

October 2014

Key Lessons for Preventing Incidents from Flammable Chemicals in Educational Demonstrations

Eliminating Flash Fire Hazards by Substituting or Minimizing the use of Flammable Chemicals and Performing an Effective Hazard Review Will Prevent Injuries

Key Lessons Summarized:

- Due to flash fire hazards and the potential for serious injuries, do not use bulk containers of flammable chemicals in educational demonstrations when small quantities are sufficient
- Employers should implement strict safety controls when demonstrations necessitate handling hazardous chemicals — including written procedures, effective training, and the required use of appropriate personal protective equipment for all participants
- Conduct a comprehensive hazard review prior to performing any educational demonstration
- Provide a safety barrier between the demonstration and the audience



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Summary

Educational demonstrations involving flammable materials are often performed at schools or museums to engage students and visitors and stimulate their interest in science. On September 3, 2014, a flash fire¹ occurred during a science demonstration at the Terry Lee Wells Nevada Discovery Museum (“The Discovery”) in Reno, Nevada. Thirteen people were injured, including eight children and one adult who were transported to the hospital as a result of the fire. One child was kept overnight for treatment and additional observation.

This incident is one of many the U.S. Chemical Safety Board (CSB) has identified in which lab demonstrations involving flammable materials have resulted in fires and injuries. Methanol, the hazardous chemical involved in The Discovery and two other recent incidents the CSB has investigated, is classified as a highly flammable liquid, and users should adopt strict safety controls.² This safety bulletin is intended to provide information about The Discovery incident and other similar incidents, as well as provide safety guidance to prevent future occurrences.

Key Lessons

- *Bulk containers³ of flammable chemicals should not be in close proximity to potential ignition sources such as open flames.* When planning scientific demonstrations that include flammable chemicals such as methanol, apply the well-established safety concept of the hierarchy of controls,⁴ placing top priority on eliminating flash fire hazards. In many demonstrations this can be accomplished by minimizing the amount of flammable chemicals used to the smallest quantity necessary (prohibiting the presence of bulk containers) or substituting a flammable chemical with a less hazardous substance (one that is not highly flammable). For some demonstrations the risks may be deemed too high or the quantity of flammable chemicals cannot be sufficiently reduced, and alternative approaches to eliminating the flash fire hazard (for example, through video demonstrations) should be considered.
- *Employers should implement strict safety controls when lab demonstrators are handling hazardous materials.* Prior to conducting any activity with flammable chemicals, it is the responsibility of employers to ensure that all presenters are sufficiently trained on (1) all hazards involved with demonstrations, (2) safety procedures, and (3) necessary safety precautions.

¹A flash fire is a fire that spreads rapidly through a diffuse fuel, such as dust, gas, or the vapors of an ignitable liquid, without the production of significant overpressure. National Fire Protection Association (NFPA) 921. *Guide for Fire and Explosion Investigations*, 2014; Section 3.3.81.

²With a flash point of approximately 50°F and a boiling point of approximately 150°F, methanol is a class IB flammable liquid, placing methanol in the second highest Occupational Safety and Health Administration (OSHA) flammability class. Flammability classification is one criteria that should be considered when evaluating for safer alternatives. https://www.osha.gov/dte/library/flammable_liquids/flammable_liquids.html (accessed October 12, 2014). The flash point is the lowest temperature of a liquid at which it gives off vapor at a sufficient rate to support a momentary flame across its surface. National Fire Protection Association (NFPA) 921. *Guide for Fire and Explosion Investigations*, 2014; Section 3.3.82.

³For the purposes of this report a bulk container is any container that is larger than the amount needed for a demonstration. In past incidents the bulk container typically was the original container purchased.

⁴The hierarchy of controls is a system widely used in the petrochemical industry to minimize or eliminate hazards.

