatory lists of chemical pollutants to identify chemicals of concern for the industry. Table 3-5 presents the chemicals of concern with the regulatory lists on which the chemicals appear.

Table 3-5

Chemicals Used in Foam Manufacturing and Listed on Priority Lists

CAS Number	Chemical Name	Number of Lists	CCL	CERCLA NPL	HAP	HPV	NAP	OSW WMP	POP	TRI	PPL	TCLP	VCCEP
1717006	1,1-dichloro-1-fluoroethane	2				x				x			
75683	1-chloro-1,1-difluoroethane	2				x				x			
7440360	antimony	3		x						x	x		
N230	glycol ethers	2			x					x			
75456	chlorodifluoromethane	2				x				x			
75003	chloroethane	5		x	x	x				x	x		
74873	chloromethane	5		x	x	x				x	x		
1163195	decabromodiphenyl oxide	3				x				x			x
75092	dichloromethane	5		x	x	x				x	x		
111422	diethanolamine	3			x	x				x			
N120	diisocyanates	1								x			
107211	ethylene glycol	3			x	x				x			
50000	formaldehyde	4		x	x	x				x			
67561	methanol	3			x	x				x			
78933	methyl ethyl ketone	6		x	x	x				x		x	x
108101	methyl isobutyl ketone	4		x	x	x				x			
110543	n-hexane	3			x	x				x			
872504	n-methyl-2- pyrrolidone	2				x				x			
85449	phthalic anhydride	3			x	x				x			
75569	propylene oxide	3			x	x				x			
100425	styrene	4		x	x	x				x			
108883	toluene	6		x	x	x				x	x		x
26471625	toluene diisocyanate (mixed isomers)	2				x				x			
584849	toluene-2,4- diisocyanate	3			x	x				x			
79016	trichloroethylene	7		x	x	x				x	x	x	x

Table 3-5 (Continued)

CAS Number	Chemical Name	Number of Lists	CCL	CERCLA NPL	HAP	HPV	NAP	OSW WMP	POP	TRI	PPL	TCLP	VCCEP
1330207	xylene (mixed isomers)	4		x	x	x				x			
N982	zinc compounds	1								x			

CCL: Contaminant Candidate List (Safe Drinking Water Act)
CERCLA NPL: Comprehensive Environmental Release, Compensation, and Liability Act National Priority List of Hazardous Substances
HPV: High Production Volume
HAP: Hazardous Air Pollutant (Clean Air Act)
PBT-NAP: Persistent, Bioaccumulative, Toxic National Action Plan
POP: Persistent Organic Pollutants; identified by the Organization of Economic Cooperation and Development
PPL: Priority Pollutant List (Clean Water Act)
OSW WMP: Waste Minimization National Plan
TCLP: Toxicity Characteristic Leaching Procedure; promulgated under the Land Disposal Restrictions (LDR) regulations (51 FR 40572)
TRI: Toxic Release Inventory (Emergency Planning Community Right-to-Know Act)
VCCEP: Voluntary Children’s Chemical Evaluation Program

4.0 ESTIMATES OF RELEASES AND EXPOSURES FROM RIGID POLYURETHANE FOAM MANUFACTURING

Fully cured polyurethanes are chemically inert, and thus, present no health hazards. Several concerns for occupational related exposures and environmental releases, however, are associated with the production of polyurethane foam. Some of the chemicals used in the production process such as diisocyanates and tertiary amine catalysts are highly reactive, and must be handled with caution. Dust is a major pathway for occupational exposure of harmful chemicals used to make polyurethane foam. Isocyanate exposure is linked to respiratory effects as well as skin and eye irritation (1). Tertiary aliphatic amines (catalysts) can cause dermatitis, severe damage to the eye, and respiratory irritation (1). It is known that certain blowing agents used to create polyurethane foam are harmful to the environment, and recent studies have begun to look at the environmental fate and toxicology of some flame retardants. This section presents general facility information for the rigid polyurethane foam industry, release estimates, 2001 TRI releases for the industry, and inhalation and dermal exposure estimates.

