Technical Note

Prevention through Design: Health Hazards in Asphalt Roofing

Deborah E. Young-Corbett, A.M.ASCE[1]

Abstract: The optimal method of preventing occupational illnesses, injuries, and fatalities is to *design out* the hazards and risks, thereby eliminating the need to control them during work operations. In 2007, the National Institute for Occupational Safety and Health launched a national Prevention through Design (PtD) initiative calling on all major industrial sectors to emphasize hazard mitigation at the design stage. PtD applies to the design of all tools, equipment, materials, and work processes that are employed during the construction process. This article reviews the asphalt roofing health hazards and currently available design solutions for their control and identifies gaps and priorities for further research. PtD solutions such as tanker systems, insulated hot luggers, mechanical asphalt spreaders, fume-suppressing asphalt, and local exhaust ventilation systems are discussed in terms of effectiveness and availability. **DOI: 10.1061/(ASCE)CO.1943-7862.0000892.**

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Introduction

Prevention through Design

The optimal method of preventing occupational illnesses, injuries, and fatalities is to *design out* the hazards and risks, thereby eliminating the need to control them during work operations. This approach involves the design of tools, equipment, systems, work processes, and facilities in such a way as to reduce or eliminate hazards associated with work. In 2007, the National Institute for Occupational Safety and Health (NIOSH) launched a national Prevention through Design (PtD) initiative calling on all major industrial sectors to emphasize hazard mitigation at the design stage of tools, facilities, and work processes (Schulte et al. 2008). NIOSH partnered with the American Industrial Hygiene Association, the American Society of Safety Engineers, the Center to Protect Workers' Rights, Kaiser Permanente, Liberty Mutual, the National Safety Council, the Occupational Safety and Health Administration, ORC Worldwide, and the Regenstrief Center for Healthcare Engineering in the development of a *National Initiative on Prevention through Design*, launched in a 2007 workshop and published in a special edition of the *Journal of Safety Research* in 2008 (Howard 2008). One conclusion of the 2007 workshop was that there are two major gaps to be addressed to advance the implementation of PtD in industry. The first is that design professionals, such as engineers, industrial designers, and architects, need to consider the health and safety implications of the end use of their designs. The second is that business decision makers, including those who purchase products and services, will need to establish a demand for such PtD designs. Therefore, the PtD initiative aims to focus "both on the supply of innovative design solutions and on creating a demand among business decisions makers who will value and request them" (Schulte et al. 2008).

PtD in Construction

In the construction sector, the term *design* is most commonly applied to the process of designing the end product to be constructed: the building, facility, or infrastructure component. However, PtD has a broader definition and applies to the design of all tools, equipment, materials, and work processes that are employed during the construction process, as well as to the design of the constructed environment itself. Therefore, hazard reduction can be accomplished via a multitude of means, such as changes in tool selection, material composition, work process management, or facility design. Much of the work done to date in PtD in the construction sector has emphasized the reduction of risk in the domain of occupational safety. Occupational safety risks are those that can cause an injury or fatality in the event of an accident. One gap in the existing construction PtD literature is in the realm of reduction of occupational *health* risks. Occupational health risks are those that cause disease or disability in the exposed worker population.

The United States is said to lag behind other developed countries in the diffusion of PtD innovation and adoption of PtD approaches within construction (Toole and Gambatese 2008). These concepts have been widely accepted throughout the European Union and Australia. Barriers to the diffusion of PtD were encountered by these countries, and lessons can be learned from their experiences. Toole (2005) makes the case that liability concerns may be a larger barrier to PtD adoption in the United States due to the litigious nature of the business climate in that country. Toole and Gambatese (2008) identify four key aspects of PtD for emphasis in the near future as the construction industry moves toward embracing a PtD approach. These four focus areas are increased prefabrication, reduced use of hazardous materials and systems, increased application of construction engineering, and enhanced spatial consideration. Several large

[1]Assistant Professor, Myers-Lawson School of Construction and Via Dept. of Civil and Environmental Engineering, Virginia Tech, 310B Bishop-Favrao Hall, Blacksburg, VA 24061. E-mail: dyoung@vt.edu

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engineering/construction firms attended the *2007 National PtD Initiative Workshop*, including Jacobs Engineering, Bechtel, Washington Group, BE&K, Southern Company, Haskell, and Parsons (Behm 2008). Behm (2008) reports that many of these large firms have been proactive in investigating and implementing PtD strategies but that industrywide diffusion of PtD innovation is currently poorly documented and that a clearinghouse of so-called best practices is needed. This article aims to address this gap by providing best practice PtD solutions for addressing occupational health risks.