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- *Prior to performing any activity with flammable chemicals, conduct a thorough hazard review. Take into account all flammability hazards and any other hazards which might possibly occur during the demonstration. Prepare a written procedure that describes all of the activity details and all of the required safety precautions (e.g. minimum personal protective equipment (PPE) requirements, safety barriers, chemical handling requirements, etc.).*
 - *Provide a safety barrier between any activity involving flammable chemicals and any audience or bystanders. Preferably, this would be a physical barrier, such as a clear shield. Alternatively, the barrier could be a minimum safe distance between the activity and the audience, established during the hazard review.*
 - *Any person inside the barrier during a chemical demonstration activity, such as the person performing the activity, must wear all appropriate personal protective equipment. Examples include gloves, safety glasses with side shields, face shields, and lab coats or clothing made of flame-resistant material.*

The Discovery Demonstration Description

A science demonstration called the “Fire Tornado” was regularly performed at The Discovery (Figure 1). The Fire Tornado demonstration is comprised of three smaller demonstrations performed sequentially to produce different colored flame “tornadoes.” Each demonstration involves igniting flammable isopropanol (rubbing alcohol) or methanol in the presence of a chemical additive to produce an orange, red, or green colored flame six to twelve inches in height. The green tornado that results from a methanol flame in the presence of boric acid (a common ant and roach killer) is shown in Figure 2. The Fire Tornado demonstration is intended to educate the audience on how tornadoes form and about the chemical properties of the materials involved.

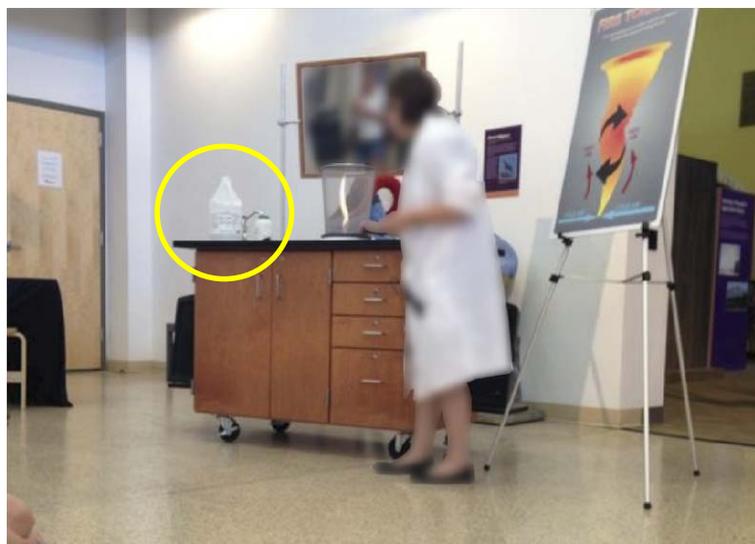


Figure 1. Fire tornado demonstration on the day of the incident⁵. The four-liter bulk methanol container can be seen on the front left corner of the table (circled in yellow).



Figure 2. Boric Acid Fire Tornado with methanol⁶

The basic procedure for all three demonstration variations, described below, is the same. Only the fuel source and color additive are changed.

⁵ <http://www.rgj.com/story/news/2014/09/03/explosion-reported-in-reno/15044399/> (accessed September 4, 2014).

⁶ <http://chemistry.about.com/od/coloredfire/a/Green-Fire-Whirlwind.htm> (accessed September 4, 2014).

- A cotton ball is placed on a glass dish and the fuel (isopropanol or methanol) is added to the dish to saturate the cotton ball;
- The color additive (strontium nitrate or boric acid) is added or sprinkled onto the cotton ball;
- The dish is placed on a turntable and the cotton ball is ignited using a barbeque-type butane lighter;
- The dish and burning cotton ball are covered using a wire mesh waste basket; and
- The educator⁷ spins the turntable, thus spinning the burning cotton ball and wire mesh basket, creating the tornado effect.

After each fire tornado is produced, the wire mesh basket is removed, the dish is placed to the side, and a new dish is brought out to repeat the process with new chemicals.

Incident Description

On September, 3, 2014, at approximately 4:00 pm, an educator was performing the Fire Tornado demonstration for a group of visitors consisting primarily of young children. The visitors were seated on the floor approximately 15 feet away from the demonstration. The first two variations of the demonstration were performed without incident. During the third variation, the educator held the lighter flame to the cotton ball, but the expected fuel flame did not rise. The educator realized that methanol fuel had not been added to the cotton ball. The educator attempted to pour a small amount of methanol from a four-liter (about one gallon) bulk methanol container onto the cotton ball. Although there had been no sign of flame from the cotton ball, it is likely that the lighter had actually ignited the cotton, and it was smoldering. The poured methanol ignited immediately, and then flashed back into the methanol container. The methanol inside the container then ignited, resulting in a pressure rise that expelled a large flame from the mouth of the container, causing a large flash fire (Figure 3). The educator dropped the methanol container after it caught fire. The container spilled, and burning methanol spread toward the audience, catching some members of the audience on fire. In response to the fire, two of The Discovery employees acted quickly, extinguishing the fire using a nearby fire extinguisher and fire blanket. The burned remains of the bulk methanol container used can be seen in Figure 4.