4.1 General Facility Assessments

This subsection provides information regarding daily production of rigid foam and daily use rates of diisocyanates and other chemicals. Rigid polyurethane foam is not simply produced as a complete product inside the confines of a manufacturing facility. The estimations presented below are based on data which is available for the portion of rigid foam produced in manufacturing facilities, and will most likely represent boardstock/laminate, slabstock, and some pour-in-place (e.g., appliances) rigid foams. Some of these estimates likely do not characterize rigid foam which is produced at the site of application, including some pour-in-place (e.g., construction) and spray foam applications.

4.1.1 Daily Throughput

Industry data from 1996 indicates that 1268 million pounds (575 million kilograms) of rigid polyurethane foam was produced in the U.S. (2). From Section 2.3 is was estimated that there are 171 facilities that manufacture rigid polyurethane foam. It can also be assumed that the typical number of operational days per year for a facility is 250, assuming a 5-day work week and 2 weeks per year of plant shutdown. The following equation estimates the average daily throughput of rigid polyurethane foam.

$$Q_{rigid\_foam\_day} = \frac{Q_{rigid\_foam\_year}}{N_{rigid\_sites} \times TIME_{year}} = \frac{575{,}000{,}000 \text{ kg / yr}}{171 \text{ sites} \times 250 \text{ days / yr}} = 13{,}500 \text{ kg / site - day}$$

where:

$Q_{rigid\_foam\_day}$	=	Average daily throughput of rigid foam (kg/site-day)
$Q_{rigid\_foam\_year}$	=	Total production of rigid foam in the U.S. (Default: 575,000,000 kg/year) (2)
N_{rigid_sites}	=	Number of rigid polyurethane foam manufacturers in the U.S. (Default: 171 sites)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

Industry data from 1996 shows a total of 616 million pounds (279 million kilograms) of diisocyanates or roughly 10 million pounds (4.5 million kilograms) of TDI and 606 million pounds (275 million kilograms) of MDI were used to manufacture 1268 million pounds (575 million kilograms) of rigid polyurethane foam. This translates to a 2 to 1 mass ratio of foam to diisocyanates. The following equation estimates the daily use rate of diisocyanates in rigid foam. Note that this use rate equation could be used to estimate the daily use rate for TDI or MDI, though MDI is predominantly used in rigid polyurethane foam.

$$Q_{rigid\_di\_day} = \frac{Q_{rigid\_di\_year}}{N_{rigid\_sites} \times TIME_{year}} = \frac{279{,}000{,}000 \text{ kg / yr}}{171 \text{ sites} \times 250 \text{ days / yr}} = 6{,}530 \text{ kg / site - day}$$

where:

$Q_{rigid\_di\_day}$	=	Average daily use rate of diisocyanate for slabstock foam
$Q_{rigid\_ di\_year}$	=	Yearly use of diisocyanate in rigid foam in the U.S. (Default: 279,000,000 kg/yr) (2)
$N_{slabstock\_sites}$	=	Number of rigid polyurethane foam manufacturers in the U.S. (Default: 171 sites)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

The daily throughput of a chemical additive used in foam manufacturing can be calculated from the percent of the additive used in the foam and the daily output of the foam manufactured.

$$Q_{chem\_day} = Q_{foam\_day} \times F_{chem\_foam}$$

where:

Q_{chem_day}	=	Daily use rate of chemical additive used in foam (kg/site-day)
Q_{foam_day}	=	Average daily throughput of rigid foam (kg/site-day)
F_{chem_foam}	=	Fraction of chemical additive in foam (Defaults: see Table 3-2)

For example, the annual use rate of blowing agents for the rigid polyurethane foam sub-industry is not currently available, but the daily throughput can still be estimated using the equation above and the F_{ba_foam} value of 0.07 from Table 3-2.

$$Q_{ba\_day} = Q_{foam\_day}(13{,}500 \text{ kg / site - day}) \times F_{ba\_foam}(0.07) = 945 \text{ kg / site - day}$$

where:

Q_{ba_day}	=	Daily use rate of blowing agents used in rigid foam (kg/site-day)
Q_{foam_day}	=	Average daily throughput of rigid foam (kg/site-day) (Default: 13,793 kg/day-site)
F_{ba_foam}	=	Fraction of blowing agent in foam (Default: 0.07) (15)

