CDC Workplace Safety and Health

NIOSH ALERT

Preventing Asthma and Death from MDI Exposure During Spray-on Truck Bed Liner and Related Applications

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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NIOSH ALERT

Preventing Asthma and Death from MDI* Exposure During Spray-on Truck Bed Liner and Related Applications

WARNING!

Workers exposed to MDI may develop serious or fatal respiratory disease.

Workers should take the following steps to protect themselves from MDI* exposure during spray-on applications:

1. Be informed.

- Participate in medical exams, medical monitoring, air monitoring, respiratory fit-testing, and training programs offered by your employer.
- Know the safety and health information and follow all safety precautions provided by the manufacturers about the product(s) you are spraying.

2. Use respirators and PPE safely.

- Make sure that you have been fit-tested for your respirators and that you have been trained in their proper use, storage, and maintenance.
- Regularly inspect and maintain all component parts of supplied-air respirators and air-purifying respirators to assure their continued effectiveness. The components include air compressors, hoses, regulators, facepiece, etc.
- When spraying MDI,
  - — always use a full-facepiece, supplied-air respirator operated in a pressure-demand or other positive-pressure mode and
  - — wear appropriate personal protective equipment (PPE) (such as hooded coveralls, chemical-resistant gloves, and footwear).
- Never remove or lift the respirator away from the face while in the spray enclosure. Use clear plastic tear-away sheets on the visor to provide better visibility throughout the spray process.
- Be aware that the highest MDI concentrations occur inside the spray enclosure.
- After spraying, leave the spray enclosure before removing your respirator and PPE and keep the ventilation system running to exhaust any remaining MDI.
- Do not re-enter the spray enclosure after spraying has stopped without PPE and a respirator (minimum protection is an air-purifying respirator with a full facepiece equipped with a combination organic vapor/N95 filter cartridge).
- Know the change-out schedule for the air-purifying respirator cartridge and strictly follow the schedule to make sure that you are adequately protected from exposure to MDI.

*MDI is methylenebis(phenyl isocyanate). In this fact sheet, MDI refers to all MDI-based isocyanates.

3. Check the ventilation system in the spray enclosure.

- Make sure that the spray enclosure ventilation is operating correctly before beginning the spray process.
- Ensure that ventilation system intake filters are not clogged and are correctly installed in their frames.
- Keep the ventilation system running until the MDI aerosol has been cleared from the spray enclosure.

4. Use good work practices and personal hygiene.

- Never eat or drink in work areas.
- Wash hands and face before eating, drinking, or smoking.

5. Report symptoms.

- Do the following if you have symptoms:
  - — Tell your employer if you develop breathing problems that could be related to MDI exposure (wheezing, chest tightness, shortness of breath, or coughing).
  - — Seek medical evaluation of those symptoms.
  - — Do not spray or remain exposed to MDI until you are medically evaluated for breathing problems that might be related to the spraying process.
- If you have been diagnosed with occupational asthma due to sensitization from MDI, do not work where you might be exposed to MDI.

Spraying base coat with protective equipment.

For additional information, see ***NIOSH Alert: Preventing Asthma and Death from MDI Exposure During Spray-on Truck Bed Liner and Related Applications*** [DHHS (NIOSH) Publication No. 2006–149]. Single copies of the Alert are available free from the following:

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WARNING!

Workers exposed to MDI may develop serious or fatal respiratory disease.

Employers should take the following steps to protect workers from MDI exposure during spray-on applications:

1. Provide workers who may be exposed to MDI with information and training about MDI as required by the OSHA hazard communication standard [29 CFR† 1910.1200].

- Inform workers about the serious health effects that may result from exposure to MDI and provide them with safety and health information.
- Inform workers about any materials that may contain or be contaminated with MDI.

2. Provide respiratory protection and personal protective equipment to workers who may be exposed to MDI.

- Develop, implement, and enforce a worksite-specific respiratory protection program that provides for medical monitoring, medical examinations, respirator fit-testing, and respirator training.
- Provide appropriate PPE (hooded coveralls, chemical-resistant gloves, and footwear) to workers who use spray guns and to other workers who may be exposed to MDI.
- Train workers to properly use, store, and maintain their respirators.
- Regularly inspect and maintain all component parts of supplied-air and air-purifying respirators to assure their continued effectiveness. The components include air compressors, hoses, regulators, facepieces, etc.
- Make sure respirators are professionally fitted.
- When workers must wear prescription eye glasses under a full-facepiece respirator, provide them with prescription inserts designed to be compatible with the respirator.

Supplied-air respirators

- When workers are spraying MDI or are inside the spray enclosure during spraying, make sure they use full-facepiece, supplied-air respirators operated in a pressure-demand or other positive-pressure mode.
- Make sure that supply air for the supplied-air respirator is taken from a clean, uncontaminated area that is well removed from any aerosolized MDI or other contaminants.

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*MDI is methylenebis(phenyl isocyonate). In this fact sheet, MDI refers to all MDI-based isocyanates.

†Code of Federal Regulations.

Air-purifying respirators

- When workers must enter or re-enter the spray enclosure after spraying, make sure they use full-facepiece, air-purifying respirators equipped with a combination organic vapor/N95 filter cartridge. This is minimum acceptable protection for these conditions.
- Establish and implement a change-out schedule for air-purifying respirator cartridges.

3. Provide engineering controls.

- Build a spray enclosure equipped with an exhaust ventilation system to
  - — isolate the spray process from the rest of the facility and
  - — maintain the enclosure under negative pressure to control and contain MDI aerosols in the spray enclosure.
- Determine the number of air changes per hour provided by the ventilation system and use this information to calculate the time required (after spraying) to reduce airborne MDI concentrations below the NIOSH recommended exposure limit (REL).
- Make sure that workers are trained to use engineering controls (such as spray enclosures with effective ventilation) and work practices to minimize MDI exposures.
- Allow only trained workers wearing NIOSH approved, full-facepiece, supplied-air respirators to enter the spray enclosure during spraying.
- Establish and implement a preventive maintenance program for the ventilation system.

4. Provide medical examinations and surveillance for workers potentially exposed to MDI.

- Provide a preplacement medical examination and periodic medical monitoring for all potentially exposed workers to detect and prevent the acute and chronic effects of MDI exposure.
- Remove from the workplace any worker showing signs or symptoms of MDI exposure.
- Make sure the worker is medically evaluated before he or she is allowed to return to work.
- If the medical evaluation determines that the worker is sensitized, the worker must not be allowed to return to a job where MDI is used.

Truck in bed liner spray enclosure.

For additional information, see ***NIOSH Alert: Preventing Asthma and Death from MDI Exposure During Spray-on Truck Bed Liner and Related Applications*** [DHHS (NIOSH) Publication No. 2006–149]. Single copies of the Alert are available free from the following:

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WARNING!

Workers exposed to MDI* may develop serious or fatal respiratory disease.

The National Institute for Occupational Safety and Health (NIOSH) requests assistance in preventing asthma, other respiratory diseases, and death from exposure to methylenebis(phenyl isocyanate) (MDI). More than 10,000 U.S. workers are potentially exposed to MDI during spray-on truck bed lining operations. This Alert summarizes four case reports: one death and several incidents of asthma or other respiratory disease following exposure to MDI during spray-on truck bed lining operations. Information about preventing adverse health effects from exposure to MDI is urgently needed by workers, employers, small business owners, and physicians and other health care providers.

NIOSH requests that editors of trade journals, safety and health officials, labor union leaders, educators, and MDI suppliers and manufacturers bring the recommendations in this Alert to the attention of all employers and workers at risk of MDI exposure through spray-on and related applications. Your assistance will help prevent asthma, other respiratory disease, and death.

*MDI is methylenebis(phenyl isocyanate). In this alert, MDI refers to all MDI-based isocyanates.

BACKGROUND

Spray-on polyurethane/polyurea products containing isocyanates such as MDI have been developed for a wide range of retail, commercial, and industrial uses to protect cement, wood, fiberglass, steel, and aluminum surfaces such as truck beds, trailers, boats, foundations, and decks. MDI, toluene diisocyanate (TDI), and the polyisocyanate products based on the diisocyanate hexamethylene diisocyanate (HDI) are the most commonly used diisocyanates in the polyurethane industry. Isocyanates are widely used in the manufacture of flexible and rigid foams, fibers, coatings such as paints and varnishes, and elastomers. Isocyanates are increasingly used in the automobile industry, autobody repair, and building insulation materials. (See Appendix A for definitions and synonyms of MDI and information about its chemical structure.)

