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Slip, Trip, and Fall Prevention: Concepts and Controversies

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Introduction

According to published research by the Liberty Mutual Research Institute for Safety, same-level slips and falls represent nearly 11% of all workers compensation claims and over 13% of all claims costs.

This is second only to manual material handling, which represents 37% and 40%, respectively. In most industry groups, slips and falls represent the highest, or second highest, type of workers compensation claim. In addition, 11% of low back pain-related claims and 12% of low back pain-related claims costs are attributed to slips and falls.[2]

The Liberty Mutual Workplace Safety Index (WSI) ranking of the 10 leading causes of workplace accidents and the initial Liberty Mutual Executive Survey of Workplace Safety in 2001 revealed some interesting statistics about the direct and indirect costs of workers' compensation slips and falls, and the perception among business executives about the extent of the problem. In reality, the direct cost of falls on same level represents nearly $8 billion, second behind overexertion or back injuries and, from 1998 to 2009, falls on same level have shown a

34.2 percent increase or real growth trend. But according to the 2001 executive survey, most executives perceived falls on the same level to be much less of a problem: the seventh most important cause overall.

Why is there a difference between reality and the perceived importance of slips and falls? Why do same-level falls continue to represent one of the most costly safety problems today? The reason might lie in a lack of understanding as to how slips and falls occur and implementation of a managed safety process that targets those complex causes. While the above statistics address falls in the workplace, equally important are falls to the general public in restaurants, retail stores, hospitals, and public buildings.

What Does Slip-Resistant Mean?

In its simplest sense, a slip-resistant surface is one that will permit an individual to walk across it without slipping. Contrary to popular belief, however, some slippage is in fact necessary for walking, especially for persons with restricted gaits who may drag their feet slightly. While increasing the slip-resistance of a surface is desirable within certain limits, a very high coefficient of friction may actually hinder safe and comfortable ambulation by persons with disabilities. In fact, "a truly non-slip surface could not be negotiated." (U.S. Access Board-ADA).

Most studies show that people can walk comfortably and safely on surfaces with a coefficient of friction greater than 0.4, but 0.5 offers an additional safety factor (Miller, 1983). This is called a "slip-resistant surface."

The definition of "slip resistance" and "slip resistant" in ASTM F1647 supports science of tribology and causes of slips and falls:

- **Slip resistance**, noun: The relative force that resists the tendency of the shoe or foot to slide along the walkway surface. Slip resistance is related to a combination of factors, including the walkway surface, the footwear bottom, and the presence of foreign materials between them.

- **Slip resistant**, noun: The provision of adequate slip resistance to reduce the likelihood of slip for pedestrians using reasonable care on the walking surface under expected use conditions.

Walkway Safety Guidelines and Standards

A COF of 0.50 or greater is a number commonly cited as the threshold of safety for a walking surface, and standards may include any combination of dry only, wet only, or may not mention either. The 0.50 safety guideline is not new; it has been around for more than 50 years.Here is some background history and supporting references for the 0.50 threshold and how it has been applied in floor products, public buildings, and workplaces.

American National Standards Institute (ANSI)
ANSI/ASSE A1264.2-2006, *Standard for the Provision of Slip Resistance on Walking-Working Surfaces*. This is a voluntary consensus standard that cites a 0.5 slip resistance safety guideline for working and walking floor surfaces for dry floor conditions only. ANSI 1264.2 specifies four slip meters to collect this measurement: the HPS, Brungraber Mark I, Brungraber Mark II,, and English XL. This standard is being revised to remove any mention of tribometers and simply refer

to ASTM F2508. *Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces*. See below.

ANSI/ASSE TR-A1264.3-2007, *Using Variable Angle Tribometers (VATs) for Measurement of Walkway Surfaces*. This technical report provides detailed information on the validity of the VAT class of slip meters, including how they work, how to operate them, recommended thresholds of safety and precision, and ruggedness studies performed.

ANSI/NFSI B101.1-2009, *Test Method for Measuring Wet SCOF of Common Hard-Surface Floor Materials*. This provides wet test values in Table 1, with high ($m\mu \geq 0.60$), moderate ($0.40 \leq m\mu < 0.60$), and minimal ($m\mu < 0.40$) available traction.

The American Society for Testing and Materials (ASTM)

ASTM C1028, *Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull Meter*. This is a test method for determining the COF on brand new ceramic tiles and similar surfaces under wet and dry conditions. Test results can be found in technical specification materials. The horizontal pull dynamometer is essentially a 50-pound drag sled, and the wet test results are controversial.