Figure 3. Methanol igniting on the day of the incident⁸

⁷ “Educator” is a term used by the museum to describe a museum staff employee whose job duties include visitor interaction and performing demonstrations. The educators do not write the procedures for the demonstrations, they only perform them.

⁸ <http://www.nbcnews.com/watch/nightly-news/video-shows-dangerous-accident-at-childrens-museum-325405251630> (accessed September 11, 2014).

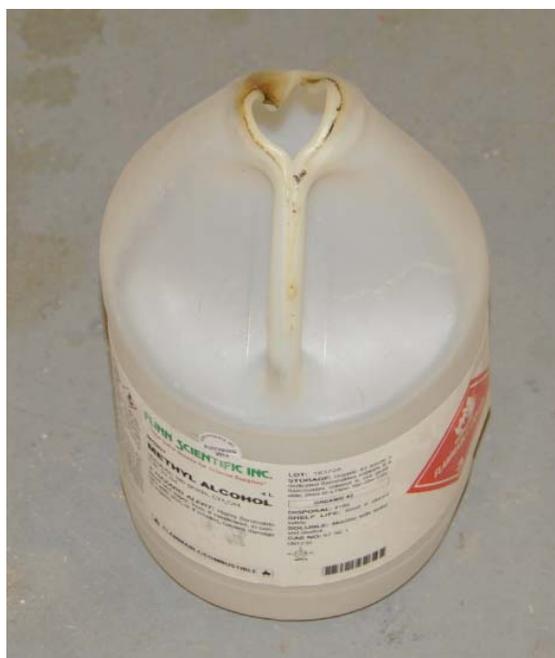


Figure 4. Methanol container following the incident

Demonstration Analysis

The Discovery has approximately 14 demonstrations that its educators perform on a regular basis. Five of these demonstrations involve the ignition of flammable chemicals such as methanol, hydrogen, and methane. To prevent serious injuries, the risks associated with these flammable chemicals should be analyzed and controlled, especially when associated with demonstrations performed in front of an audience. Despite the inherent flammability of methanol, no effective hazard review was ever carried out by The Discovery for any of the demonstrations. The CSB learned that neither The Discovery educators nor their managers had experience or were expected to perform hazard analyses.

As a result of not performing an effective hazard review, the Fire Tornado demonstration procedure lacked sufficient safety precautions. For example, during the initial demonstration training, educators were told verbally to first pour the methanol from the bulk container into a small beaker in a separate room. However, the written procedure for the Fire Tornado demonstration did not contain such a requirement. Had the demonstration procedure included this requirement, the likelihood that the flash fire would have reached the audience would have been substantially minimized, if not eliminated.

The lack of an effective hazard analysis and formal safety procedures resulted in a normalization⁹ of the improper use of the four-liter bulk methanol container during the Fire Tornado demonstrations. The

⁹ Normalization of deviance is the acceptance of events that are not supposed to happen. Objective outside observers view the given situation as abnormal or deviant, whereas those individuals on the inside become accustomed to it and view it as normal and acceptable. *See* Interview: Diane Vaughan, Consulting Newsline, May, 2008.

[http://www.consultingnewsline.com/Info/Vie%20du%20Conseil/Le%20Consultant%20du%20mois/Diane%20Vaughan%20\(English\).html](http://www.consultingnewsline.com/Info/Vie%20du%20Conseil/Le%20Consultant%20du%20mois/Diane%20Vaughan%20(English).html) (accessed October 7, 2014).