Production and consumption data for the polyurethane industry in the United States and North America are available through the Alliance for the Polyurethanes Industry (API). Their publications *End-Use Market Survey on the Polyurethane Industry* [API 2003] and *Socio-Economic Impact of Polyurethanes in the United States* [API 2004a] provide the following facts:

- In 2002, the U.S. market for polyurethane was 5,528 million pounds (87% of the North American market).
- The manufacture of products such as flexible slabstock, flexible molded foams, rigid foams, coatings, binders, elastomers, adhesives, sealants, reaction injection molding, thermoplastic polyurethanes, and spandex used 212 million pounds of MDI as a raw material and 1.3 billion pounds of polymeric MDI in 2002.
- About 253,700 workers at 853 locations throughout the United States are employed in transportation industries that use polyurethane. Uses include resistant polyurethane coatings such as truck bed liners and other products such as headrests, armrests, adhesives, insulation, and other molded components used in vehicle production.

Information gathered by a major spray-on truck bed liner company identified 17 companies that supply, distribute, and franchise spray-on truck bed lining equipment, materials, and products [Naik 2004]. Nationally, the number of spray-on truck bed liner businesses is estimated to exceed 2,000 [Lofgren et al. 2003]. Press releases from two of the major truck bed liner companies indicate that the spray-on bed liner industry is rapidly growing. Conservative estimates indicate that more than 10,000 workers are employed in the spray-on bed lining industry nationwide.

Inspections by the Washington Industrial Safety and Health Administration (WISHA) of the Washington State Department of Labor and Industries at 13 spray-on truck bed lining businesses and a review of industrial insurance records found that workers are at risk of developing illnesses associated with diisocyanate exposure [Lofgren et al. 2003]. Seven of the 13 inspected worksites had MDI monomer air concentrations that were greater than the regulatory limit, resulting in regulatory citations.

During their preparation of the report on inspections in Washington State, the authors contacted NIOSH and requested help with developing engineering controls and alerting affected employers and workers throughout the Nation. As a result, NIOSH began a study of the spray-on truck bed lining industry. NIOSH conducted walk-through surveys at spray-on truck bed liner facilities in Washington State, Colorado, Ohio, and Kentucky [NIOSH 2003a; Almaguer et al. 2004]. Six sampling surveys were conducted in Ohio and Kentucky. The results of the NIOSH sampling surveys are described later in this document.

In 2003, Washington and Michigan actively began alerting the industry in their States of the hazards associated with spraying MDI in truck bed liner applications. In March 2003, WISHA issued a Hazard Alert warning of isocyanate exposures related to the spray-on truck bed lining industry [WISHA 2003]. The Michigan Occupational Safety and Health Act News described a fatality that occurred in Michigan during the application of an MDI-based spray-on bed liner to the interior of a van in February 2003 [MIOSHA 2003]. In December 2003, the Michigan Fatality and Control Evaluation (MIFACE) Program issued a report on the death, and the Michigan Occupational Safety and Health Administration

(MIOSHA) issued an Alert in January 2004 [MIFACE 2003, MIOSHA 2004]. In February 2004, WISHA issued a Hazard Alert Update briefly discussing the Michigan death and the health hazards associated with exposure to isocyanates [WISHA 2004].

This Alert is intended to notify workers and employers in the truck bed lining and related industries of the adverse health effects associated with exposure to MDI during the application of spray-on truck bed liners. The current Alert also provides preliminary recommendations to reduce worker exposures to MDI during the spray-on bed liner process.

Figure 1. Spraying base coat with protective equipment.

SPRAY-ON TRUCK BED LINING PROCESS

The spray-on truck bed lining process involves applying a protective polyurethane or polyurea coating to the bed of pickup trucks or other vehicles and surfaces in a manner similar to undercoating. Bed liners are applied as a two-part resin. Part A is an MDI-based product; part B is usually a polyol or polyamine that reacts with the isocyanate to form a tough, resilient elastomeric surface coating. The MDI-based liners are applied to pickup truck beds and other surfaces to protect them from damage and to provide a nonskid surface. The spray-on application process is usually done in a spray enclosure. The spray-on truck bed lining process is commonly performed in spray-on truck bed specialty shops, auto body centers, and auto dealerships (see Figure 1).

NIOSH identified two spray-on processes commonly found in the industry [Heitbrink and Almaguer 2003]: one process applies truck bed liners at room temperature and pressures of approximately 50 pounds per square inch (low temperature/low pressure); a second process applies truck bed liners at temperatures above 165 °F and pressures of approximately 1,500 pounds per square inch (high temperature/high pressure). In both processes, the A and B components are pumped separately to the spray gun and mixed at the time of application. The worker uses a hand-held spray gun to apply the rapidly curing product onto the truck bed interior. The shape of the spray pattern is determined by the nozzle shape. To create a textured, nonslip surface on the bed, a small quantity of the coating is sprayed into the air, allowing the product to settle onto the truck bed. To obtain a bed liner thickness of 0.125–0.25 inches (a standard in the industry), approximately 50 pounds of the two-part resin (part A and part B) are sprayed onto the bed and inside walls of a typical pickup truck (see Figure 2).

A third type of spray-on process that was not included in the NIOSH sampling surveys is the cold-batch, pre-mix process. The information contained in this Alert may apply to this process as well. During this process, isocyanate/resin and catalyst materials are

Figure 2. Spraying texturizing coat with protective equipment.

generally mixed in small quantities (quarts or gallons) at room temperature with a high-speed drill. Afterwards, the mixture is poured into a hopper gun and applied at 30–60 pounds per square inch from inside the truck bed. The chemicals used in the cold-batch operations typically contain less MDI (less than 20%). However, the cold-batch materials contain higher amounts of flammable solvents (toluene and N-butyl acetate) which should have their own exposure prevention and ventilation requirements. Cold-batch systems are popular because of the lower startup costs [Krupinski 2005].

SPRAY APPLICATIONS OTHER THAN TRUCK BED LINING

Polyurethane and polyurea coatings are marketed and used for truck trailers, house decks, walls, foundations and sports flooring, and they are likely to be used for other applications as well. In many cases, these applications use the same or similar chemicals, spray techniques, and equipment as the spray-on truck bed lining process. Because of these similarities, excessive exposure to MDI may occur during these related applications, resulting in risk to spray gun users and other nearby workers. Owners and managers of these operations should assess and sample as necessary as well as implement needed controls and work practices, including engineering controls, worksite-specific respiratory protection programs, chemical hazard training, administrative controls, and use of personal protective equipment for exposed workers as outlined in this Alert [Lofgren et al. 2003].

HEALTH EFFECTS OF ISOCYANATES

Isocyanates are the leading attributable chemical cause of occupational asthma in the United States and many other industrialized countries [Tarlo et al. 1997b]. Workers with asthma symptoms from isocyanate exposure often continue to have symptoms after exposures have been terminated. Affected workers often have to leave their jobs to prevent progression of respiratory symptoms. The major route of work-related exposure to MDI is inhalation of the vapor or aerosol.

Because the odor threshold for MDI is many times above the recommended exposure limit (REL), smell should never be relied on as an indication of exposure, nor should the absence of odor be used to indicate safety. MDI can be detected by odor only after dangerous concentrations exist, resulting in potential overexposure.

Exposure may also occur through skin contact during the handling of liquid MDI-based products. Work-related exposure normally occurs during the spray application of MDI-based products. In 1996, NIOSH issued *Preventing Asthma and Death from Isocyanate Exposure,* which summarizes reported cases of disease and death following occupational exposure to diisocyanates and diisocyanate-based products [NIOSH 1996].

Irritation and Lung Injury

MDI and other isocyanates may irritate the mucous membranes of the eyes, upper and lower respiratory tracts, gastrointestinal tract, and skin [Swensson et al. 1955; Fisher 1967; Upjohn Company 1970; Lofgren et al. 2003]. Eye tearing, nose and throat irritation, and cough may occur [Littorin et al. 2000]. Respiratory irritation may progress to chronic upper and lower respiratory symptoms, although symptoms of local irritation do not reliably indicate chronic respiratory conditions [Wang and Petsonk 2004]. Acute respiratory distress syndrome or reactive airways dysfunction syndrome may also result from short-term high exposures [Tarlo et al. 1997b; Banks 1998].

Respiratory Sensitization

Isocyanates can sensitize workers, making them subject to severe asthma attacks if they are exposed again, even when concentrations are continuously below the NIOSH REL [NIOSH 1973, 1978; Banks 1998]. Skin exposures may be associated with the onset of respiratory symptoms [Petsonk et al. 2000]. Respiratory disorders associated with isocyanate exposure include asthma and hypersensitivity pneumonitis [Baur et al. 1984; Baur 1995]. Sensitization may result from a single episode of overexposure or intermittent exposures at low concentrations. Once a worker is sensitized, even low concentrations may trigger symptoms such as wheezing, chest tightness, shortness of breath, and cough. Persons with chronic hypersensitivity pneumonitis may also experience fatigue and weight loss. These symptoms may begin immediately or may be delayed for up to 8 hours after exposure. Death from severe asthma in sensitized subjects has been reported [Fabbri et al. 1988; MIFACE 2003].

