Practice
Designing Out Hazards in the Real World

By Anjali Lamba

NIOSH is leading a national initiative, launched in July 2007, called Prevention Through Design (PTD). This initiative has engaged the government, academia and industry in promoting the concept of designing out and minimizing occupational risks. Following is a comprehensive definition of PTD:

> 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 order to reduce or eliminate, hazards associated with work. (Young-Corbett, 2011)

IN BRIEF

- **This article provides real-world examples of prevention through design (PTD) and successful applications of PTD concepts and principles.**
- **Early collaboration among stakeholders is crucial for successful incorporation of PTD elements in design and construction.**
- **Other potential avenues to maximize PTD benefits include working with design-build firms, incorporating PTD into LEED and involving OSHA in actively promoting PTD in construction.**
- **Strong federal agency leadership support of this initiative is crucial.**

The purpose of PTD is to eliminate hazards and reduce risk at the source by considering safety and health implications early in the design cycle; this is more effective than the traditional risk management approach. PTD principles also tie in with the well-known hierarchy of controls where engineering controls are always the most effective, because they either remove the hazard at its root, or contain or isolate the hazard so that exposures are controlled through design. PTD supports the adoption of hazard control measures higher in the hierarchy of controls by focusing on hazard elimination and substitution followed by risk minimization through the application of engineering controls and warning systems applied during design, redesign and retrofit activities. However, PTD also supports the application of administrative controls and PPE when they supplement or complement an overall risk minimization strategy and include appropriate program development, implementation, employee training and surveillance (Schulte & Heidel, 2009).

As awareness of the PTD concept grows, more SH&E professionals are calling for a concerted emphasis on the engineering and technical aspects of a safe design during the planning phase, which reduces risks and minimizes hazards throughout a facility's life. This requirement is illustrated by a recent request for proposal for work at the Portsmouth Naval Shipyard that specified, "If it is not feasible to eliminate or prevent the need to work at heights with its subsequent exposure to fall hazards, control measures shall be included in the design to protect personnel conducting maintenance work after completion of the project."

Research conducted in the U.S., European Union and some countries in the British Commonwealth has linked a good percentage of construction injuries and fatalities to decisions made before any construction work started. This has resulted in an effort to get the designers to assess the risk their designs create for construction workers during construction of facilities and structures (Furst, 2011).

This article is based primarily on proceedings of the practice session held during the August 2011 NIOSH conference, "Prevention Through Design: A New Way of Doing Business," which was organized to highlight the progress made in implementing the PTD initiative since its inception. Through presentations focusing on real-world practice, presenters showcased successful applications of PTD concepts and principles that resulted in the design or redesign of work premises, tools, equipment, machinery, substances and work processes. Design solutions ranged from reducing asphalt-fume exposure of workers paving roads to redesigning a forklift to optimize the operator's field of vision.

Many sources create workplace hazards. A common way to classify hazards is by type of hazard or hazard category. With this in mind, and to allow readers to quickly identify their areas of interest, practice examples have been organized according to these hazard categories: chemical, physical, ergonomic and safety. Several presentations also promoted the implementation and evaluation of PTD practices by utilizing rating systems and other tools and products that aid practitioners in the design and construction of safe and green buildings and workplaces. These are discussed in the "Rating Systems, Tools, Products and Approaches" section (p. 38).

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PTD: Practice Area

The area of practice in PTD focuses on demonstrating the value of including workers' safety and health in design decisions and exploring links with the movements toward green and sustainable design. It also includes identifying and sharing successful procedures, processes, equipment, tools and results through various means (e.g., online databases). For worker safety and health, sustainable design enhances indoor environmental quality and optimizes operational and maintenance practices. Including provisions during facility design, construction, occupancy and maintenance to prevent injuries, illnesses and fatalities among workers is an essential component of sustainable design.

Chemical Hazards

In keeping with PTD principles and the hierarchy of controls, engineering controls were developed and implemented to reduce worker exposures to chemicals in the examples highlighted here. In addition, in two cases, multifaceted control strategies were developed through partnership between government agencies, unions and industry to reduce worker exposures to chemicals.