4.1.2 Number of Sites Using Specialty Additives

Certain raw materials used to manufacture rigid polyurethane foam, such as diisocyanates and polyols are expected to be used at every manufacturing facility; however, some foam may require specialty additives that may only be used in a fraction of the total rigid foam produced in the U.S. The number of sites at which specialty additives are used can be determined from the total amount of the chemical consumed by the rigid foam industry and the daily use rate of the chemical at each facility.

$$N_{sites} = \frac{Q_{chem\_year}}{Q_{chem\_day} \times TIME_{year}}$$

where:

N_{sites}	=	Number of sites estimated to use the chemical
Q_{chem_year}	=	Yearly consumption of chemical used in the flexible polyurethane foam industry (kg/yr)
Q_{chem_day}	=	Daily use rate of chemical additive used in foam (kg/site-day)
$TIME_{year}$	=	Days of operation (Default: 250 days/yr)

4.2 Environmental Releases

Releases into the environment from the production of rigid polyurethane foam are expected to occur from residuals remaining in transport containers, air releases during production, cleaning of production equipment, and disposal of leaks, scraps, and off-spec foam. Estimation techniques for each of the above mentioned releases are presented in this subsection along with a summation of 2001 TRI-reported releases.

4.2.1 Transport Container Residue

Chemicals used to manufacture foam in the U.S. are expected to be in liquid form; however, additives may be received as a solid and mixed into a solution before charged to the foam making process. The majority of foam manufacturing facilities in the U.S. require liquid ingredients due to the process equipment used. It is expected that a small amount of liquid or solid will remain in the transport container after the container is emptied and the material is charged to the process equipment. The amount of liquid remaining in the container depends on the size of the container. For small containers (<5 gallons), it is estimated that 0.6 percent of the liquid remains in the container (7). For larger containers (<110 gallons), it is estimated that 3 percent of liquid remains in the container (8,9). Chemical used in large amounts may be delivered in tanker trucks. For tanker trucks, it is estimated that 0.2 percent of the liquid remains in the tanker truck (22). The amount of solids remaining in any size container is estimated as 1 percent (22). The media of release for container residue is not certain. Containers could be rinsed out with water or solvent, the rinsate could be sent to wastewater treatment or incineration, or the containers could be sent to a landfill or recycler. The following equations calculate the release of a chemical from container residue.

Number of containers per site per year

$$N_{container\_year} = \frac{Q_{chem\_year}}{Q_{container} \times TIME_{year}}$$

Release of chemical from container residue per container

$$Elocal_{container\_residue\_disp} = Q_{container} \times F_{container\_residue}$$

where:

$N_{container\_year}$	=	Number of containers used at a site per year (container/year)
Q_{chem_year}	=	Yearly consumption of chemical used in the flexible polyurethane foam industry (kg/yr)
$Q_{container}$	=	Capacity of container used to transport chemical (Default: 200 kg/container for 55 gal drum)
$Elocal_{cotnainer\_residue\_disp}$	=	Daily release of chemical of interest to water, incineration, or landfill from container residue per container (kg/site-container)
$F_{container\_residue}$	=	Fraction of liquid that remains in the container (Defaults: Liquids: 0.002 for tank trucks, 0.006 for small container, and 0.03 for large containers; Solids: 0.01) (9,10,11,12)

4.2.2 Air Emissions

Diisocyanates

Data on MDI conversions and releases in rigid foam manufacturing are not currently available. It is assumed that the rate of release of MDI in rigid foam manufacturing is similar to the rate of release of TDI in flexible foam manufacturing. This is a conservative estimate for MDI releases because MDI is less volatile than TDI. Industry contacts estimate that 35 pounds of TDI is released during the flexible foam making process for every 1,000,000 pounds of TDI consumed. This means that 0.0035 percent of diisocyanate used is released to the atmosphere or to air pollution controls. The following equations estimate the release of diisocyanates to the air per day.

$$Elocal_{rigid\_air\_di} = Q_{rigid\_di\_day}\ (13{,}500\ kg/site\text{-}day) \times 0.000035 = 0.473\ kg/site\text{-}day$$

where:

$Elocal_{rigid\_air\_di}$	=	Daily release of diisocyanates to air from rigid foam production
$Q_{rigid\_di\_day}$	=	Average daily use rate of diisocyanates for rigid foam (Default: 13,500 kg/site-day)