ASTM D2047, *Test Method for Static Coefficient of Friction of Polish-Coated Surfaces as Measured by the James Machine*. This is one of the few test methods prescribing a minimum criterion of 0.50 SCOF as the threshold of safety. The James Machine is a laboratory-only slip meter and not used in the field. The result is for dry floor surfaces only.

ASTM F609, *Standard Test Method for Using a Horizontal Pull Slipmeter (HPS)*. This is the test method for Liberty Mutual's HPS slip meter. COF results are stated by multiplying the measured Slip Index by 10. For example, 6 or more: relatively non-slippery, 5-6: generally acceptable, 5 or less: relatively slippery. F609 was reaffirmed in late 2005 for dry floors only.

ASTM F1679, *Standard Test Method for Using a Variable Incidence Tribometer (VIT)*. This test method is for the English XL Tribometer. There is no stated COF but above guidelines generally followed by users, i.e., a 0.50 Slip Index or higher. **ASTM F1679 was withdrawn September 2006 but is still available for purchase by ASTM.**

ASTM F1677, *Standard Test Method for Using a Portable Inclineable Articulated Strut Slip Tester (PIAST)*. This test method is for the Brungraber Mk II slip meter. There is no stated COF but above guidelines generally followed by users i.e., a 0.50 SCOF or higher. **ASTM F1677 was withdrawn September 2006 but is still available for purchase by ASTM.**

ASTM F2508, *Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces*. Published in 2011, this is one of the first evidence-based standard practices intended to establish the parameters for validation and calibration of walkway tribometers using a suite of reference surfaces. Tribometers need to statistically rank and differentiate between the surfaces to be in calibration. References for ASTM F2508 include:

- Powers, C.M., Brault, J.R., Stefanou, M.A., Tsai,J.Y., Flynn, J., and Siegmund, G.P., "Assessment of Walkway Tribometer Readings in Evaluating Slip Resistance: A Gait-Based Approach," *Journal of Forensic Science*, Vol. 52, No. 2, pp 400-405, March 2007.

- Powers, C.M., Blanchette, M.G., Brault, J.R., Flynn, J., and Siegmund, G.P., "Validation of Walkway Tribometers: Establishing a Reference Standard," *Journal of Forensic Science*, Vol. 55, No. 2, pp 366-370, March 2010.

ASTM F2913, *Standard Test Method for Measuring the Coefficient of Friction (Slip Resistance) of Footwear and Test Surfaces/Flooring Using a Whole Shoe Tester*. This was published in 2011; the criteria for footwear test results for quarry tile dry must be no less than 0.4, and quarry tile wet no less than 0.3.

Measuring Slip Resistance

Slipmeters or tribometers allow us to measure relative "slipperiness" of a floor or the friction interface between the shoe sole and the floor surface. What to call the output from a tribometer is subject to considerable debate and varies by manufacturer, but SCOF or simply coefficient of friction (COF) are generic terms commonly used.

What is Stiction?

In tribometry, *stiction* (pronounced *stickshon*) also spelled sticktion, is "the tendency of two surfaces (a test foot) in forceful contact, in the presence of a lubricating interface or contaminant, to bond together if there is a period of time between initial contact and initiation of relative motion, as a result of residence time" (ANSI A1264.2). Simply, stiction occurs when two surfaces are in contact with each other in the presence of water. When the water is squeezed away, the two surfaces have a tendency to "stick" to each other.

A similar but less obvious phenomenon occurs when the test pads of a drag-sled slip meter are in contact with the floor in the presence of water. Water is squeezed away from the test pad surfaces from the weight of the slip meter. In other words, a period of time goes by from when the device is placed on the wet floor to when the horizontal pulling force is applied to obtain the COF or slip index. When the horizontal forces are applied *after* the normal force F_N, stiction can occur. Stiction can artificially increase the SCOF and produce an erroneous measure of slip resistance. In other words, the floor appears to be more slip resistant than it really is.

For this reason, Horizontal Pull Slip meter (HPS) is not recommended for use on wet floors. The Brungraber Mark II, Mark III and English XL slip meters apply the horizontal and vertical forces *at the same time,* thereby eliminating stiction.

Figure 1. Horizontal Pull Slipmeter (HPS)

The HPS was developed by Charles H. Irvine at the Liberty Research Institute for Safety back in the 1960s. The HPS is used to measure slipperiness for clean, dry floors only. Liberty Mutual helped develop ASTM F609, the current test method standard for the HPS (see Figure 1).