Asphalt Roofing Overview

It has been estimated by the Asphalt Roofing Environmental Council (AREC, Comments of the Asphalt Roofing Environmental Council on NIOSH's September 1998 hazard review document: Health effects of the occupational exposure to asphalt, unpublished report) that more than 50,000 United States workers spend in excess of 40% of their working lives exposed to roofing asphalt. Asphalt is the residuum produced by the distillation of crude petroleum. Performance specifications, and not chemical composition, direct asphalt production. To meet specifications, asphalt may be processed by being air blown or solvent precipitated. Also, the products of other refining processes may be blended with asphalt to achieve the desired performance specifications. Therefore, the exact chemical composition of asphalt depends on the chemical complexity of the original crude petroleum plus the manufacturing processes involved. Asphalt is employed in three different roofing systems: shingles or roll roofing, built-up roofing (BUR), and modified bitumen roofing. Worker exposures to asphalt fumes and vapors are only of concern in those roofing systems that involve the heating of asphalt: BUR and modified bitumen systems (NIOSH 2003a). Mopping-grade asphalt is typically delivered to the construction site in solid form and then heated in a roofing kettle prior to application. Alternatively, it is delivered in a liquid state in a temperature-controlled tanker. Potential worker exposures are related to the operation of the kettle and application on the rooftop. The recommended temperature for mopping-grade roofing asphalts is 330–445°F (166–229°C) (NIOSH 2003b). To achieve this temperature at the point of application, the temperature of the asphalt in the kettle has been reported to be as high as 600°F (316°C). Hot asphalt is then delivered to the roof through a metal supply line from the kettle (or tanker). It is emptied into a rooftop storage container called a hot lugger. This hot asphalt is then accessed either manually by workers who pour it into carts and perform the mopping operation or by automated systems that pour and apply the mopping layer. In the manual method, workers apply the asphalt with handheld mopping tools and open-topped containers for the liquid material, making worker exposures a concern in the kettle operation and manual mopping functions of these roofing operations.

Chemical Constituents of Roofing Asphalt

Roofing asphalt vapors and fumes have been found to differ from those associated with paving operations because of the higher temperatures involved in roofing asphalt application and the differences in the manufacturing process. While few field studies have been conducted to characterize the constituents of asphalt fumes and vapors, a small number of laboratory studies have analyzed the emissions. Thayer et al. (1981) and Niemeier et al. (1988) performed gas chromatography/mass spectrometry (GC/MS) analysis on laboratory emissions of asphalt generated at 232°C and 316°C. The results indicated that emissions consisted mainly of two- and four-ring polyaromatic hydrocarbons (PAHs) with small amounts of five-ring PAHs. Notable is the presence of the carcinogenic substances benz(a)anthracene, Benzo(a)pyrene (BaP), and dibenzanthracenes. Also using GC/MS, A. Lunsford and T. Cooper (unpublished data, 1989) characterized the chemical classes present in roofing asphalt fractions separated by high-performance liquid chromatography (HPLC). Several sulfur- and oxygen-containing polyaromatic compounds (PACs) were identified. Little is known about the toxicity of these compounds; however, they bear a structural similarity to known mutagens and carcinogens (NIOSH 2001). Also found were unalkylated isomers of chrysene and benz(a)anthracene, identified as probable human carcinogens by the International Agency for Research on Cancer (IARC) (Malaiyandi et al. 1982). Naphthalene, a major constituent in both laboratory studies, is classified by IARC as possibly carcinogenic to humans and animals (IARC 1985). In a field study of roofing asphalt exposure, Hatjian et al. (1997) reported on the GC/MS analysis of personal-breathing-zone air samples of asphalt fumes collected at several work sites. Two- and three-ring PAHs accounted for 84–94% of the PAH exposures. Naphthalene accounted for 80–96% of the measured PAHs. Other PACs detected include acenaphthene, phenanthrene, pyrene, benz(a)anthracene, and BaP. BaP was detected in 25–28% of the samples. In its *Hazard Review of the Health Effects of Occupational Exposure to Asphalt*, NIOSH recommended additional research to characterize worker exposures to BaP, chrysene, benz(a) anthracene, and the S- and O-PACs (NIOSH 2001). It was noted that asphalt fumes generated at higher temperatures, such as those in roofing operations, are probably more hazardous than fumes generated at lower temperatures.

Health Effects of Roofing Asphalt Exposure

Asphalt fumes and vapors have been associated with both acute and chronic health effects. Studies concerning the acute toxic effects of exposure to asphalt fumes have repeatedly found symptoms of irritation of the mucous membranes of the upper airways, the eyes, and the skin. Mucosal irritation tends to be mild and transient in nature. Skin irritation, pruritus, and occasional rashes have been reported (Norseth et al. 1991). Asphalt-related dermal photosensitization has been suggested, but additional investigation will be required to substantiate the claim (Hervin and Emmett 1976). In contrast to pavers, studies of roofers have generally demonstrated an excess number of lung cancer cases. A meta-analysis of epidemiologic studies of roofers indicates an excess of lung cancer and neoplasm of the buccal cavity and pharynx among roofers (Partanen and Boffetta 1994). This 1994 comprehensive review of epidemiologic studies of asphalt workers found that the relative risk for lung cancer was elevated for asphalt roofers but not for highway pavers. Several cohort mortality studies of roofers exposed to asphalt fumes have been conducted. A retrospective study of members of the United Slate, Tile, and Composition Roofers, Damp and Waterproof Workers' Association, found that asphalt roofer lung cancer mortality increased with time on the job (Engholm et al. 1991). The Swedish construction industry's Organization for Working Environment, Safety, and Health conducted a study of cancer mortality and incidence among construction workers, including 704 roofers. Increased mortality for cancer of the lung was observed among roofers. Data from experimental studies in animals and cultured mammalian cells indicate that laboratory-generated roofing asphalt fume condensates are genotoxic and cause skin tumors in mice when applied dermally (McFall et al. 1984). In its *Hazard Evaluation* report, NIOSH concludes that roofing asphalt fumes are a potential

occupational carcinogen, based on the review of epidemiologic studies and the evidence of known carcinogenic constituents in characterization studies (NIOSH 2001).