Blowing Agents

HCFCs used as blowing agents are also released from the production of rigid polyurethane foam. This is cause for concern because HCFCs have been linked to depletion of the ozone layer. Typically a small amount of the blowing agent escapes during the foaming process. Rigid foam production systems do not make recovery of lost the blowing agent very feasible, so blowing agents are generally vented directly into the atmosphere (6). One source estimates that approximately 6 percent of the blowing agent is released during the production of rigid foam (15). The following equations estimate the release of blowing agents to the air per day.

$$Elocal_{rigid\_air\_ba} = Q_{rigid\_ba\_day}(945 \text{ kg/site-day}) \times 0.06 = 57 \text{ kg/site-day}$$

where:

$Elocal_{rigid\_air\_ba}$	=	Daily release of blowing agents to air from rigid foam production
$Q_{rigid\_ba\_day}$	=	Average daily use rate of blowing agents for rigid foam (Default: 945 kg/site-day)

4.2.3 Equipment Cleaning

Transfer, or loss, of a small percentage of chemicals used to manufacture rigid polyurethane foam to equipment the chemicals come into contact with is inevitable. It is assumed that 2 percent of each chemical by volume remains in or on the equipment and is then released to water or incineration following cleaning activities (13). The frequency of equipment cleaning, type of cleaning media, and media releases are not currently available. It can be conservatively assumed that cleaning of equipment takes place on a daily basis and that waste remaining on equipment is released to water or incineration. The following equation can be used to estimate the daily release of chemicals used to produce rigid polyurethane foam to water or incineration from equipment cleaning activities.

$$Elocal_{equip\_disp} = Q_{equip} \times F_{equip}$$

where:

$Elocal_{equip\_disp}$	=	Daily release of chemical to water or incinerator from equipment cleaning (kg/site-day)
Q_{equip}	=	Capacity of foam making equipment (kg/equipment) (Default: daily use rate of chemical per site Q_{chem_day} (kg/site-day)
F_{equip}	=	Fraction of liquid remaining in the equipment (Defaults: 0.02 for multiple vessels and 0.01 for a single vessel) (13)

4.2.4 Scraps and Off-spec Foam Disposal

Scrap foam or off-spec foam is produced when the rigid foam is not made to the correct specification for end use. The following equation can be used to estimate the daily release of rigid foam to a landfill if the parameters are known or estimated.

$$Elocal_{scrap\_disp} = Q_{foam\_day} \times F_{scrap}$$

where:

$Elocal_{scrap\_disp}$	=	Daily release of foam from waste scrap to landfill (kg/site-day)
Q_{foam_day}	=	Average daily throughput of rigid foam (kg/site-day) (Default: 13,500 kg/site-day)
F_{scrap}	=	Fraction of foam produced disposed of as scrap

Some chemicals used in the manufacture of rigid foam, such as flame retardants and other fillers, will remain throughout the lifetime of the foam and are expected to be released to a landfill when the scrap foam is disposed. The following equation estimates the amount of a chemical that is released to a landfill from scrap disposal.

$$Elocal_{scrap\_additive\_disp} = Q_{foam\_day} \times F_{scrap} \times F_{chem\_foam}$$

where:

$Elocal_{scrap\_add\_disp}$	=	Daily release of additive from waste scrap foam to landfill (kg/site-day)
Q_{foam_day}	=	Average daily throughput of rigid foam (kg/site-day) (Default: 13,500 kg/site-day)
F_{scrap}	=	Fraction of foam produced disposed of as scrap
F_{chem_foam}	=	Fraction of chemical additive in foam (Defaults: see Table 3-2)

4.2.5 TRI Releases

Under the primary SIC code 3086, 224 facilities reported nearly 19 million pounds of TRI releases to air, surface water, and land, including transfers offsite for disposal and transfer of metals to POTWs. These releases consisted of 59 chemicals/chemical groups. Table 4-1 presents the top 25 chemicals released from SIC 3086 TRI reporting facilities.

Figure 4-1 presents the geographic distribution and total TRI releases for the 10 companies reporting the largest discharges. Of these companies listed in Figure 4-1, two manufacture rigid polyurethane foam; Dow Chemical (Peverly, MO), Dow Chemical (Ironton, OH). Pactiv may also be included in this list of rigid foam producers as their specialty is packaging material.