Spray Polyurethane Foam

In 2009, EPA established the Federal Advisory Spray Polyurethane Foam (SPF) workgroup in partnership with NIOSH, OSHA, Consumer Product Safety Commission and the polyurethane industry to address several issues associated with worker exposure to methylene diphenyl diisocyanate (MDI) and other chemicals in SPF products. The workgroup has developed guidance on simple exhaust ventilation design principles for SPF applicators and helpers since engineering control strategies are the most effective means to protect workers during all phases of SPF application (**www.epa.gov/dfe/pubs/projects/spf/ventilation-guidance.html**). Other on-site controls such as isolation that are also effective in controlling chemical migration include: enclosing the spray zone as much as possible; supplying air (active or passive) at one end of spray zone and directing airflow through spray zone from clean to contaminated; filtering and exhausting air at the opposite end of the spray zone; and creating negative pressure within the enclosure (Lamba, 2011).

Controls that are already being used at application sites include plastic sheeting to cover wall studs, metal grating to control expansion of foam (Photo 1), and using air movers to exchange air in the spray zone to reduce airborne chemical concentrations (Photos 2 and 3). In addition, NIOSH has developed a prototype SPF spraying booth (Photo 4). Comprehensive hands-on safety and health training for workers also is crucial to prevent and reduce exposures. The SPF industry provides online training for applicators and plans to offer hands-on worker training in the near future (Lamba, 2011).

Asphalt Partnership

During the 1990s, National Asphalt Pavement Association formed a partnership with industry, NIOSH, other government agencies and unions to improve working conditions at paving sites. As a result, all U.S. manufactured slip-form pavers were redesigned with ventilation mechanisms to reduce workers' exposure to asphalt fumes. In Europe, warm-mix asphalt has been successfully used to improve working conditions, cut overall emissions, save fuel, extend the paving season, improve quality and increase the life span of the pavement. The first warm-mix demonstration sections in the U.S. were constructed in 2004 (Acott, 2011).

Laboratory Chemicals

Transportation of hazardous liquids poses risks to facility occupants. Designing suitable routing through low-traffic areas and avoidance of exit corridors becomes difficult if not addressed during the early-stage design of the facility (e.g., design of vapor-mitigation systems can enhance a facility's operational safety should a liquid spill occur). Some facilities use highly toxic, flammable and even pyrophoric gaseous materials. Exposure can be prevented and mitigated by using overpacks and containment carts for liquid chemical transportation; installing emergency exhaust systems for vapor exhaust in case of a liquid spill event; and separating dock area and gas storage area to handle dock area traffic when hazardous chemicals are present (Weaver, 2011).

Physical Hazards

Noise and radiation were two physical hazards addressed during the presentations. Repeated exposures to loud noise can lead to permanent, incurable hearing loss or tinnitus. Ionizing radiation has wide application in medicine and industry (e.g., in X-rays, as radioactive isotopes). Exposure to ionizing radiation can cause genetic changes, cancer and other health effects including death in extreme cases.

Buy Quiet & Quiet-by-Design

Controlling equipment noise emissions limits employee exposure and reduces the need for personal hearing protection. It lowers the risk of noise-induced hearing loss, enables better speech intelligibility, and improves safety, productivity

From top: Metal grating (Photo 1) controls expansion of foam, while air movers (Photos 2 and 3) can be used to exchange air in the spray zone.

NIOSH has constructed a prototype spray booth (Photo 4, front view).

NIOSH, DART

and comfort in the workplace. Buy-Quiet and Quiet-by-Design concepts apply to the engineering of inhabited spaces and focus on controlling ambient noise instead of directly controlling exposure; this is achieved by purchasing and designing equipment that is inherently low noise.

The Quiet-by-Design approach, typically applied to large gas flow systems, encompasses Buy-Quiet purchases of source components. In addition to the obvious hearing loss prevention and other advantages, it makes good economic sense to invest in low-noise equipment during planning and design, rather than implementing expensive retrofit noise control solutions later (Cooper, 2011).