Discovery has a storage cabinet for flammable chemicals in the basement of the facility where the methanol was intended to be stored. Prior to performing the Fire Tornado demonstration, the methanol was originally brought upstairs to an adjacent room near the demonstration area in order to provide educators more convenient access for filling the beaker. The beaker of methanol was then used in the demonstration and the bulk methanol container remained in the adjacent room. When demonstrations were over, the bulk methanol container would be returned to the basement cabinet.

More recently, some educators began bringing the bulk methanol container to the demonstration to show the audience. These educators stopped transferring the methanol to the beakers and instead soaked the cotton balls directly from the bulk methanol container during the demonstration. In fact, when the educator who performed the Fire Tornado demonstration on the day of the incident received the initial demonstration training, the beakers were not used and the cotton balls were soaked with methanol straight from the bulk methanol container. As a result, this was the practice the educator used on the day of the incident. As previously mentioned, the written Fire Tornado demonstration procedure did not require the use of a beaker for methanol transfer. It provided no warnings about storing the methanol container outside of the flammables cabinet, or about using it directly during the demonstration.

The CSB also learned that the training provided to the educators did not effectively emphasize the inherent methanol flammability hazards. Due to The Discovery staff's lack of understanding and appreciation for the flammable hazards of methanol, the demonstration procedures and training focused primarily on the best ways for educators to interact with the audience and communicate science findings. Insufficient emphasis was placed on the safe use of methanol and other flammable materials during the demonstrations. In fact, periodic evaluations focused on presenting an engaging demonstration rather than ensuring good safety practices during demonstrations. For example, displaying the bulk methanol container to the audience, tone of voice, clear explanation of the science principles, and enthusiasm about the demonstration were highly valued features of the presentation.

The Discovery did not emphasize the importance of the use of a small container with a minimum amount of methanol during the demonstration. However, the CSB determined that only a few milliliters of methanol were actually needed to perform the Fire Tornado demonstration. The quantity of methanol could have been minimized by pre-moistening the cotton balls with methanol prior to the demonstration.

Related Educational Demonstration Incidents

The incident at The Discovery is not an isolated event. Incidents involving demonstrations that use flammable materials and an open flame have occurred across the country. Just recently, the CSB has investigated three methanol demonstration incidents that occurred within 48 days of each other.

In December 2013, the CSB issued a safety message video about a 2006 incident similar to The Discovery incident.¹⁰ Ohio high school students were severely burned when a demonstration called the "Rainbow" experiment resulted in a flash fire. The Rainbow demonstration also used various chemicals and methanol to produce different colored flames. When the flame did not rise as desired, the instructor added methanol directly from a four-liter container and the methanol in the container ignited. More

¹⁰ This video can be found at <http://www.csb.gov/videos/> and is entitled *After the Rainbow*.

recently, in January 2014, the same Rainbow demonstration resulted in two New York high school students being burned.¹¹

As a result of the continued occurrences of injuries caused by methanol demonstrations, the American Chemical Society issued a Safety Alert to recommend that demonstrations on open surfaces (outside of a chemical fume hood¹²) involving the use of flammable solvents such as methanol should be immediately discontinued due to the “unacceptable risk of flash fire and deflagrations¹³ that can cause serious injuries to students and teachers.”¹⁴ The ACS Safety Alert also informs recipients of safer demonstration alternatives if it is determined that the demonstrations must be conducted for educational purposes.

On September 15, 2014, only 12 days after the incident at The Discovery, an incident involving a methanol flash fire occurred at the STRIVE Preparatory School (“STRIVE”) — a high school in Denver, Colorado. This incident resulted in four students being burned in the flash fire, one seriously. Similar to the other incidents discussed above, a chemistry teacher, a recent college graduate who had just started his teaching career, was giving a demonstration on flammable properties by igniting a small pool of methanol to create a flame in front of students. When the flame did not rise as high as he had hoped, he added additional methanol to the flame from a four-liter bulk container. The small flame flashed back into the bulk methanol container and formed a flash fire that shot out about 12 feet and hit a student in the chest, resulting in serious burn injuries to the student. Three other nearby students were also injured in the flash fire.