Carcinogenicity

Isocyanates may cause cancer in animals; however, evidence is insufficient to describe the carcinogenic potential of MDI in humans. Data from recent studies show that methylene dianiline (MDA), a known animal carcinogen and the principal metabolite of MDI monomer, is found in the blood of MDI-exposed rats and in the urine of humans exposed to a mixture of polymeric MDI and MDI monomer [NIOSH 1986; Sepai et al. 1995]. Another study found that a commercial grade of MDI (45% MDI monomer by weight) induced chromosome aberrations in human blood lymphocyte cultures after a 24-hour treatment [Mäki-Paakkenen and Norppa 1987]. NIOSH recommends that work-related exposure to MDI be minimized because of the potential for respiratory sensitization and the potential carcinogenicity of the metabolite MDA [NIOSH 1986].

CURRENT EXPOSURE LIMITS

Occupational exposure standards for MDI are based on respiratory irritation and sensitization. The available human evidence is insufficient to describe the carcinogenic potential of MDI [NIOSH 1989]. The evolution of the occupational exposure standards for isocyanates is discussed in the literature review *Polyisocyanates in Occupational*

Environments: A Critical Review of Exposure Limits and Metrics [Bello et al. 2004]. The isocyanate product frequently used in bed-liner formulations consists of varying amounts of MDI monomer and higher molecular weight species. Long-term aerosol inhalation studies suggest that monomeric MDI and polymeric MDI, which typically contain 50% monomer, have a similar response in rat lungs [Feron et al. 2001]. Mandatory and recommended limits have been established for MDI monomer, as discussed below. However, no recommended or regulatory limit exists for higher molecular weight species at this time. Therefore, regardless of the relative amount of MDI monomer present, owners and workers are encouraged to adhere to the control methods outlined in this Alert whenever MDI aerosols may be generated through a spray-on bed-lining operation.

NIOSH

NIOSH recommends that MDI monomer exposure be limited to 0.05 milligram per cubic meter of air (mg/m^3) or 0.005 part per million parts of air (0.005 ppm) as a time-weighted average (TWA) for up to a 10-hour workday during a 40-hour workweek, with a ceiling limit of 0.2 mg/m^3 (0.02 ppm) for any 10-minute period [NIOSH 1978]. This NIOSH REL is intended to prevent acute and chronic irritation and sensitization of workers but not to prevent health effects in workers who are already sensitized. Available data do not indicate a concentration at which MDI fails to produce adverse reactions in sensitized persons. Unless otherwise stated, use of the term *NIOSH REL* in this document means the NIOSH REL of 0.2 mg/m^3 as a 10-minute ceiling concentration when referring to spray-on truck bed liner processes.

OSHA

The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for MDI monomer is 0.2 mg/m^3 as a ceiling limit (0.02 ppm) [29 CFR* 1910.1000 (a)(1)].

WORKPLACE EXPOSURE ASSESSMENTS

Washington State

In response to health concerns, Washington Industrial Safety and Health Administration (WISHA) inspectors conducted exposure assessments at 13 spray-on bedliner establishments [Lofgren et al. 2003]. Airborne concentrations of MDI monomer during the 10- to 20-minute application process varied between shops and ranged from 0.045 to 6.5 mg/m^3. In 7 of the 13 shops, airborne concentrations of MDI monomer exceeded the State and OSHA ceiling limit of 0.2 mg/m^3. The method used for most samples consisted of an open-faced cassette having a filter treated with 1-(2-pyridyl) piperazine. WISHA concluded that conditions contributing to excess exposure included inadequate exhaust and make-up air, clogged ventilation filters, and a lack of training and awareness of the hazard. Workers who applied spray used either a supplied-air respirator or an air-purifying respirator with filter cartridge. Companies were cited for deficient respirators, inadequate respirator training programs, and lack of respirator fit-testing and engineering controls. Seven of the worksites with overexposure to MDI had one or more serious violations related to respirator use.

**Code of Federal Regulations.* See CFR in references.

In addition, one establishment using a bedliner product containing a flammable solvent received a violation for the presence of sources of ignition in the spray area.

NIOSH

The following summarizes MDI monomer exposure assessments from NIOSH surveys conducted at six spray-on truck bed liner sites. These exposure assessment sites included three surveys at low-temperature/low-pressure operations and three surveys at high-temperature/high-pressure operations. Samples were collected in the spray enclosures during the bedliner application process, in truck preparation areas, in the office areas, and outdoors as close as practicable to the spray enclosure exhaust grill. Sampling was done for the duration of the process, which ranged from 16 to 43 minutes in the spray enclosure. Longer-duration sampling was done in areas outside the spray enclosure. The air samples were collected and analyzed using NIOSH Method 5525 [isocyanates, total (MAP)], which uses 1-(9-anthracenylmethyl)-piperazine (MAP) as the derivatizing reagent [NIOSH 2003b]. In accordance with the recommendations in NIOSH Method 5525 for sampling MDI aerosols, an impinger with MAP reagent solution followed by a MAP reagent-coated filter was used for collecting the air sample. The laboratory analysis of samples used high-performance liquid chromotography with ultraviolet absorbance/fluorescence detection.

Spray Enclosure

The data from these six surveys show that the greatest risk for exposure occurs, as expected, in the spray enclosure. Airborne concentrations of MDI monomer were up to 27 times the NIOSH REL of 0.2 mg/m^3 as a 10-minute ceiling concentration in the spray enclosure during the spray-on process. The geometric mean MDI monomer concentration in the spray enclosures at the low-temperature/low-pressure process was 0.99 mg/m^3, or approximately 5 times the NIOSH REL. The geometric mean MDI monomer concentration in the spray enclosures at the high-temperature/high-pressure process was 0.78 mg/m^3 or approximately 4 times the NIOSH REL. Nonmonomeric MDI was detected in the spray enclosure samples and ranged up to 42% of the total isocyanate group. All workers applying spray wore supplied-air, full-facepiece respirators, except for one who wore a supplied-air, half-facepiece respirator [Almaguer et al. 2004].

After the spray application process, post-spray air samples were collected inside the spray enclosure. Eight of 12 post-spray samples showed low concentrations of MDI monomer; 4 of the 12 samples had non-detectable concentrations. These samples were typically 15- to 30-minute samples and ranged from below the limit of detection to 0.08 mg/m^3. These results are averaged over the duration of the sample; concentrations immediately after spray application are expected to be higher and may require respiratory protection when re-entering the booth (usually to remove the vehicle) (see *Recommendations*).

Truck Preparation Area

Airborne MDI monomer in the truck preparation area averaged 0.56% of that in the spray enclosure. Eight of the 12 samples taken in the truck preparation area were below the limit of detection. The four samples above the limit of detection had concentrations that ranged from 0.0057 to 0.022 mg/m^3. Unlike spray gun users, the workers in the truck preparation areas did not wear respirators designed to protect from exposure to MDI. The concentrations in the truck preparation area were below the NIOSH REL. However, detecting any MDI in the truck preparation area indicates that the spray enclosure was not under negative pressure as recommended. Because of the potential for worker sensitization to MDI, the spray enclosure should be maintained under a negative pressure to minimize the possibility that MDI monomer will escape from the spray enclosure to the truck preparation area or other adjacent work areas, and prevent worker sensitization.

Office Area

In five of the six surveys, airborne MDI monomer in the office/lobby areas was below the limit of detection. Trace concentrations of MDI monomer (below the limit of quantitation) were detected in the office/lobby area of one shop. Again, this finding indicates that the spray enclosure was not under negative pressure as recommended, thereby presenting the potential for exposure to the office occupants. Placing the office/lobby areas as far as possible from the spray enclosure and exhaust areas minimizes possible exposure to MDI in these areas.

Exhaust Area

Five of eleven outdoor samples for MDI monomer taken near the spray enclosure exhaust had concentrations greater than the limit of detection; the highest was 0.41 mg/m^3. These data indicate a potential for exposure to MDI in the exhaust area of the building, requiring restrictions as addressed in the *Recommendations*.

Observations at the surveyed worksites suggest effective exhaust ventilation may have reduced MDI monomer concentrations in the spray enclosure during spray applications [Almaguer et al. 2004]. Only one site had an exhaust system designed to effectively capture containminants in the spray enclosure; at this site, airborne MDI was reduced to concentrations near the NIOSH REL. Airborne concentrations at 5 other sites with general exhaust ventilation were 3 to 27 times the NIOSH REL.