National Aeronautics and Space Administration (NASA) has adopted the Buy-Quiet approach in an effort to reduce noise at its field centers across the U.S. In 2006, NASA added specific requirements to its agency-wide occupational health policy. Each NASA site must establish a program that includes noise emissions with technical and performance criteria when purchasing or designing new equipment that is "expected to produce noise that is approaching hearing conservation levels of 80 dBA and higher." Noise emissions are considered equally with all other specification criteria during the procurement process, and a trade-off analysis is used to inform the selection by assessing the long-term cost of exposure to each candidate product. NASA's Buy-Quiet Roadmap (**http://buyquietroadmap.com/buy-quiet-purchasing**), a publicly available online resource facilitates the stepwise navigation of low-noise purchase (Cooper, 2011).

Purdue University Engineering Solutions

At Purdue University, design-based engineering solutions have been implemented to prevent radiation exposure among nuclear pharmacists. Radiation shields were redesigned to be adjustable to accommodate differences in the height and reach of petite female and taller male workers (McGlothlin, 2011).

Ergonomic Hazards

Ergonomic hazards can cause disabling, lifetime musculoskeletal disorders (MSDs) to the muscles and joints. MSDs are the fastest-growing category of work-related injuries, with billions of dollars paid out in compensation costs each year. Following are examples of reducing injuries by redesigning work processes. PTD also can increase productivity and product quality, as one example illustrates.

Toyota Manufacturing Design Process

Toyota has established ergonomic design criteria in its vehicle design process. The criteria address 42 elements covering six categories (Toyota-specific): force, weight, posture, tools, equipment and environment. Development and implementation of these criteria are part of kaizen, the company's culture of continuous improvement (Horsford, 2011).

Purdue University Research

Three different ergonomic hazards were eliminated by graduate students at Purdue. Injuries related to the use of surgical tools (to perform laparoscopic surgery) were prevented by redesigning surgical tools for persons with smaller hands. Most surgical tools are designed for males although many laparoscopic surgeons are female.

Knee and back injuries suffered by EMT workers were addressed by designing an adjustable stretcher. Laboratories were redesigned to comply with Americans With Disabilities Act, including wheelchair accessible workspaces to prevent injuries among laboratory workers with lower limb disabilities (including amputations) through design (e.g., changing sink height and depth, repositioning switches) (McGlothlin, 2011).

Safety Hazards

Falls remain a consistent cause of fatalities in the U.S., and working at heights when installing roof rafters and roofing on conventional buildings is particularly hazardous (Lyons, 2011). In 2009, falls accounted for more than one-third (34%) of fatal occupational injuries in construction (Behm, 2011).

Preventing Slips, Trips & Same-Level Falls

In 2008, same-level falls represented nearly 16% of total disabling injuries with more than $8 billion in costs (Liberty Mutual, 2010). Same-level fall frequency and cost trends have shown a rising trend since the first Workplace Safety Index was published in 2000. Fall prevention programs must be proactively managed and this starts with facility design. Prevention strategies include selecting the right walkway surface, maintaining the surface through good housekeeping programs and conducting periodic inspections for defects. A viable slip, trip and fall prevention strategy focuses on parking lot and sidewalk/curb design, stairway design, entrance design and proper installation and design of matting systems (Maynard, 2011).

Falls From Height: Contractors' Perspective

Interviews with contractors involved in industrial, commercial and residential construction reveal a theme that early recognition and control of possible hazards during design is much cheaper over a facility's lifetime than working around those hazards after occupancy. Prefabrication of elements off site in controlled areas can reduce the risk of falls from work at height during construction (Hinze, 2011).

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Falls at jobsites are the primary cause of fatalities in construction (CPWR, 2007). Consider these five solutions to reduce the risk of falls:

•Temporary straps embedded in a building's concrete frame and attached to the reinforcement can be used with a personal fall arrest system by construction crews. Once the permanent exterior frame is complete, the exposed portion of these straps can be removed (Tymvios, 2011).

•Increasing the height of roof parapets allows construction crews to work safely and install roof fixtures without the risk of falling. The same parapets later protect maintenance workers (Tymvios, 2011).

•The placement of electrical conduit and mechanical systems underground or within the floor slab, as opposed to overhead, eliminates the need for maintenance crews to work on ladders (Tymvios, 2011).

•At the Bowen Wind Farm, permanent anchor points were attached to wind turbine structures to provide fall protection for maintenance workers (McGlothlin, 2011).