The CSB found in its investigation of the STRIVE incident that the school lacked adequate safety procedures and a lab safety training program. Also, the teacher was not aware of the potential for a methanol flash fire and had received no training about the hazards involved with demonstrations involving large quantities of methanol or other flammable materials. School officials acknowledged that training, procedures, and personal protective equipment were not provided, but they believed that the teacher had the appropriate level of training and experience to conduct laboratory experiments based on the fact that the teacher obtained a Bachelors degree in Chemistry and gained some experience supervising college chemistry labs. However, the CSB identified in its investigation of the January 7, 2010, Texas Tech University research lab explosion that graduates of university chemistry programs are often only introduced to limited, basic safety training that may not be effective beyond “cookbook” laboratory work with well-understood and defined risks.¹⁵ As such, employers should not rely on college level experience in lieu of an effective safety management system that ensures effective oversight, hazard assessments, training, and procedures.

¹¹ <http://newyork.cbslocal.com/2014/01/02/students-treated-for-burns-as-uws-high-school-chemistry-experiment-goes-awry/> (accessed September 12, 2014).

¹² Laboratory safety chemical fume hoods are often the primary control device for protecting laboratory workers when working with flammable chemicals. See <https://www.osha.gov/Publications/laboratory/OSHAquickfacts-lab-safety-chemical-fume-hoods.pdf> (accessed October 15, 2014).

¹³ A deflagration is the propagation of a flame at a velocity that is less than the speed of sound. NFPA 921. *Guide for Fire and Explosion Investigations*, 2008.

¹⁴ American Chemical Society (ACS). *Safety Alert Rainbow Demonstration*. <http://www.acs.org/content/acs/en/about/governance/committees/chemicalsafety/safety-alert-rainbow-demonstration.html> (accessed October 7, 2014).

¹⁵ U.S. Chemical Safety Board (CSB). *Case Study: Texas Tech Laboratory Explosion*. See http://www.csb.gov/assets/1/19/CSB_Study_TTU_.pdf (accessed October 17, 2014).

On October 20, 2014, less than five weeks after the incident at STRIVE, three Cub Scouts¹⁶ and one adult were injured during a demonstration at a Cub Scout event in Raymond, Illinois. This incident occurred when methanol¹⁷ was poured from a container onto boric acid near an open flame. Similar to other incidents, the flame propagated back into the bottle and resulted in a flash fire that burned members of the group and seriously injured one Cub Scout. Like The Discovery incident, this demonstration involved burning methanol with boric acid to produce a green colored flame.

Flash Fire Hazard

Flammable liquids such as methanol or other alcohols used in educational demonstrations are capable of igniting and forming a fire that can cause severe burn injuries and property damage. These liquids are often used because of their desired flammable properties. Frequently, however, the educator is not aware that the flammable materials used can cause fires that are much more dangerous than a small flame. One type of fire that is common with methanol lab incidents is a flash fire. A flash fire occurs when the combustion of a flammable gas and air mixture produces a fire that does not last very long but may be large.¹⁸ Also, if a flash fire burns back to its source, such as a large methanol container, a jet fire can form that can spray a long distance (illustrated in Figure 3 above), which is what occurred in both The Discovery and Denver high school incidents. Any educators who perform scientific demonstrations with flammable materials capable of causing a fire in the open atmosphere of a lab should be aware of the hazards and trained in methods to prevent flash fires from occurring.

Safety Programs

Educational chemical demonstrations are valuable in that they help teach important science concepts in ways that make lasting impressions and help inspire students to become involved in science. When performing demonstrations that use hazardous chemicals, care must be taken to make sure these activities are conducted as safely as possible. The hazards involved need to be identified and adequately addressed before demonstrations involving flammable materials are performed in front of children and audiences of any age. A hazard review should be completed prior to performing any chemical demonstrations to identify potential hazards and risk mitigation strategies (Figure 5), such as minimizing bulk material, using a safety barrier, and wearing appropriate personal protection equipment.

¹⁶ Cub Scouts is a program of the Boy Scouts of America intended for boys aged seven to ten. *See* <http://www.scouting.org/scoutsourc/CubScouts/FAQS/program.aspx#aa> (accessed October 23, 2014).

¹⁷ The source of the methanol was a 12-ounce bottle of HEET®. HEET® is a gas line antifreeze and water remover that is readily available at auto supply stores and contains 99 weight percent methanol. *See* <http://www.goldeagle.com/brands/heet> and <http://complyplus.grainger.com/grainger/msds.asp?sheetid=2986281> (accessed October 23, 2014).