CASE REPORTS

The following case reports highlight examples of isocyanate-induced asthma, other respiratory disease, and death.

Case 1—Spray-on Truck Bed Lining (Fatal Asthma)

A 45-year-old male worker with 1 year of tenure died from an acute asthma attack after spraying an MDI-based bed liner onto the floor and sides of a cargo van interior. The worker was wearing a half-mask, supplied-air respirator as well as latex gloves and coveralls. The spray area was defined only by “two curtains that could be pulled together to enclose the area and limit product overspray into the general shop area.” The room had no local exhaust ventilation. Room ventilation during the spray-on bedliner application was provided by raising the overhead door a few feet, opening the door near the rust-proofing area, and placing a box fan at this door to provide air circulation. After completing the job, the worker turned off the mixer for the spray-liner components (MDI and polyether polyol). He disconnected his airline from the respirator and walked around to the front of the building, where a coworker found him in acute respiratory distress. The coworker took him to a nearby urgent care facility where he developed cardiac arrest. He did not respond to cardiopulmonary resuscitation. An ambulance took the worker to the local hospital emergency room where he was declared dead. After an autopsy, the county medical examiner stated that the worker had died of an "acute asthmatic reaction due to inhalation of chemicals."

In the past, the worker had tried to spray bed liners when customers and coworkers were not present because of the strong odors associated with the product. After the fatality, coworkers informed the owner that the victim said he had difficulty breathing after applying the bed liners and that he had used an inhaler.

This fatality may have been caused by MDI sensitization. The spray area was enclosed with a curtain (not a permanent enclosure) and had no dedicated exhaust ventilation. The worker used a spray-gun and a half-mask, supplied-air respirator. Furthermore, the MIFACE report indicates that the worker told coworkers that he had had previous breathing difficulties after spraying bed liners and that he had used an inhaler in the past. This suggests that MDI sensitization probably occurred in the past and played a significant part in the fatality. The information reinforces the need for strict adherence to the recommendations in this Alert.

Whether the worker knew that his past breathing problems were associated with his exposures at work was unclear, since he did not report them to the owner. No exposure assessment data are available for this fatality [MIFACE 2003; MIOSHA 2004].

Case 2—Spray-on Truck Bed Lining (Asthma)

A 29-year-old male ex-smoker who worked spraying truck bed liners arrived at a hospital emergency room with complaints of chest discomfort and wheezing. He reported having been exposed to "fumes" generated during the application of MDI-based spray-on truck bed liners. He reported increasingly frequent episodes of shortness of breath and wheezing associated with exposure to isocyanates during 8 months of work at the truck bed lining company. The worker was diagnosed with asthma, treated with inhaled bronchodilators and intravenous steroids, and advised to see a pulmonologist. The emergency room record indicated that the physician failed to identify the isocyanate exposure reported by the worker as a possible etiology of the worker's asthma [Bonauto and Lofgren 2004].

Case 3—Spray-on Truck Bed Lining (Asthma)

A 30-year-old man developed rhinitis, a cough, wheezing, and shortness of breath 4 months after starting work spraying truck bed liners. On one occasion, the worker reported to the emergency room but was not diagnosed with asthma. Symptoms persisted with daily episodes of shortness of breath, wheezing, and nausea. These symptoms occurred at midday after four to five bed liner applications. After 4 months of symptoms, which culminated in hospitalization for respiratory distress, the worker was diagnosed with work-related asthma from exposure to MDI. After hospitalization, the worker was documented to have nonspecific bronchial hyperreactivity by methacholine challenge testing. No inhalation challenge with MDI or workplace challenge testing was ever performed. The worker was removed from the workplace.

One year later, the worker was employed elsewhere as a manual laborer. He still had symptomatic asthma and was maintained on bronchodilators and inhaled steroids [Bonauto and Lofgren 2004].

Case 4—Spray-on Truck Bed Lining (Asthma)

A 22-year-old worker who used a spray gun was employed in the truck bed lining industry for 18 months. He developed a runny nose and nasal congestion that occurred during the workweek but improved over the weekend. Increased breathing difficulty on exertion restricted his daily activities. The worker underwent a medical evaluation that included spirometry before and after the administration of bronchodilators. He was documented to have a reversible airflow limitation and was diagnosed with asthma. No workplace challenge testing was performed. The material safety data sheets (MSDSs) provided to the medical personnel revealed that the spray-on bed liner material consisted of 50% to 60% MDI monomer and 5% to 20% diisooctyl phthalate. The worker was removed from the workplace.

A year and a half after medical removal from the workplace, the affected worker was still unemployed. He continued to have symptomatic asthma and was maintained on bronchodilators and steroid inhalers [Bonauto and Lofgren 2004].

CONCLUSIONS

The cases described in this document reveal the potentially serious nature of respiratory disease resulting from exposures to MDI in the spray-on truck bed liner industry. Exposures may increase the risk of serious respiratory disease, respiratory sensitization, and death. MDI concentrations generated by the spray-on application of truck bed liners at the NIOSH exposure assessment sites routinely exceeded the NIOSH and OSHA ceiling limits and varied throughout the process with unpredictable, rapid increases in airborne concentrations. On the basis of these findings, NIOSH concludes that only a full-facepiece, supplied-air respirator provides the necessary protection during MDI spray operations.

RECOMMENDATIONS

Manufacturers and distributors of spray-on polyurethane/polyurea products containing MDI and other isocyanates should work together to assess and determine the best controls for the spray-on bed liner process. The ultimate goal is to establish procedures and develop controls (such as proper ventilation) to minimize MDI concentrations within the spray enclosures. These procedures and controls—together with respirator use, a written respiratory protection program, and ongoing worker training—will reduce the risk for worker exposures during the spray-on process.

General Responsibilities for Shop Owners and Workers to Prevent MDI Exposures

- Use any training, information, and literature available through the manufacturers, distributors, franchisers, and government agencies (see examples under manufacturer responsibilities).
- Isolate the spray process by building an enclosure equipped with exhaust ventilation.
- Use a pressure manometer or tracer smoke along cracks and walls to ensure that the spray enclosure is under

negative pressure and prevents the escape of MDI to adjacent work areas.

- Use a full-facepiece, supplied-air respirator and wear personal protective clothing such as hooded coveralls, chemical-resistant gloves, and footwear to prevent dermal absorption during the spray application process.
- When entering or re-entering the enclosure immediately after spraying, use a full-facepiece, air-purifying respirator equipped with a combination N95 filter/organic vapor cartridge as minimum protection and wear appropriate clothing to prevent dermal exposure.
- To prevent fouling of the exhaust system and fan blades, filter all exhaust air at its collection point within the spray enclosure before it enters the exhaust system.
- Discharge exhaust from the spray enclosure away from occupied areas and ensure that the exhaust outlet is located away from HVAC air supply intakes and supplied-air respirator pumps/compressors.
- Ensure that only authorized persons trained in the use of safe work practices, ventilation, and personal protective equipment are allowed to perform spraying.

General Responsibilities of Manufacturers, Distributors, and Franchisers of Spray-on Chemicals and Equipment

- Provide safety and health information to users of your chemicals and equipment. Include information about design of spray enclosures, engineering controls, safe work practices, and the hazards of exposure. These two references are excellent examples of useful information:
  - — *MDI and TDI: Safety, Health and the Environment* [Allport et al. 2003], by the International Isocyanate Institute Inc. for occupational safety and health information about MDI.
  - — The API brochure *Truck Bed Liners: Worker Protection*, available in both English and Spanish. The brochure outlines safety precautions for spray gun users who apply spray-on truck bed liners [API 2004b]. The brochure is available through the API Web site at www.polyurethane.org.
- Develop, publish, and distribute additional safety and health resources to help workers using spray-on MDI products.

Detailed Recommendations

The following sections provide detailed recommendations for this industry, including further guidance about the choice of respirators and appropriate ventilation parameters.

Product Substitution

When feasible, substitute a less hazardous material for MDI and other isocyanates. NIOSH policy is always to recommend using a less toxic substitute if available. Water-borne acrylic coatings, polysulfide rubber coating, and epoxy are other chemicals that have been used to make truck bed liners. Drop-in truck bed liners are also commercially available. NIOSH cannot address the quality or performance and has not addressed the safety of these products.

In addition, using substitute chemical processes or products may have advantages and disadvantages, including safety and health issues that are not addressed in this Alert.

Equipment/Formulation Modification

- *Manufacturing and distribution:* Investigate design changes that result in less aerosolization or fewer fugitive emissions during the spray process.