•Prefabricated structural elements reduce the need to work at heights. One contractor has eliminated construction of roofs on projects by assembling them on the ground. This not only eliminates the potential for someone to fall but the contractor noted "we actually did it 30% faster than expected" since materials were easier to access and workers were not limited to the work area of one ladder step. He is now installing the shingles, lighting, ventilation ductwork and electrical systems in the ceiling spaces on the ground before the roof is lifted (Photo 5), further increasing safety and speed of the work (Lyons, 2011).

Falling Objects

Huge PTD opportunities are evident when buildings are constructed or renovated but execution requires early planning. When the building rooftop structures and mechanicals are being repaired, the typical overhead pedestrian protection is common and expensive (Photo 6). A simpler method keeps the items on the roof and requires little maintenance when installed correctly. For example, at one New York City, NY, site, the cost of maintaining such sidewalk protection was $500,000 since the project was to take 1 year and pedestrian protection was needed over a full city block. Instead, a rooftop barrier was designed and installed (Photo 7) before work started at a total cost of $110,000 to protect the same area (Lyons, 2011).

Buildings: Safe to Construct, Operate & Maintain

Green technology on rooftops (e.g., solar panels, wind turbines, vegetation) is an area in which the integration of PTD concepts could eliminate hazards and reduce risk to workers. Rooftop and vertical vegetation are an emerging green building science. PTD does not compromise aesthetics or the environmental benefits of rooftop greenery. Examples from green roof research in Singapore and the U.S. illustrate the opportunity for PTD to influence life cycle safety and health on vegetative roofs.

While no occupational deaths stemming from installing or maintaining rooftop vegetation have been documented, the hazards and risks are evident. Design considerations include safe access to users, fall protection for installers and maintenance staff, structural load implications and the relationship of vegetation to other known building hazards. Rooftop gardens provide a classic business case for why safe design is preferred to safe redesign (Behm, 2011).

RANDALL BUTLER

A roof built on the ground (Photo 5) being placed on a structure.

Capital Project Design & Execution

Smart design can provide the design engineer with the ability to promote correct responses during emergencies. Examples include installing safety glasses holders at entry points to areas in which they must be worn; use of voice commands to supplement building alarm tones for evacuation and take-cover events; and use of automatic locking and unlocking functions on doors to keep people away from areas where a hazard exists, while facilitating access for emergency responders during emergency situations. Building security systems can be programmed for access control to particular areas. That control can be integrated into the safety-training program to ensure that all personnel entering an area have been adequately trained for known present hazards and their training is current (Weaver, 2011).

Ambulance Redesign to Reduce EMS Injuries

NIOSH's Division of Safety Research, Department of Homeland Security and National Institute for Standards and Technology (NIST) are

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Typical overhead protection (Photo 6, above) and overhead protection installed on the roof (Photo 7, left).

SCHNEIDER ELECTRIC

In Photo 8, an arc-rated switchgear test shows arc-flash energy channeled away from where a person could be standing.

conducting ongoing research regarding ambulance design standards. The effort addresses vehicle crashworthiness, occupant ergonomics and human factors. Results of NIOSH vehicle crash tests, dynamic tests of equipment mounts, occupant restraints and seating systems are being translated into standards by the National Truck Equipment Association's Ambulance Manufacturers Division. Future NIOSH testing and NIST human factors/ergonomic evaluations will support development of new NFPA 1917, Automotive Ambulance Standards (Moore, 2011).

DUPONT

IRISS

From top: A simple device (Photo 9) allows the safe insertion and removal of breakers while the installer is a safe distance away. Viewing ports (Photo 10) allow for inspection and measurement from outside the panel.

Electrical Safety

Technical activities addressing safety by design, supported by Institute of Electrical and Electronics Engineers (IEEE) and NFPA, have advanced development and application of engineering design solutions in reducing exposure to electrical hazards. Changes made to the initial equipment design can protect downstream users from the risk of electrocution and arc flashes. Switchgear and equipment have been designed to contain and deflect away an arc within the unit (Photo 8). A simple device (Photo 9) allows the safe insertion and removal of breakers while the installer is a safe distance away. Viewing ports (Photo 10) allow for inspection and measurement from outside the panel (Floyd, 2011).