The Brungraber Mark II and Mark III, also known as a Portable Inclinable Articulated Strut Slip Testers (PIAST) or class of tribometers called Variable Angle Tribometers (VATs), are used on wet and dry floors. These devices, unlike the HPS, applies the horizontal (F) and vertical (F_N) at the same time, thus eliminating residence time and adhesion effects or stiction. The Brungraber Mark II (Figure 2) and Mark III (Figure 3) report a slip resistance value (COF) result from 0.0 to 1.1.

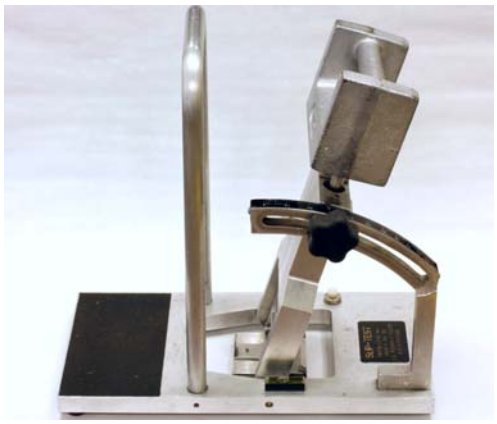

Figure 2. Brungraber Mark II (PIAST)

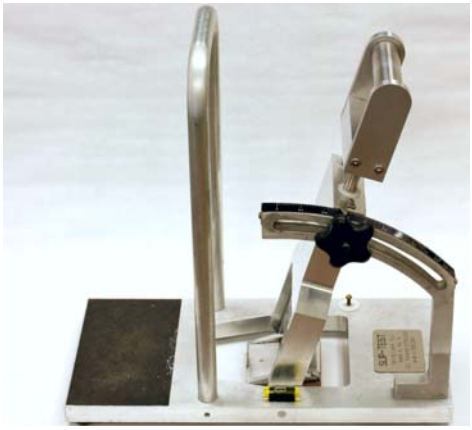

Figure 3. Brungraber Mark III (PIAST)

The English XL, also known as the Variable Incidence Tribometer (VIT). is also a class of tribometer called Variable Angle Tribometers or VAT (see Figure 4). Like the Brungraber, it can be used on both wet and dry floors. Like the Brungraber devices, the English XL is intended to eliminate adhesion associated with dwell time or stiction. The English XL uses a miniature CO2 cartridge, which needs replacement after use. The English XL reports a slip-index value from 0 to 1.

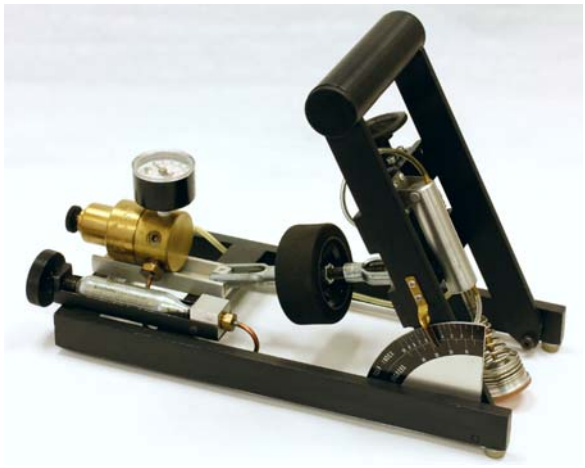

Figure 4. English XL

Final Comments on Tribometers

There is considerable debate going on today as to what the interpretation of "research" means with respect to validation and calibration of tribometers. To be scientifically credible, it is important for researchers to publish their data in the peer-reviewed scientific literature. Unless a study design undergoes the rigor of peer review, it is nothing more than an opinion. A study published as an internal report, a proprietary study, a technical report, in a safety magazine or even a conference proceedings paper is not a scientific study. Differing opinions about a scientific study are not uncommon but unless refuting data is published in a credible scientific journal, then it doesn't officially enter into the scientific argument.

Controls and Solutions

Everyone in the organization must work together to prevent falls. Stakeholder groups in a slip and fall prevention process include facilities management, operations management, risk management, safety, purchasing, occupational health, engineering, maintenance, and housekeeping. Designing facilities to reduce risk by selecting the right flooring, matting systems, cleaning chemicals, footwear and more must be done right the first time. Preventing falls requires a strategy with goals and objectives and managed like other safety hazards and exposures.