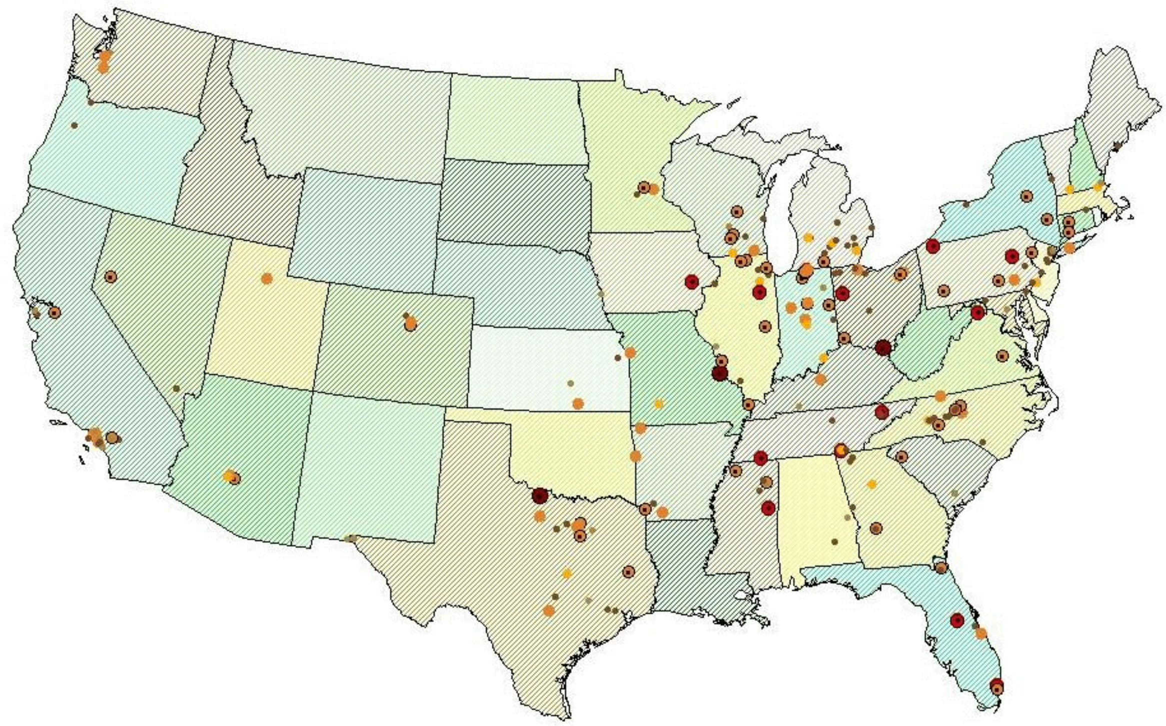
Table 4-1

2001 TRI Releases for SIC 3086 Top 25 Chemicals

CAS No.	Chemical Name	No. of Facilities Reporting	2001 TRI Releases and Other Waste Management (pounds)									
			Total Quantity Released	Sub-Categories of Releases					Quantities to Waste Management			
									Off-Site Transfers			On Site Treatment
				Fugitive Air Emissions	Stack Air Emissions	Discharged to Surface Water	Released to Onsite Land	Transferred Offsite for Disposal	Treatment	Energy Recovery	Recycled	
000075683	1-chloro-1,1-difluoroethane	9	3,461,162	430,540	3,021,849	0	0	9,087	0	0	0	0
001717006	1,1-dichloro-1-fluoroethane	39	1,889,271	936,840	836,745	0	20,498	94,426	2,713	0	0	0
007440360	Antimony	1	7,052	0	0	0	0	7,052	0	0	0	0
N230	Certain glycol ethers	3	24,100	1,000	22,800	0	5	250	3,050	0	0	0
000075456	Chlorodifluoromethane	24	399,534	357,827	36,203	0	0	5,935	0	0	0	0
000075003	Chloroethane	5	674,620	340,617	330,368	0	0	3,635	0	0	0	0
000074873	Chloromethane	1	53,560	53,560	0	0	0	0	0	0	0	0
001163195	Decabromodiphenyl oxide	1	26,503	0	0	0	0	26,503	0	0	0	0
000075092	Dichloromethane	36	9,917,129	3,276,696	6,655,565	5	5	250	147,797	0	10,500,286	0
N120	Diisocyanates	123	109,150	2,815	2,848	0	92,295	25,219	40,808	0	550	2,450
000050000	Formaldehyde	3	7,219	6,954	239	0	0	26	0	0	0	89,079
000067561	Methanol	3	27,704	25,695	35,492	0	0	0	438,207	0	0	0
000108101	Methyl isobutyl ketone	5	37,120	19,740	17,379	0	0	0	4,403	0	0	66,000
000078933	Methyl ethyl ketone	8	903,827	774,788	129,955	0	5	250	179,540	0	12,312	310,000
000110543	N-hexane	5	26,655	8,462	18,191	0	0	0	0	0	0	39,932
000872504	N-methyl-2-pyrrolidone	5	123,336	1,000	122,036	0	5	750	207,780	0	0	0
000085449	Phthalic anhydride	2	6,067	0	5	0	0	6,067	0	0	0	0
000075569	Propylene oxide	3	12,210	6,147	6,063	0	0	0	250	0	0	0
000100425	Styrene	7	80,405	25,136	55,227	0	0	0	122,495	160,899	0	0
026471625	Toluene diisocyanate (mixed isomers)	74	27,080	4,131	16,225	0	250	6,768	77,382	0	0	745

Table 4-1 (Continued)

			2001 TRI Releases and Other Waste Management (pounds)									
									Quantities to Waste Management			
				Sub-Categories of Releases					Off-Site Transfers			