- *Bed liner industry:* Investigate potential process changes and work practices to determine whether reduced application pressure and slower application techniques result in lower MDI monomer air concentrations during the spray process.

- *Chemical manufacturing:* Consider changes in chemistry and formulation that would reduce the amount of fugitive MDI released during spraying.

These design, process, and formulation changes could reduce airborne MDI, resulting in reduced worker exposures. They would also place less financial burden on retail owners and operators in controlling airborne contaminants during the spray process. Furthermore, less overspray would produce less waste and provide further economic benefit for the retail owner. Unverified evidence from a spray-on bed liner company suggests that using lower pressures (10 pounds per square inch) may reduce airborne MDI concentrations and thus lower the exposure.

Spray Enclosure and Ventilation

Ventilation design (see Appendix B)

- Design and build a spray enclosure to isolate the spray process and contain airborne MDI within the enclosure.

- Minimize the size of enclosure to the smallest floor area and room volume compatible with the operation. This helps to maximize the efficiency of the ventilation system.

- Equip the spray enclosure with an exhaust ventilation system to capture vapor and particulate MDI near the point of generation.

- Ensure that the spray enclosure is under negative pressure to prevent leakage of airborne MDI into other areas within the shop.

- Provide clean "make-up" air to the spray enclosure to replenish exhausted contaminated air.

- Place the make-up air supply and exhaust locations of this ventilation system so that the system generates a directed air (push-pull type) flow that maximizes ventilation efficiency and contaminant control.

- Discharge the exhaust high above the roof and away from air intakes, garage doors, or other openings where the exhaust could re-enter the shop. Also ensure that the exhaust is discharged above the roof recirculation region (See *Industrial Ventilation: A Manual of Recommended Practice* [ACGIH 2004] to determine the recirculation region).

- Control access to exhaust discharge areas by physical barriers and warning signs.

Work practices

Spray gun users should be trained to make their work practices compatible with the control concepts of the ventilation system:

- Avoid standing between the spray nozzle and the ventilation system exhaust hood.

- Work with the spray nozzle downstream of the breathing zone, where the MDI contaminant will be diluted, directed away from the breathing zone, and less likely to contribute to the worker's exposure.

- Allow the exhaust ventilation system to operate for an additional period at the end of spraying operations before deactivating the exhaust or allowing personnel to enter the spray enclosure without proper respiratory protection (see Respiratory Protection, page 14). This delay allows the ventilation system to purge or remove most remaining airborne contaminants.
- Do not enter exhaust discharge areas without respiratory protection.

Ventilation system capabilities

- Obtain a site-specific exposure assessment that includes sampling data at desired intervals following the spray operation. These data are the best way to determine the purge time (time required to reduce MDI concentrations consistently below the NIOSH REL) required for your ventilation system.
- In the absence of exposure assessment data, determine the time required for the ventilation system to exhaust an air volume equal to a single room air change.
- Calculate the required purge time, allowing sufficient time for at least three complete air exchanges—or even longer for systems with poor air mixing.
- During the purge time, use respiratory protection when entering the spray enclosure (see Respiratory Protection, page 14).
- For assistance calculating the time required for a single air change and the purge time of the ventilation system, see Appendix B.

Ventilation maintenance

- At least once per month, inspect and maintain the ventilation equipment to ensure adequate system performance (or more frequently if a decrease in performance is suspected).
- Document and re-evaluate baseline ventilation performance measurements, including hood static pressure, pressure drop across filters, and velocity or volumetric flow measurements for indications of system performance degradation.
- Develop a maintenance schedule to change exhaust filters as needed to prevent reduced airflow.
- Ensure that exhaust fans have inspection access doors.
- Ensure proper filter placement at air exhaust points to prevent filter bypass and the fouling of the exhaust system.
- Inspect fan blades regularly for material buildup and clean them to prevent a decrease in system performance.
- Check fan belts for deterioration and slippage and replace as necessary.
- Follow lock-out, tag-out procedures [29 CFR 1910.147] during inspection and maintenance procedures whenever worker injury may result from unexpected start-up of this equipment.

Spraying in Enclosed Areas

- Take additional precautions when spraying inside vans, enclosed trailers (e.g., horse trailers), and other similarly enclosed spaces.
- Determine whether the area to be sprayed meets the definition of a *confined space* and, if so, follow all OSHA requirements

for working in a confined space [29 CFR 1910.146].

- Use supplemental local exhaust ventilation in addition to the exhaust ventilation of the spray enclosure.
- Wear a full-facepiece, supplied-air respirator and appropriate clothing to minimize the exposure.

Worker Isolation

- Restrict access to the spray enclosure to spray gun users.
- Allow only essential workers wearing appropriate respiratory protection into the truck preparation areas or other areas where workers may be exposed to isocyanates.

Exposure Monitoring

- If you are a shop owner, conduct an exposure assessment for airborne MDI at the onset of business and any time a major change (structural or ventilation) is made to the spray enclosure.
  - Even if you install a ventilated enclosure design tested as effective for a product and process, conduct exposure monitoring to verify the effectiveness and proper installation at that site.
  - Ensure that spray gun users and the areas adjacent to the spray enclosures are sampled.
  - Use the appropriate sampling methods, as described in the NIOSH and OSHA analytical methods [NIOSH 2003b, OSHA 1989].
- Use the NIOSH REL of 0.2 mg/m^3 as a 10-minute or the OSHA PEL of 0.2 mg/m^3 as a 15-minute ceiling limit concentration when interpreting exposure monitoring results. The short-term, intermittent nature of the spray-on truck bed liner process makes the NIOSH or OSHA ceiling limits the most appropriate exposure criteria for this process. Collect personal breathing zone samples from the time a spray operation begins to the time when spraying has stopped (typically a 10–20 minute period). Compare results with the NIOSH or OSHA ceiling limit.

Additional assistance about managing this or other hazards can be obtained from the free, onsite OSHA consultation service in your State. For information about the OSHA Consultation Program, visit www.osha.gov/dcsp/smallbusiness/consult.html or call 1–800–321–OSHA (1–800–321–6742).

Respiratory Protection

Typically, respirators should not be used as the primary control for routine operations except during situations such as implementation of engineering controls, some short-duration maintenance procedures, and emergencies. NIOSH exposure assessment data show that the engineering controls at the NIOSH survey sites did not reduce MDI concentrations below the occupational criteria, even at the sites with the best ventilation controls [Almaguer et al. 2004]. Airborne MDI monomer concentrations in the spray enclosures during the spray-on application process routinely exceed both the NIOSH 10-minute ceiling limit (0.2 mg/m^3) and the OSHA PEL as a 15-minute ceiling concentration (0.2 mg/m^3). Therefore, NIOSH recommends the following respiratory protection for the spray-on truck bed liner industry. (See Appendix C for more information about respirators and respiratory protection.)

Use supplied-air respirators when spraying MDI

- When spraying MDI-based products (including spray-on truck bed liners), use only supplied-air, NIOSH-certified respirators [42 CFR 84] with a full facepiece operated in a pressure-demand mode. MDI concentrations generated during the spraying process routinely exceed both the NIOSH and OSHA ceiling limits, even with engineering controls. NIOSH does not recommend air-purifying respirators for the spray-on truck bed-liner industry during the spray application, even though OSHA allows the use of air-purifying respirators for isocyanates under certain circumstances in accordance with the revised OSHA respiratory protection standard [29 CFR 1910.134(d)(1)(i) and 1910.134(d)(3)(iii)] (see the OSHA Standard Interpretations Letter dated 07/18/2000 and titled *Selection of Air Purifying Respirators for Gases and Vapors with Poor Warning Properties (Diisocyanates)* [OSHA 2000]).
- While in the spray enclosure, do not lift or remove the respirator facepiece for any reason.
- If visibility is a problem during or after spraying, apply several tear-away layers of clear plastic film to the respirator visor before entering the booth. This would allow the worker to remove the top layer for increased visibility as needed during the spray-on process.

Use air-purifying respirators for entry into the enclosure after spraying

- To enter the spray enclosure after spraying is completed, use a full-facepiece, air-purifying respirator with an appropriate cartridge changeout schedule that is strictly enforced. NIOSH data indicate that MDI aerosol is still present in the air after spraying. An air-purifying respirator may be the most convenient and practical way to provide protection to workers needing to enter the spray enclosure after the spraying process is completed. A NIOSH-approved, full-facepiece, air-purifying respirator equipped with a combination organic vapor/N95 filter cartridge is the minimum acceptable protection necessary after spraying is complete and when no exposure assessment data or ventilation purge data are available.
- Use a full-facepiece to provide the necessary eye and dermal exposure protection.
- Because MDI has inadequate warning properties (i.e., odor threshold) and is a potent sensitizer, follow a changeout schedule to ensure that the air-purifying respirator cartridge is replaced before saturation of the cartridge elements. Since MDI in this industry is principally an aerosol, equipping the air-purifying respirator with a particulate pre-filter element to protect the cartridge filter from premature clogging would extend the life of the more expensive filter/cartridge.
- Before re-entry, allow sufficient time for the ventilation system to remove airborne MDI (see Appendix B to calculate purge time). NIOSH exposure assessments determined that three air changes, combined with gravitational settling, was sufficient to reduce the MDI concentrations to less than 50% of the NIOSH ceiling limit at every sampled site (see Appendix B for details).