PtD Approaches to Asphalt Vapor/Fume Control

The main exposing activities are those associated with asphalt kettle operation and rooftop application. Some engineering control options are available to reduce exposure to fumes and vapors: delivery to the rooftop via tanker rather than kettle and hot lugger system; lidded rooftop containers such as hot luggers, mechanical asphalt spreaders, and felt-laying machines; insulated kettles; insulated hot luggers; fume-suppressing asphalt; and local-exhaust ventilation systems. Delivery of the hot asphalt to the job site can be accomplished via a tanker, which would eliminate the on-site kettle operation for handling and heating the asphalt. Roof application exposures can be reduced through the use of lidded and insulated distribution systems. Asphalt fume emissions from the kettle can be reduced by maintaining a constant temperature and preventing the release of fumes. A variety of thermostatically controlled heating systems are available to maintain a set asphalt temperature in the kettle. Kettles are often constructed of double walls with thermal insulation. They may also have double lids to maintain temperature and control exposures. Local exhaust ventilation (LEV) emission capture systems have been introduced for use on kettles to evacuate fumes from the headspace inside the kettle. Automated mechanical systems for rooftop application of mopping layers can be used to remove the human operator. Low-fuming asphalt has been developed to reduce the emission of asphalt fumes from the kettle. A polymer additive to the asphalt separates and forms a floating skim on the surface of the hot asphalt. Initial field studies indicate that the skim dramatically reduces fume emissions (NIOSH 2003a).

Conclusions

Occupational health risks arise when workers are exposed to chemical, biological, or energetic hazards that might lead to resulting short-term illness, long-term chronic disease, fatal disease, or diminished wellness. Prevention through Design, the elimination or significant reduction of risks at the design stage of tools, materials, processes, and projects, holds great promise for the reduction of occupational health risks in construction operations. While there remains a need for the development and dissemination of novel and innovative designs to accomplish this end, several categories of solutions have been identified. Their relative ranking is presented below and can be described in terms of impact on the reduction of risk and on value added to business operations: elimination, substitution, reduction, containment/removal, alarm systems, work process redesign, and personal protective equipment (Fig. 1).

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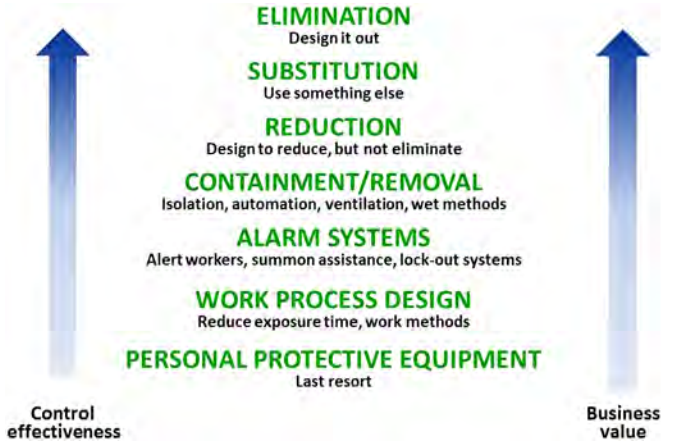

Fig. 1. Hierarchy of control solutions (Young-Corbett 2013; republished with permission of Taylor and Francis Group, from *The Handbook of Industrial and Systems Engineering*, 2nd Ed., 2013; permission conveyed through Copyright Clearance Center)

in construction prevention through design activities, however. Designers of tools, equipment, and materials are engaged in the design of new ventilated and water-fed tools and equipment and of less toxic materials. Designers of facilities are responsible for ensuring that specifications for these tools and materials are incorporated into building designs and construction plans. In addition, builders of facilities are responsible for ensuring that those materials and tools are adopted for use during the construction process. The current review has identified gaps in the current practice in all three of these aspects of design. In some cases, designs are needed for better tools or materials. In others, effective tools exist but are not widely adopted within the industry. Further research is needed in these cases to elucidate the barriers to PtD adoption and identify strategies for improved diffusion within the construction industry.

Practical Applications

Further research is needed to describe current industry usage of all the PtD design solutions described in this note so that diffusion strategies can be developed. Local-exhaust ventilation emission capture systems for roofing asphalt kettles, automated systems for hot asphalt conveyance, and low-fuming asphalt are all promising PtD strategies for risk reduction in roofing; however, the industry adoption trends and barriers have yet to be described empirically.

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