CAS No.	Chemical Name	No. of Facilities Reporting	Total Quantity Released	Fugitive Air Emissions	Stack Air Emissions	Discharged to Surface Water	Released to Onsite Land	Transferred Offsite for Disposal	Treatment	Energy Recovery	Recycled	On Site Treatment
000108883	Toluene	12	726,623	395,257	330,969	0	0	345	104,717	0	0	76,747
000584849	Toluene-2,4-diisocyanate	8	8,855	1,137	2,315	0	0	5,663	920	0	0	2
000079016	Trichloroethylene	2	23,199	232	22,967	0	0	0	7,177	0	0	0
001330207	Xylene (mixed isomers)	4	319,849	304,940	14,661	0	0	248	62,830	0	0	9,524
N982	Zinc compounds	8	60,607	255	2,250	0	5	3,366	250	0	0	0



LEGEND

TRI Releases (in pounds)

- 0-99
- 100-999
- 1,000-9,999
- 10,000-99,999
- 100,000-999,999
- 1,000,000-4,999,999
- >5,000,000

Top 10 TRI Dischargers in SIC 3086

1. Dow Chemical (Peverly, MO)	7,252,566 lbs
2. Texas Recreation (Wichita Falls, TX)	5,798,952 lbs
3. Dow Chemical (Ironton, OH)	5,141,066 lbs
4. Foamex (Milan, TN)	4,401,064 lbs
5. Foamex (Corry, PA)	3,738,651 lbs
6. Carpenter (Elkhart, IN)	3,214,265 lbs
7. Pactiv (Winchester, VA)	1,931,024 lbs
8. Lear (Iowa City, IA)	1,923,600 lbs
9. Foamex (Elkhart, IN)	1,815,824 lbs
10. GFC Foam (West Hazleton, PA)	1,752,033 lbs

Figure 4-1. Facilities Reporting TRI Releases under SIC 3086

4.3 Occupational Exposure

This section presents information relating to worker activities in rigid foam manufacturing facilities and associated inhalation and dermal exposures. This section also addresses work practices and occupational exposures related to the production of rigid foam outside of a controlled factory environment.

4.3.1 Number of Workers Exposed in Rigid Foam Manufacturing Facilities

Boardstock/laminate, pour-in-place used in appliance manufacturing, and slabstock rigid foams and are the types of foam that may be fully manufactured in a manufacturing facility. It was estimated that there are approximately 58 employees per rigid polyurethane foam manufacturing facility, based on analyses presented in Section 2.3. The 2001 Annual Survey of Manufacturers found that 80 percent of employees under NAICS 326150 work on production (14). Under the assumption that all production workers have the potential to be exposed to chemicals used to manufacture foam, approximately 47 workers per facility face potential exposure.