Figure 5. Slip and Fall Prevention Process

Incident and Hazard Surveillance

Surveillance is defined as the ongoing, systematic collection, analysis, and interpretation of health and exposure information (NIOSH). For slips and falls that means analysis of:

- *Proactive* or pre-loss hazard and incident data obtained through inspections, observations, employee interviews and self reports etc and,
- *Reactive* or post-loss data such as past accidents and injuries from insurance WC and/or GL claim reports and other accident reports.

Both are essential to a managed safety process and for establishing safety priorities. Understanding past injury trends and existing hazards helps develop results-oriented

objectives and goals. Unfortunately, loss trends, serious injuries and expensive lawsuits (rather than proactive prevention) seem to drive most interventions.

A proactive approach is often under-utilized, but a valuable source of information is unreported incidents, i.e., slips without fall and slips with a fall but without injury. Let's face it, these are embarrassing events; many people fall, brush it off, and move on, leaving the hazard for others to fix or fall victim to. These incidents need to be reported. How many slips and/or falls occur that are not reported? Limited data is available but it is estimated to be many times more than those reported.

For this reason, an essential element of a proactive managed slip and fall prevention is a system to report close-call incidents that didn't cause injury, in combination with hazard information, using that data along with claims and injury cost data to establish safety priorities.

Injury and hazard surveillance also must involve the worker. Three participative safety and health surveillance approaches are recommended to assist managers and safety and health professionals in managing risks associated with slips and falls:

1. **Employee incident reports**: As mentioned, prompt reporting of slips and/or falls with or without injury is important. The American Society for Testing and Materials (ASTM) addresses this issue in ASTM F1694, Standard Guide for Composing Walkway Surface Evaluation and Incident Report Forms for Slips, Stumbles, Trips, and Falls. The standard includes incident reporting guidelines, investigation approaches, information to collect, and sample forms.

2. **Review of existing records**: Records, such as workers' compensation claims reports and OSHA logs, can provide valuable information and should be shared with managers and supervisors. Focusing on this data alone is a reactionary approach bu,t when combined with close-call and hazard information, can provide a good profile of actual and potential loss sources.

3. **Hazard surveys**: Falls can happen in a split second. The challenge in dealing with slips and falls is that physical hazards are dynamic and variable from minute to minute or even second to second! Employee involvement is thus critical. "Clean as you go" policies in the restaurant industry and sweep logs in the retail grocery industry are two examples of programs that recognize the dynamic nature of hazards and correct them immediately. Reporting hazards and cleaning up spills immediately are an important part of a successful slip and fall program.

Housekeeping and Maintenance

Dirty floors and defective floors can cause slips, trips, and falls. Surface roughness is reduced as soil, grease, etc,. fills surface pores or valleys in the floor surface. Defective floors can cause trips and falls and should be repaired. Removing the contaminate and/or water improves traction, thereby, reducing the likelihood of a slip and fall.

Surface roughness offers the best slip resistance on a floor surface. To maintain surface roughness and maximum slip resistance, contaminates need to be removed from floor surfaces. In restaurants, polymerized grease in kitchens and dining areas is difficult to remove unless a cleaning protocol is developed and consistently followed.

Floor surfaces are most slippery when they are wet with grease present. In general, recommendations to remove grease include scrubbing the floor briskly, using a deck brush and

detergent with hot, softened tap water, followed by a wet vacuum or squeegee removal before rinsing. More specifically though, a floor cleaning protocol needs to consider the type of floor, the contaminant involved, and the type cleaning solvent best suitable for each of the above. An effective floor cleaning protocol must also be implemented uniformly and training must be provided to workers.

Types of cleaners include alkaline cleaners, acidic cleaners, neutral pH cleaners, and enzymatic cleaners. Alkaline cleaners react with fats and oils, converting them into soap (saponification) and must be thoroughly rinsed with clean, hot water or they will polymerize. Acidic cleaners use a process called oxide reduction instead of saponification and thus, polymerization cannot occur, and rinsing is less of an issue but still recommended. Neutral cleaners are typically used on glossy finishes or those that can be dulled by the abrasive qualities of acidic or alkaline cleaners. They are usually rinse-free. Enzymatic cleaners use enzymes from non-pathogenic forms of bacteria that consume and digest oil, fat, grease. and petroleum hydrocarbons. No rinsing is required and hot water should *not* be used.