Structural Collapses

The fatality rate in the construction industry is approximately four times higher than the fatality rate for all other industries. Construction errors contributed to 80% of the structural collapses investigated by OSHA from 1990 to 2008 (Ayub, 2011). The remaining 20% of the incidents were attributed to structural design flaws.

These fatal incidents might have been prevented had the hazards been considered and remedies been incorporated during the design phase, along with proper coordination between the engineer and the contractor during construction. Particular areas of interest for engineers at the design stage are (Ayub, 2011):

- Column width should be greater than or equal to perimeter beam width.
- Provide details for rebar spacing, proper development length and splice length at beam-to-column joints. Avoid congestion of rebar to prevent honeycombing (voids) in concrete.
- Consider construction loads during the design of (parking garage) floor slabs and columns.
- For post tensioning beams, avoid fixed-end anchorage at both ends of an interior column.
- Formwork design calculations should consider properties of actual concrete mix used; rate of pour; and use of retarder in concrete mix.
- Composite steel beam design calculations should consider noncomposite beam design during construction for construction live loads; and composite beam design for final condition.
- Check structural stability against lateral-torsional buckling during the construction phase for bridge girders and any primary exterior steel truss that supports secondary steel trusses.
- Wood truss manufacturers should design temporary braces for spans greater than 60 ft.
- Provide anchor points for fall protection during construction work and for future maintenance work.
- OSHA's requirements for a factor of safety are different from consensus standards such as ACI, AISC, AITC and IBC regarding topics such as scaffold design, fall protection anchorage, cable size for lifting beams and equipment.

In a steel and concrete construction project, the Canopy Steel Bridge (575 ft long and 11 to 18 ft wide) was under construction when it collapsed (Photos 11 and 12). At the time of the collapse, the entire structural frame was supported by more than 15 temporary shoring towers and concrete was being poured over the deck. Contributing factors included:

- Permanent structures were made of high strength steel. Shoring designer assumed higher steel strength for temporary structure too, but were not specified in the shoring sketch.
- Contractor did not specify steel strength while procuring shoring towers.
- Design drawings required shoring towers to be spaced not more than 30 ft. Towers were relocated by contractor to protect trees.
- Some helical anchors had insufficient embedment depth (Quintero & Menon, 2011).

Rating Systems, Tools, Products & Approaches

Owner's Role in Facilitating PTD

PTD is facilitated when SH&E professionals are included in the early stages of the capital project process. Safety design checklists help the design team identify possible hazards. The informed owner may then select several options to design out a hazard. Facilitating this decision-making process are specific tools, such as building information management systems, that virtually depict a building and all its components before it is built (Toole, 2011).

Environmental Sustainability & Occupational Safety for Preventive Maintenance of Green Buildings

As the number of green buildings increases, a better understanding of the risks associated with green features could prevent injuries. The Occupational Safety and Health Assessment and Rating System for Green Buildings promotes the design of green building features that can prevent or minimize occupational hazards. One example may be introducing numerous skylights for additional lighting but ensuring design considerations for workers who may shovel snow around the skylights or clean them so they cannot fall through when the skylights are hidden under the snow (Omar, 2011).

PTD Development Tools

Tools and processes to move these concepts forward include:

•Use a risk-assessment-driven process that promotes zero harm to people/environment.

•Use hierarchy of controls to achieve a tolerable level of risk (as low as reasonably practicable, or ALARP).

•Investiage incidents and conduct root-cause analysis to generate lessons learned that drive improved understanding of risk and behaviors.

•Train senior managers to understand the effect of facility design on injury/illness.

•Use of 3-D simulation software to create virtual facilities that enable viewers to tour the planned project (Borowski, 2011).

ANSI Z10: Occupational Health & Safety Management Systems

ANSI/AIHA/ASSE Z10-2012 provides a comprehensive systematic approach to occupational safety management within organizations, and addresses processes to recognize opportunities to prevent incidents that may be missed by contemporary safety and health programs. Systems based on ANSI Z10-2012 and equivalent global standards are proactive and include processes for continuously ensuring and improving element effectiveness (i.e., plan, do, check, act) (Dotson, 2011).