Spray polyurethane foam and pour-in-place foam used in construction are generally created on the site of application. The application of the foam can be completed by construction workers and "do-it-yourself" home improvers. Information on number of persons exposed from these routes of production is not available.

4.3.2 Production Activities

Manufacturing Facility Activities

Information on worker activities for boardstock/laminate, slabstock, and pour-in-place rigid polyurethane foam manufacturing was not readily available. The worker activities for boardstock/laminate and slabstock rigid foam production are expected to be similar to those for slabstock flexible polyurethane foam manufacturing. Pour-in-place worker activities are likely not similar because the foam is produced by injection of reactants into appliance walls, rather than production on a foam line.

For slabstock flexible foam production, foam line worker activities can be divided into four basic job functions: foam head operator, foam line operator, cut-off saw operator, and bun handler. Workers also handle foam after manufacturing and perform post production (further trimming and cutting and glueing) and packing activities. (29)

The foam head operator works primarily on the bridge at the front of the foam line, and rarely leaves the bridge (where raw materials are dispensed onto the conveyor), except during upset conditions. Depending on the particular plant layout, the foam head operator may be situated close to the foam head or some distance away. The foam head operator is the least likely to go into or under the tunnel during operation. (29)

The working area of the foam line operator ranges along the entire foam line including the bridge, and often leaves the bridge to attend to problems with the paper or plastic on the conveyor line. The foam line operator is the most likely to go into or under the tunnel during operation, and sometimes enters the tunnel for start-up. (29)

The cut-off saw operator, generally, does not leave the saw area; however, it is routine for the saw operator to enter the tunnel to label foam buns and to remove scrap. Saw operators might also be required to enter the tunnel at start-up. (29)

The fourth job category, the bun handler, is responsible for moving foam blocks, or buns, from the cut-off saw area to the curing area. The nature of the bun handler’s job varies from plant to plant. At some facilities, this position might require moving short buns with a dolly or forklift, or long buns with a crane, while some newer plants have conveyor systems that require no operator. The bun handler may sometimes enter the tunnel at start-up. (29)

Construction Site Activities

Information on worker activities during the application of spray or pour-in-place rigid polyurethane foam in construction was not available. Activities are expected to vary based on a variety of factors, such as building surface (e.g., walls or roofs), indoor or outdoor application, and method of foam application (e.g., spray or injection).

4.3.3 Inhalation Exposure

Diisocyanates and tertiary amine catalysts are chemicals of concern for exposure during the production of rigid polyurethane foam. Occupational exposure limits for diisocyanates are regulated by the Occupational Safety and Health Administration (OSHA) and recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). Though tertiary amine catalysts are known to cause contact dermatitis, severe damage to the eyes, and irritation of the upper respiratory tract and lungs (1), OSHA and ACGIH have not established exposure limits. Table 4-2 presents the exposure limits for diisocyanates.

Table 4-2

OSHA PEL and ACGIH TLVs for Chemicals Used During the Manufacture of Rigid Polyurethane Foam

Chemical	OSHA PEL			ACGIH TLV	
	TWA	STEL	Ceiling	TWA	STEL
Toluene-2,4-Diisocyanate (TDI)	NE	NE	20 ppb 0.14 mg/m^3	5 ppb 0.036 mg/m^3	20 ppb 0.14 mg/m^3
Methylene Diphenyl Diisocyanate (MDI)	NE	NE	20 ppb 0.2 mg/m^3	5 ppb 0.051 mg/m^3	NE

NE - Not established.

Sources: OSHA 29 CFR Subpart Z
American Conference of Governmental Industrial Hygienists'. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. 1996.

5.0 ENGINEERING CONTROLS AND PERSONAL PROTECTIVE EQUIPMENT

This section presents information on engineering controls, personal protective equipment use, and regulatory requirements for the control of exposure to harmful chemicals released during the production of rigid polyurethane foam, specifically for MDI, blowing agents, and tertiary amine catalysts.