Floor Mats and Runners

Ideally, floor surface materials should be selected that offer the best slip resistance and durability characteristics for the environment in which it will be used. However, mats might be installed when a walking surface does not meet slip resistance requirements, such as when wet or contaminated floors are present. There are two types of matting systems: 1.) entrance mat systems and 2.) multi-purpose mats. The restaurant industry refers to these as "front of the house" and "back of the house" respectively. Examples of "back of the house" mats might be those used around machinery process areas, water fountains, dish areas, near food counters, and where spills may occur.

Whether "front of the house" or "back of the house", a strategy needs to be employed in selecting the right mat for the right environment and the expected contaminant. Many times matting systems are chosen based on cost or simply subcontracted to a vendor for cleaning and replacement. Mats that are dirty, worn, and old offer little slip prevention benefits.

Entrances

Entrances represent unique slips and fall issues. For outdoor walkways at entrances exposed to the elements, consider installing a canopy to reduce snow, ice and water from being tracked into the building.

Entrance floor mats are important as they can improve overall floor maintenance by absorbing moisture and scraping soil particles from footwear, thereby, keeping the floor in a clean dry condition and protecting the floor from excessive wear. A rule of safe practice is that footprints or water prints should not be seen beyond the last mat of an entrance. Mats can protect a floor from unnecessary wear and remove water between the shoe and floor. Can a matting system improve the "Tribology" of a floor? Yes, because friction, lubrication, and wear can be improved by using a properly installed matting system.

The depth of the entrance mat is important. The number of steps required to effectively scrape and wipe feet depends on climate. As climate improves, the demands on floor matting becomes less intense. In snow strategies, a minimum of 10-12 walking steps is a good guide to the depth of floor mat needed. Rain strategies can gauge about 8-10 steps and dry strategies require about 6-8 steps. Mat depth distance would extend from outside overhangs (if any), to vestibules (if any) and walk-off mats inside the building.

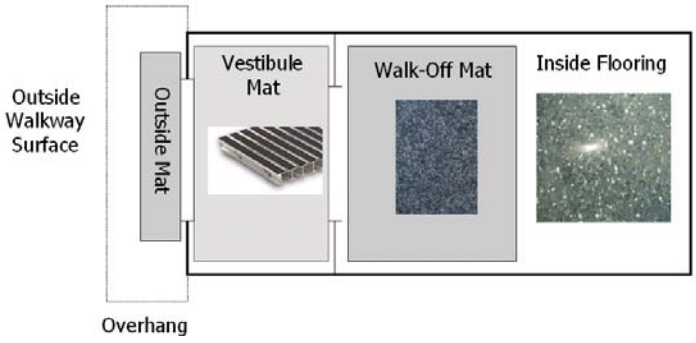

Figure 6. Entrance Mat Strategy: Slip and Fall Prevention

The size of the entrance mat depends on expected foot traffic, moisture and debris. For example, a store that has 1,000 customers a day in a snow strategy needs a larger mat than the same store in a dry strategy.

Multi-purpose mats and runners have varying surfaces including some with slip resistant surfaces. Use the following guidelines when selecting mats:

- Select mats whose edges will not curl by design. These mats often have a beveled edge or a flat edge to reduce tripping exposure.
- Select mats with non-slip backing that resists movement.
- Select mats that guard against damage to underlying floor surface caused by mold and mildew.
- Routinely inspect mats for damage and excess wear, and replace as necessary.
- Store mats or runners to prevent curling of edges.
- Do not place mats or runners against objects that don't allow the mat to lie flat, e.g. machinery and process areas, doors, and furniture.

Floor Surface Selection

The preferred strategy for preventing slips and falls is to select the right floor right the first time. The right floor for the right environment means the floor offers optimum slip-resistant qualities and is durable in high-traffic areas.

There are many different types of flooring, including a variety of tiles, carpeting, epoxy floors, terrazzo, and concrete. In the selection of flooring, one should consider contaminants expected and transition areas. A transition from a carpeted floor or non-slippery floor to a glazed tile or more slippery walking surface could increase the likelihood of a slip and fall due to the individual's lack of detection of the transition (change in slip-resistance) and adjustment of gait accordingly. In general, flooring should have similar slip-resistance properties when transitioning between different types of flooring, especially when liquid contaminants may be present.

Surface roughness affects friction; selection of floor surfaces with adequate roughness characteristics may potentially reduce slip and fall accidents. A rough floor surface offers the best slip resistance. A floor that will be used under mostly dry conditions offers more flexibility in terms of both selection and use, since most dry, clean floors are "slip-resistant" by design. If liquid contaminants are expected on the floor, potential interventions could include molded

surface patterns or profiled surfaces at the macro-scale, or surface roughness at the micro-scale. At the moment, there are few guidelines on surface roughness criteria and slips and falls but this Slip Assessment Tool from the HSE in the UK offers an approach.