Building Life Cycle

Looking holistically at the life cycle of a capital project means identifying hazards inherent at every stage. Detailed steps are needed when planning a capital project to assess the risks to workers not only during its assembly but also after occupancy. Long-term threats to maintenance workers must be considered in the project cost calculations (Furst, 2011).

Costs/Benefits of Ergonomic Interventions for Small Business

A new technique called time and physical demands analysis is a proven tool to increase safety, quality and production from practical, simple but effective changes in workstations for warehouse workers. For example, reengineering a pallet lift reduced back and shoulder strain incidents by 58% and 33%, respectively, and produced a 48% time savings. PTD solutions in another plant increased output from 125 units per day to 250. Changes in the method used to load a machine reduced the time spent on the task by 93%. Not only did the facility reduce lost-time incidents and claims, it also realized a significant increase in efficiency and quality (MacLeod, 2011).

Sustainable Construction Safety & Health Rating System

The Sustainable Construction Safety and Health (SCSH) Rating System is a tool designed to improve construction worker safety and health. SCSH is used to plan and assess the extent to which construction safety and health are given priority and are addressed in project planning, design and construction. SCSH aims to eliminate construction site hazards and, thereby, reduce worker injuries and fatalities. Researchers recently launched a website (**www.sustainablesafetyandhealth.com**) that features an online SCSH calculator (Rajendran, 2011).

OSHA, DIRECTORATE OF CONSTRUCTION

Canopy Steel Bridge (575 ft long and 11 to 18 ft wide) was under construction when it collapsed (Photos 11 and 12).

OSHA Alliance: Construction Roundtable

OSHA has developed a series of educational products through the Construction Roundtable Alliance. The slide presentation, "Prevention of Fall Fatalities and Injuries in Construction" (available in English and Spanish), addresses the major causes of falls in the construction industry and provides fall prevention guidance for design engineers, contractors and workers. Another slide presentation, "Design for Construction Safety, 2-to-4-Hour Course," provides technical information on designing for construction safety. Common exposures can be eliminated through design, such as falls from unprotected roof edges, falls through floor openings, roof hatch access, skylights and insufficient heights of roof parapets (Quintero & Menon, 2011).

Conclusion

Early collaboration between various stakeholders is crucial for successful incorporation of PTD elements in design and construction. Ideally, architects and engineers, SH&E professionals, facilities and operations management, and contractors would review and examine the constructability aspect of the projects they design before construction begins (Ayub & Menon, 2011). During initial de-

Referenced Presentations

Referenced presentations are available at **www.asse.org/professionalaffairs_new/ptd.php,** under "Supporting Documents." Biographical sketches for speakers are available under "Speaker Bios" on the same website. Referenced presentations were:

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Disclaimer

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sign and planning, all hazards to construction and maintenance workers as well as to occupants must be identified and eliminated (Furst, 2011) with administrative or procedural controls serving as support functions rather than the primary methods of mitigating risk (Weaver, 2011).

Improved worker safety and reduced injury and illness rates translate into lower workers' compensation costs and increased business value, including faster time to market, improved operational efficiency, improved employee morale, reduction in employee absenteeism and turnover, higher product quality and greater market share (Schulte & Heidel, 2009).

For example, successful long-term Buy-Quiet programs produce significant cost savings by reducing the need for hearing protection, reducing lost-time accidents and preventing costly mistakes during production (Cooper, 2011). Interviews with contractors in industrial, commercial and residential construction reveal that it is much cheaper to make changes targeted at improving safety in the construction budget as opposed to the operations budget (Hinze, 2011).

Education of all identified stakeholder groups is an important task. Conference participants emphasized that a demand for PTD should be created through avenues such as the Construction User's Round Table, U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) and design-build firms. Working with design-build firms that have an incentive to incorporate PTD, incorporating these principles into LEED, and actively involving OSHA in promoting PTD in construction are other potential avenues to maximize the benefits of this concept (Schneider, 2011).

In the few years since NIOSH launched its initiative, significant progress has been made in minimizing worker risks through the design and redesign of facilities, work methods, processes, equipment and products, and by implementing engineering-focused controls. The examples highlighted in this article demonstrate that PTD is an effective and efficient tool in creating safe and highly functional facilities. However, much more remains to be done, and strong federal agency leadership that has supported some of the initiatives detailed must continue. **PS**

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