5.1 Engineering Controls

The use of engineering controls is expected to vary for the different types of rigid polyurethane foam processes. For processes in manufacturing facilities, such as rigid boardstock manufacturing, many polyurethane manufacturers have incorporated engineering controls in order to meet OSHA workplace exposure limits for MDI. Since worker exposure to these chemicals is highest near the foam tunnel, a combination of containment (i.e., enclosure) and local exhaust ventilation (LEV) is a common method of control. The balance between containment and LEV is governed by both exposure limitation and economic factors, e.g., capital and operating costs. Spray rigid foam applications typically require general ventilation if the foam is sprayed indoors. Engineering controls are not expected for outdoor spraying, such as exterior roof applications.

Unlike the flexible polyurethane foam industry, rigid foam manufacturers are not expected to send LEV exhaust to air pollution control (APC) equipment to control air releases to the environment. This is due to a difference in regulations, and the lower vapor pressure of MDI compared to toluene diisocyanate (TDI), the primary diisocyanate used in flexible polyurethane foam manufacturing. Whereas the EPA has promulgated a NESHAP for flexible polyurethane foam, there is no NESHAP for the rigid foam industry. In addition, while TDI has a vapor pressure of 0.008 mm Hg at room temperature, MDI has a vapor pressure of 5×10^{-6} mm Hg at room temperature (23). While the vapor pressure of MDI is higher during processing at elevated temperatures, it is not expected to be high enough to warrant APC technology to control air releases[2].

[2]Communication with an APC technology supplier to the FPF industry confirmed that MDI abatement technologies are typically not used in the RPF industry.

5.2 Personal Protective Equipment (PPE)

To supplement containment and LEV, foam line workers should use personal protective equipment, particularly when responding to an upset condition or other spill. The Alliance for the Polyurethanes Industry (API) offers guidelines for selecting appropriate protective equipment when handling MDI (24, 25). These guidelines cover eye protection, respiratory protection, gloves, and suits. API also offers similar information on PPE for handling amine catalysts, many of which are more volatile than MDI, and/or are corrosive (26).

According to industrial hygiene studies by the Dow Chemical Company and Huntsman Polyurethanes, when using air-purifying respirators (APRs) the use of appropriate cartridges is particularly important (27, 28). In the Dow study, several types of organic vapor (OV) cartridges, with and without particulate filters, were tested for MDI breakthrough from test atmospheres containing both MDI vapor and aerosols. The test atmospheres had MDI concentrations between one and ten times the ACGIH TLV of 0.051 mg/m^3. For atmospheres one to two times the TLV, in which most MDI was vapor, an OV cartridge with no prefilter blocked approximately 80 percent of the MDI atmosphere. For atmospheres with concentrations of seven or more times the TLV, the same type of OV cartridge blocked only 30-35 percent of the MDI due to the predominance of MDI in the aerosol form. OV cartridges with either dust/mist or HEPA filters blocked 99 percent or more of the MDI for all concentrations.

In the Huntsman study, worker exposures to MDI and a blowing agent, dichlorofluoroethane (HCFC-141b), were measured for spray rigid foam application in homes. Airborne concentrations of MDI were as high as 2.05 mg/m^3, more than ten times the OSHA PEL-C of 0.2 mg/m^3. Particle size distribution data showed that 15-35 percent of the MDI aerosols were smaller than 3.5 microns in diameter and therefore respirable by OSHA standards. Exposures to the blowing agent were within the eight hour AIHA Workplace Environment Exposure Limit (WEEL). Similar to the Dow study’s findings, the Huntsman study concluded that the minimum respiratory protection for spray foam workers is an APR with an OV cartridge and a dust/mist or HEPA prefilter. The Huntsman study also suggested use of supplied-air respirators for greater protection and worker comfort in hot work conditions.

5.3 **Regulatory Requirements**

As stated above, EPA has not promulgated a NESHAP for the rigid polyurethane foam industry. OSHA and ACGIH have developed exposure limits for some chemicals used in the foam manufacturing industries. See Table 4-2 for a summary of OSHA PELs and ACGIH TLVs for diisocyanates used in the rigid polyurethane foam manufacturing industry.

There are other regulations pertaining to chemicals used in the rigid polyurethane foam manufacturing industry, including the Toxic Release Inventory where MDI and other chemicals are required to be reported. This section, however, focuses on regulations that pertain to diisocyanates.

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