Develop a respiratory protection program

- Develop a written, site-specific respiratory protection program that, at a minimum, meets the requirements of the

OSHA respiratory protection standard [29 CFR 1910.134] (See Appendix C).

- Fully implement the respiratory protection program to protect spray gun users and any other workers who enter the spray enclosure.
- When respirators are needed to protect the health of the worker or when respirators are required by the employer, select a NIOSH-certified respirator based on (1) the respiratory hazards to which the worker is exposed and (2) workplace and user factors that affect respirator performance and reliability [29 CFR 1910.134 (d)(1)(i) and (ii)].
- Refer to the following publications for additional information about selection, fit-testing, use, storage, and cleaning of respiratory equipment:
    - — NIOSH Guide to Industrial Respiratory Protection [NIOSH 1987]
    - — NIOSH Respirator Selection Logic 2004 [NIOSH 2004] www.cdc.gov/niosh/docs/2005-100
    - — NIOSH Certified Equipment List (CEL). The CEL is a database of all certified respirators. It can be accessed at www.cdc.gov/niosh/npptl/topics/respirators/CEL/default.html

The following links provide additional guidance for developing written respiratory protection programs:

- — www.osha.gov/SLTC/respiratory protection/index.html [OSHA 2004]
- — www.polyurethane.org/pdfs/MRPP.pdf [API 2001]

Personal Protective Clothing

When spraying MDI-based products or during entry immediately after spraying, wear protective clothing such as hooded coveralls, chemical-resistant gloves, and footwear to protect the skin of the face, scalp, and neck areas from MDI aerosol as recommended in the publications *Quick Selection Guide to Chemical Protective Clothing* [Forsberg and Mansdorf 2003] and *PMDI User Guidelines for Protective Clothing Selection* [API 2002] (see Figure 3).

Figure 3. Worker wearing protective clothing and equipment.

Worker and Employer Education

Employers

Worker education is vital to an effective occupational safety and health program. To comply with the OSHA hazard communication standard [29 CFR 1910.1200], inform workers about the following:

- Methods and observations that may be used to detect the presence or release of a hazardous chemical in the work area (such as monitoring conducted by the employer, continuous monitoring devices, visual appearance or odor of hazardous chemicals when being released, etc.)
- Physical and health hazards of the chemicals in the work area, including the likely physical symptoms or effects of overexposure
- Protective measures, such as engineering controls, appropriate work practices, emergency procedures, and personal protective equipment
- The details of the hazard communication program developed by the employer, including an explanation of the labeling system, the MSDSs, and means for workers to obtain and use the appropriate hazard information

Workers and employers

- Use this Alert to facilitate chemical hazard training for workers spraying MDI-based products, including spray-on truck bed linings.
- Obtain MSDSs from suppliers or manufacturers.

Chemical manufacturers and distributors

- Provide customers with information about the health effects of your products, including MSDSs and labels.
- Develop safe handling procedures for the chemicals and equipment used in the spraying of MDI-base products. Ensure that the end users are informed of these procedures.
- Provide easy-to-read information explaining the health effects of your products and steps to keep workers safe. Include safe handling brochures such as the API brochure *Truck Bed Liner: Worker Protection* [API 2004b]. The API brochure is a good example of manufacturers working cooperatively to improve worker safety by communicating important information in an easy-to-read format.

Medical Monitoring

- Conduct preplacement examinations to obtain baseline health status.
  - — Include all potentially exposed workers for the early detection and prevention of the acute and chronic effects of exposure to isocyanates.
  - — Consult an occupational medicine physician who (1) has sufficient training and experience to recognize the adverse health effects of exposure to isocyanates and (2) is aware of the control measures required to decrease potential worker exposures.
  - — Include the following in preplacement examinations:
    1. A standardized questionnaire that includes detailed medical and work histories with emphasis on respiratory or allergic conditions
    2. A physical examination that centers on the respiratory tract
    3. Baseline pulmonary function tests (including FEV_1 and FVC).
- Inform workers who report pre-existing asthma or severe allergies on the preplacement examination that it will be difficult to monitor their health status and that if they

become sensitized to MDI, their asthma symptoms are likely to worsen.

- Conduct periodic examinations to update medical and work histories every 6 months during the initial 24 months of potential exposure and annually thereafter, with repeat pulmonary function tests every 1 to 2 years.

- Increase the frequency of the periodic examinations if indicated by the health status of the worker or if there is reason to suspect a lapse in control of isocyanate exposures.

- In case of onset or progression of asthma-like symptoms or excessive declines in lung function, arrange for a thorough medical evaluation to determine the presence of asthma.

  — If asthma is present, establish the relationship to the work environment.

  — Ensure that any person who has been medically evaluated and determined to be sensitized to isocyanates (including MDI) stop all exposure to the implicated agent. Several references are available to guide the evaluation of symptoms in exposed persons [Nicholson et al. 2005; Friedman-Jiménez et al. 2000].

- Record and store information in such a way as to be usable for both the ongoing respiratory protection program and to evaluate the distribution of respiratory complaints, patterns of decline in respiratory function, or sentinel events.

- Although respiratory protection programs have a separate function from medical monitoring, information obtained through a respiratory protection program can be incorporated and used as part of an overall medical surveillance program.

- Consult published literature for information about how successful medical monitoring programs are associated with an earlier recognition and improved prognosis for workers who develop occupational asthma [Liss et al. 2000; Tarlo et al. 2002, 1997a, 1997b, 1995].

Surveillance and Disease Reporting

- To enhance the uniformity of reporting work-related asthma, use the reporting guidelines and asthma surveillance case definition and case classification (see Appendix D). These guidelines and case definition, which have been updated since the 1996 NIOSH Alert, are recommended for public health surveillance of work-related asthma reported by physicians and other health care providers [NIOSH 1996; Jajosky et al. 1999]. As of 2004, six States—California, Massachusetts, Michigan, New Jersey, New York, and Washington—are actively engaged in work-related asthma surveillance and preventive activities; one other State—Connecticut—has a work-related asthma surveillance system in place (see Appendix E for State contact information for these States).

Decontamination and Waste Disposal

- If you are a manufacturer or distributor, establish procedures for decontamination, waste disposal, and transport for isocyanate-contaminated materials or equipment. Further information about waste disposal is available through local, State, or Federal EPA offices (**www.epa.gov**); the Alliance for the Polyurethanes Industry (API) (**www.polyurethane.org**);

and *MDI and TDI: Safety, Health and the Environment* [Allport 2003].

FUTURE RESEARCH AND PRODUCTS

NIOSH is continuing research on solutions for the spray-on truck bed liner industry in collaboration with other government agencies, academia, and industry representatives. This research includes the following:

- Investigation of the particle size distribution of the overspray and the relative contributions of gravitational settling and ventilation in removing MDI from the atmosphere of the spray enclosure.
- Design and evaluation of a negative-pressure ventilation system to reduce MDI concentrations within the spray enclosure and to prevent escape of MDI to other areas.
- Analytical methods research for MDI and other isocyanates.
- Production and dissemination of a NIOSH *Workplace Solutions* document detailing ventilation designs and work practices for the spray-on truck bed liner industry.

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We greatly appreciate your assistance in protecting the lives of U.S. workers.

John Howard, M.D.
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APPENDIX A

This appendix includes (1) a definition of isocyanates and MDI terms used in the text, (2) a list of commonly used synonyms for MDI monomer, (3) a table of Chemical Abstract Service (CAS) numbers associated with MDI, their CAS name and common names or descriptions, and (4) a table of several manufacturers' MDI-based products used in the truck bed liner industry and their associated CAS numbers.

The spray-on truck bed liner industry uses MDI-based products as one component of a two component spray-on process. Component A typically contains a mixture of MDI monomer(s) and modified MDI. All have reactive isocyanate groups present and should be considered possible health hazards.