Floor Surface Treatments

There are two reasons floor treatments might be applied; 1.) the wrong floor was installed in the first place and a hard lesson is learned, i.e. slips and falls are occurring or 2.) a surface application is desired to improve an existing floor slip resistance. Examples of slip resistant treatments include abrasive floor coatings, chemical etching, carpeting, and slip resistant floor cleaners and polishes:

Abrasive floor coatings and applications provide a rough surface treatment to enhance surface traction and impart greater slip resistance. Cleaning, durability, and cost must be considered. Some inexpensive floor applications can deteriorate or wear away with time and need to be reapplied. Broom-finished concrete floors, certain paints, urethane coatings, and epoxy compounds containing abrasive granules are good examples of durable floors. Abrasive strips wear away quickly and must be replaced often but some newer products can be quite durable.

Chemical etching or Ammonium Biflouride (AB) which has been professionally applied to mineral, porcelain, natural stone, or concrete floors produces microscopic ridges and valleys in the floor and increases surface roughness. Etching produces a higher coefficient of friction with most shoe sole materials. This type of floor can lose its effectiveness if not cleaned thoroughly and frequently.

Carpeting offers inherent slip-resistant qualities, but can be difficult to keep clean and needs to replaced often in high traffic areas.

Slip-resistant floor cleaners, polishes and waxes are available and some have tested and certified their products as to coefficient of friction using ASTM D2047. Most do not certify their products but claim to offer outstanding slip resistance qualities including when wet. The problem with such applications is that they do wear away over time and need to be reapplied.

Slip-Resistant Footwear

Slip-resistant is a specific term given to footwear that reduces likelihood of slipping. Any shoe called "slip-resistant" should have corresponding test data to support the claim. There are no standardized test methods for slip resistance testing of shoes. Terms such as oil, fat, acid, alkaline or skid resistant does not mean slip-resistant.

Most slip-resistant footwear companies perform laboratory testing of their products under "realistic" conditions using wet and oily or greasy quarry tile. The device used is mostly the Brungraber Mark II. The Brungraber devices are preferred because the 3" X 3" test pad surface is larger than the other devices and perfect for attaching a good size sample of soling material.

However this could change with ASTM F2913, *Standard Test Method for Measuring the Coefficient of Friction (Slip Resistance) of Footwear and Test Surfaces/Flooring Using a Whole Shoe Tester*. Published in 2011. ASTM F2913 follows SATRA test method TM144 and STM 603 for the whole shoe tester. This standard could become the test method all U.S. footwear manufacturers will use to classify any sole as slip resistant. Criteria: Footwear test results for Quarry tile dry must be no less than 0.4, and Quarry tile wet no less than 0.3.

Implementing a Slip-Resistant Footwear Program - A slip-resistant footwear program should be in writing and include a written policy for selection, purchase, reimbursement, and replacement of footwear. A slip-resistant footwear policy needs to be customized to meet the **needs** of your organization. Before implementing a slip-resistant footwear program, a good idea is to have legal counsel review the policy for potential legal exposures. Purchasing slip-resistant footwear and specifying who pays is an important decision. The following are common footwear purchase options:

- Company purchase: employer purchases slip-resistant footwear from a specified vendor and workers then pick their sizes. Employer subsidizes the entire cost and specifies the look and style of footwear they want their employees to wear.
- Employee purchase: workers purchase their own footwear from specified vendors or any vendor that meets the specifications defined in the employer's policy. Discounts might be offered for work purchase of shoes from retail outlets or mail order.
- Payroll deduction plans: employees order their own footwear from specified vendor(s) according to the policy and cost is automatically deducted from their paycheck. Footwear vendor(s) work with the company on tracking purchases and providing information for payroll deduction.

Conclusion

Slips and falls are not well understood by many organizations. This in turn leads to prevention approaches that are reactive rather than proactive, only being triggered by undesirable loss trends or expensive injuries. Preventing requires a combined effort among all members of the organization; communication across the entire work system is critical. Focusing on addressing problems at the work system level results in a safer and more productive work environment for everyone involved. Applying tribology concepts in the design of facilities at the design phase is an important proactive approach to prevention and can go a long way toward reducing direct and indirect costs of slip, trip and falls injuries.

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