ISOCYANATE DEFINITIONS AND CHEMICAL STRUCTURE

An isocyanate is any compound that contains the -NCO functional group. A functional group is any group of atoms that represents a potential reaction site in an organic compound. An isocyanate thus has a nitrogen (N), carbon (C), and oxygen (O) bonded together in such a way as to create a reactive site within the molecule. In this document, the term diisocyanate refers to a chemical compound that contains two isocyanate groups (NCO) per molecule. When specifically referring to the diisocyanate methylenebis(phenyl isocyanate), the term MDI monomer will be used. The MDI monomer is depicted in Figure 1. The term MDI refers to a mixture containing any combination of MDI monomer, MDI prepolymer, or polymeric MDI.

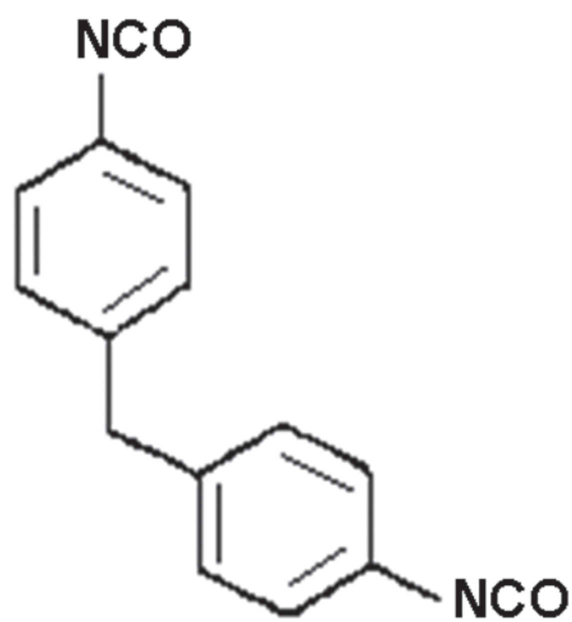

Figure 1. MDI Monomer

Methylenebis(phenyl isocyanate) Synonyms

MDI

1,1-Methylenebis(4-isocyanatobenzene)

4,4'-Diisocyanatodiphenylmethane

4,4'-Diphenylmethane diisocyanate

4,4'-Methylenebis(phenyl isocyanate)

4,4'-Methylenediphenyl diisocyanate

Bis(1,4-isocyanatophenyl)methane

Bis(4-isocyanatophenyl)methane

Diphenylmethane 4,4'-diisocyanate

Diphenylmethane diisocyanate

Methylenebis(4-isocyanatobenzene)

Methylenebis(4-phenylene isocyanate)

Methylenebis(phenyl isocyanate)

Methylene-di-p-phenylene isocyanate

Methylene di(phenylene isocyanate)

Methylene bisphenyl isocyanate (Chemical name used in OSHA documents.)

Sources: Lewis [1993], NIOSH [1995], Sax and Lewis [1987].

Table 1. CAS numbers associated with MDI*

CAS number	CAS preferred name	Description/ common names
101–68–8	benzene, 1,1'-methylenebis[4-isocyanato-	4,4'-MDI isomer, pure MDI
5873–54–1	benzene, 1-isocyanato-2-[(4-isocyanatophenyl) methyl]-	2,4'-MDI isomer
2536–05–2	benzene, 1,1'-methylenebis[2-isocyanato-	2,2'-MDI isomer
26447–40–5	benzene, 1,1'-methylenebis[isocyanato-	MDI (generic), mixture of isomers
9016–87–9	isocyanic acid, polymethylenepolyphenylene ester	PMDI, polymeric MDI (generic), mixture of chemical homologues made from the phosgenation of the reaction product of aniline and formaldehyde
25686–28–6	benzene, 1,1'-methylenebis[4-isocyanato-, homopolymer	Main components of polymeric MDI, mixture of chemical homologues derived from the 4,4'-MDI isomer
17589–24–1	1,3-diazetidine-2,4-dione, 1,3-bis[4-[(4-isocyanatophenyl) methyl]phenyl]-	4,4'-MDI dimer, self-reaction product
31107–36–5	1,3-diazetidin-2-one, 1,3-bis[4-[(4-isocyanatophenyl) methyl]phenyl]-4-[[4-[(4-isocyanatophenyl)methyl]phenyl]imino]-	Uretonimine of 4,4'-MDI, a modified MDI (variant) made from self-reaction of 4,4'-MDI at high temperatures
39310–05–9	benzene, 1,1'-methylenebis[isocyanato-, homopolymer	Generic polymeric MDI, mixture of chemical homologues derived from the mixture of MDI isomers

Source: Allport et al. [2003].
*This list is not all inclusive.

Table 2. CAS numbers associated with specific MDI products†

Company	CAS number	Description
The Dow Chemical Company	26447–40–5	5 MDI products support the TBL business. All but one contains MDI prepolymers, which generally do call out the MDI prepolymer CAS number on the MSDS.
Bayer MaterialScience	39420–98–9	Bayer systems that are sold into the TBL industry are identified as Baytec SPR 085A and Baytec SPR 092A. Component A of each of these systems contains the MDI-based isocyanate.
Rhino Lining	26447–40–5 101–68–8 9016–87–9	The first two CAS numbers are for commercial Tuff Stuff A Side. The last CAS number is for PMDI (Durabond A Side)
Line-X Corporation	26447–40–5	
Huntsman Polyurethanes		**MDI product name/Chemical name(s)**
	101–68–8	RUBINATE® 8001/ 4,4'-Diphenylmethane Diisocyanate
	101–68–8	RUBINATE® 1209/ 4,4'-Diphenylmethane Diisocyanate
	26447–40–5 39420–98–9	RUBINATE® 9465/ Generic Diphenylmethane Diisocyanate Modified MDI
	101–68–8 (not disclosed)	RUBINATE® 9495/ 4,4'-Diphenylmethane Diisocyanate Modified MDI
	101–68–8 (not disclosed)	RUBINATE® 9009/ 4,4'-Diphenylmethane Diisocyanate Modified MDI
	101–68–8 (not disclosed)	SUPRASEC® 9537/ 4,4'-Diphenylmethane Diisocyanate Modified MDI

Source: API
†This list is not all inclusive.

APPENDIX B

SPRAY ENCLOSURE/VENTILATION DESIGN CONSIDERATIONS

This Appendix contains information about spray enclosure and ventilation design, including how to determine the number of air changes per hour and calculate the minimum required purge time.

When substitution is not feasible, engineering controls should be the primary method for reducing airborne isocyanates in the workplace. Spray enclosures should incorporate exhaust ventilation systems designed to contain, capture and remove vapors and particulates. It is generally advisable to minimize the size and volume of the spray area while seeking to increase the exhaust capacity from the spray area. General design concepts and operating considerations for the ventilation control of occupational exposures may be found in the most recent edition of *Industrial Ventilation: A Manual of Recommended Practice*, published by the American Conference of Governmental Industrial Hygienists (ACGIH) [ACGIH 2004b].

The design and operation of a ventilated spray enclosure for MDI-based spray-on bed liners should include the following four parameters with the aim of containing and minimizing exposure to MDI and maintaining exposure to MDI monomer below the NIOSH 10-minute ceiling limit and OSHA 15-minute ceiling limit of 0.2 mg/m^3:

1. The spray enclosure should be designed as a negative pressure enclosure to prevent leakage of airborne MDI into other work areas within the shop. Three different design configurations have been identified to lower MDI concentrations within the spray enclosure and prevent escape to adjacent work areas:
   - A spray booth similar to that used in the automotive paint spray industry; or
   - A spray enclosure (smallest floor area and room volume compatible with the operation) that incorporates local exhaust ventilation hood(s) to capture and remove MDI near the point(s) of generation; or
   - A spray enclosure (smallest floor area and room volume compatible with the operation) that uses a general ventilation system to dilute airborne contaminants. The ventilation system's make-up air supply and exhaust locations should be strategically placed to generate a directed air flow that pushes airborne contaminant toward the exhaust points to maximize ventilation efficiency and contaminant control.
2. If MDI were removed solely by dilution ventilation using an efficient (well-mixed) system design, the recommended three

air changes would be sufficient to remove 95% of the airborne MDI after spraying has ceased. However, NIOSH field experience has shown that gravitational settling contributes significantly to the removal of the MDI aerosol. When these two removal mechanisms act together, the time required to achieve three air changes was more than sufficient to reduce the MDI concentrations to less than 50% of the NIOSH ceiling limit in every field situation evaluated by NIOSH. During the purge time any worker entering the spray enclosure should continue to use the necessary respiratory protection (see Respiratory Protection section).

Ventilation System Capabilities

- Obtain a site-specific exposure assessment that includes sampling data at desired intervals following the spraying operation. These data are the best way to determine the purge time (time required to reduce MDI concentrations consistently below the NIOSH REL) required for your ventilation system.
- In the absence of exposure assessment data, determine the time required for the ventilation system to exhaust an air volume equal to a single air change.
- Calculate the required purge time, allowing sufficient time for at least three complete air exchanges—or even longer for systems with poor air mixing.
- During the purge time, use respiratory protection when entering the spray enclosure (see Respiratory Protection in Recommendations).

Purge Time

- To calculate the time required to exhaust an air volume equal to a single room air change, you must know the exhaust capacity of the fan (as installed) as well as the dimensions of the spray area.

$$T = \frac{(L \times W \times H)}{Q}$$

where:

T = time for one air change (minutes)

L = length of spray enclosure (feet)

W = width of spray enclosure (feet)

H = height of spray enclosure (feet)

Q = fan capacity in cubic feet per minute (cfm)

- A minimum purge time of three air changes ($3 \times T$) is recommended for spray enclosures that incorporate very good ventilation efficiency (that is, mixing factor close to 1.0), such as those discussed in item 1 above. Less efficient designs will need to multiply the calculated time requirement by a mixing factor between 2 and 10, depending upon the prevalence of dead air spots within the spray area [ACGIH 2004]. During the recommended purge time, workers entering the spray enclosure should continue using respiratory protection.

APPENDIX C

This appendix contains additional information about full-facepiece, supplied-air respirators and a respiratory protection program.

SUPPLIED-AIR RESPIRATORS

Many issues pertaining to this industry led to the selection of the full-facepiece, supplied-air respirator as the most appropriate respirator during the spray-on process. These reasons include the following:

- MDI is a potent sensitizer and a NIOSH-approved supplied-air respirator provides a higher level of protection, thus lowering the potential for sensitization.
- A supplied-air respirator provides the high level of protection needed in a work environment in which concentations of MDI aerosol are highly variable with unpredictable spikes to concentrations well above the NIOSH REL.
- A supplied-air respirator decreases the possibility of momentary breakthrough in a work environment in which an air-purifying filter cartridge would likely become clogged, leading to higher breathing resistance and leakage around the side of the mask.
- Full-facepiece, supplied-air respirators provide the eye and dermal protection necessary from the aerosolized spray-on product.
- An air-purifying respirator requires frequent cartridge changes due to the concentrations documented.

ELEMENTS OF A RESPIRATORY PROTECTION PROGRAM

A complete respiratory protection program as required by 29 CFR 1910.134 (c) (1) (i) through 1910.134 (c) (1) (ix) shall include the following:

- Procedures for selecting respirators for use in the workplace
- Medical evaluations of employees required to use respirators
- Fit-testing procedures for tight-fitting respirators
- Procedures for proper use of respirators in routine and reasonably foreseeable emergency situations
- Procedures and schedules for cleaning, disinfecting, storing, inspecting, repairing, discarding, and otherwise maintaining respirators
- Procedures to ensure adequate air quality, quantity, and flow of breathing air for atmosphere-supplying respirators
- Training of employees in the respiratory hazards to which they are potentially exposed during routine and emergency situations

- Training of employees in the proper use of respirators, including putting on and removing them, any limitations on their use, and their maintenance
- Procedures for regularly evaluating the effectiveness of the program

Appropriate management is a critical part of an effective respiratory protection program. Therefore, the program should be evaluated regularly as required by 1910.134 (c) (1) and administered by a qualified program administrator as required by 1910.134 (c) (3). Workers using supplied-air respirators must follow the manufacturer's instructions on how to maintain and verify the specified minimum air pressure for the respirator.

APPENDIX D

Surveillance Guidelines for State Health Departments

Work-Related Asthma

REPORTING GUIDELINES

State health departments should encourage health-care professionals to report back all the diagnosed or suspected cases of asthma that are caused or exacerbated by workplace exposures or conditions. Reported cases should include asthma caused by sensitizers or irritants and should include cases of reactive airways dysfunction syndrome.

SURVEILLANCE CASE DEFINITION

The surveillance case definition requires

1. a health care professional's diagnosis consistent with asthma and
2. an association between symptoms of asthma and work.

Asthma is a chronic condition characterized by inflammation of the tracheobronchial tree associated with increased airways responsiveness to a variety of stimuli. Symptoms of asthma include episodic wheezing, chest tightness, cough, and dyspnea, or recurrent attacks of bronchitis with cough and sputum production. The primary physiological manifestation of airways hyperresponsiveness is variable or reversible airflow obstruction. It is commonly demonstrated by significant changes in the forced expiratory volume in 1 second (FEV_1) or peak expiratory flow rate. Airflow changes can occur spontaneously, with treatment, with a precipitating exposure, or with diagnostic maneuvers such as nonspecific inhalation challenge.

Patterns of association can vary and include the following:

- Symptoms of asthma that develop or worsen after a worker starts a new job or after new materials are introduced on a job (a substantial period can elapse between initial exposure and development of symptoms)
- Symptoms that develop within minutes of specific activities or exposures at work
- Delayed symptoms that occur several hours after exposure (for example, during the evenings of workdays)
- Symptoms that occur less frequently or not at all on days away from work and on vacations
- Symptoms that occur more frequently when the affected worker returns to work
- Symptoms that are temporally associated with workplace exposure to an agent with irritant properties

Work-related changes in medication requirements can accompany these symptom patterns.

APPENDIX E

Contact Information for Selected States

The following States have surveillance systems for work-related asthma:

California

California Department of Health Services
Occupational Health Branch
850 Marina Bay Parkway
Building P, 3rd Floor
Richmond, CA 94804–6404
510–620–5757
www.dhs.ca.gov/ohb/Default.htm

CAL/OSHA Consultation Service
Department of Industrial Relations
2424 Arden Way, Suite 485
Sacramento, California 95825
916–263–5765
www.dir.ca.gov/DOSH/consultation.html

Connecticut

State of Connecticut Department of Public Health
410 Capitol Avenue, Mail Stop: 11 OSP
P.O. Box 340308
Hartford, CT 06134–0308
860–509–7744
www.dph.state.ct.us/BRS/EOHA/HPEEOH.html

Connecticut Department of Labor
Division of Occupational Safety and Health
38 Wolcott Hill Road
Wethersfield, CT 06109
860–566–4550
www.ctdol.state.ct.us/osha/osha.htm

Massachusetts

Massachusetts Department of Public Health
Occupational Health Surveillance Program
250 Washington Street, 6th Floor
Boston, MA 02108
617–624–5632
www.mass.gov/dph/bhsre/ohsp/ohsp.htm

MA Division of Occupational Safety
On-site Consultation Program
Department of Labor and Workforce Development
1001 Watertown Street
West Newton, MA 02465
617–969–7177
www.mass.gov/dos/consult/index.htm

Michigan

Michigan Department of Labor and Economic Growth
Michigan Occupational Safety and Health Administration (MIOSHA)
Consultation, Education, and Training Division
7150 Harris Drive
P.O. Box 30659
Lansing, MI 48909–8149
517–322–1809
www.michigan.gov/cis/0,1607,7-154-11407---,00.html

Michigan State University
Department of Medicine
Occupational and Environmental Medicine
117 West Fee Hall
East Lansing, MI 48824–1315
517–432–1008
www.oem.msu.edu

New Jersey

New Jersey Department of Health
and Senior Services
Occupational Health Surveillance Program
P.O. 360, Room 701
Trenton, NJ 08625–0360
609–984–1863
www.nj.gov/health/eoh/survweb

NJ Department of Health and Senior Services
Public Employees Occupational Safety
and Health Consultation Project
P.O. Box 360
Trenton, NJ 08625–0386
609–984–1863
www.state.nj.us/health/eoh/peoshweb/
peoshcon.htm

New Jersey Department of Labor
and Workforce Development
Division of Public Safety and Occupational
Safety and Health
P.O. Box 953, Trenton, NJ 08625
609–984–0785
www.state.nj.us/labor/lsse/lsonsite.html

New York

State of New York Department
of Health
Center for Environmental Health
Bureau of Occupational Health
Flanigan Square
547 River Street, Room 230
Troy, New York 12180–2216
518–402–7900
www.health.state.ny.us/nysdoh/boh/
homeoccu.htm

New York State Department
of Labor
Division of Safety and Health
Onsite Consultation Program
State Office Campus, Bldg. 12, RM 168
Albany, New York 12240
518–457–2238
www.labor.state.ny.us/

Washington

Washington State Department of Labor
and Industries
Safety and Health Assessment and
Research for Prevention (SHARP) Program
P.O. Box 44330
Olympia, WA 98504–4330
888–667–4277
www.lni.wa.gov/Safety/Research/default.asp

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
4676 Columbia Parkway
Cincinnati, Ohio 45226–1998

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