¹⁸ When a flash fire occurs it can expand the cloud volume of the flammable material through combustion heat by a factor of eight. CCPS. *Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards, 2nd Edition*, Chapter 5, 2010.

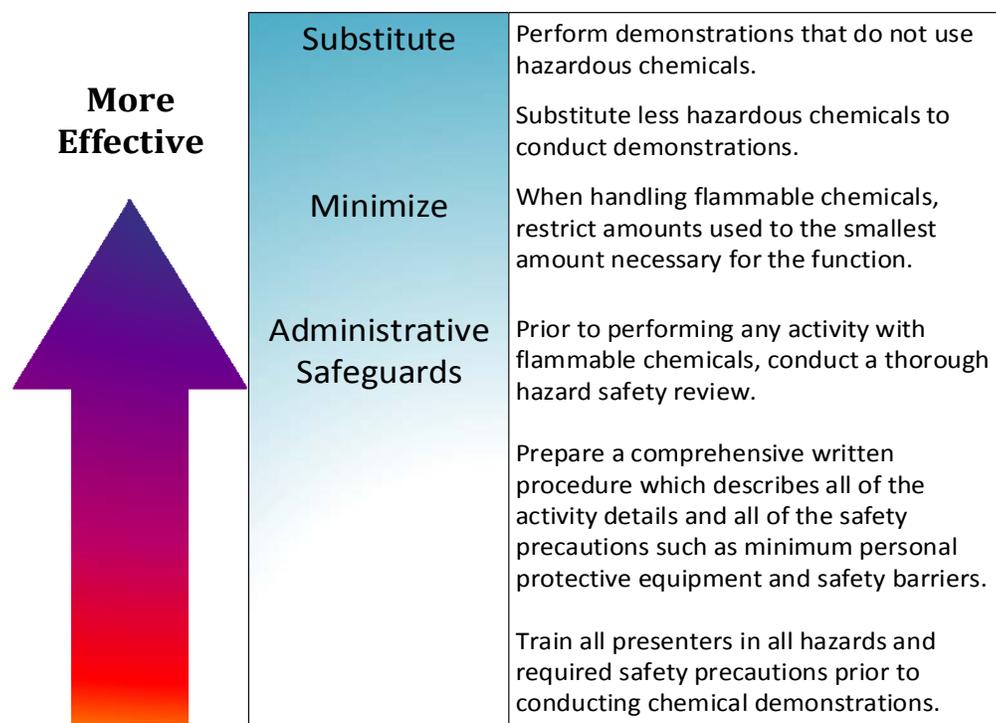


Figure 5. Risk reduction examples for science demonstrations involving flammable chemicals

Not all prevention and mitigation strategies offer the same level of protection from an incident. The safety potential of various strategies can be ranked from most to least effective, a concept known as the ‘hierarchy of controls’.¹⁹ As depicted in Figure 6, the further left on the hierarchy chain, the more effective the technique is in reducing risk, or ensuring safety. Two highly effective risk reduction techniques on the hierarchy of controls would be to eliminate the flash fire hazards by substituting²⁰ a less hazardous chemical or minimizing the amount of hazardous chemical used in a chemical demonstration. For some demonstrations the risks may be deemed too high, or the quantity of flammable chemicals cannot be sufficiently reduced and alternative approaches to eliminating the flash fire hazard (for example, through video demonstrations) should be considered. Lower risk reduction actions include administrative safeguards that help prevent or mitigate an incident involving hazardous chemicals such as training, comprehensive procedures, and wearing personal protective equipment. Even if a greater risk-reduction action, such as substitution of a less hazardous chemical, is used, it is still important to maintain other, lower level, administrative controls. This way even if one risk reduction system fails, others are in place to prevent an incident. It is important for managers to ensure that these methods used for safer chemical demonstrations remain in place and are followed.

¹⁹ Prevention and mitigation strategies represent the safeguards designed to eliminate, prevent, reduce, or mitigate a scenario; they are also referred to as barriers, layers of protection, lines of defense, or control measures.

²⁰ One example for a substitution of the colored flame methanol experiments would be to soak wooden splints in salt solutions and then burn the wooden splints in a Bunsen burner to generate different colored flames.

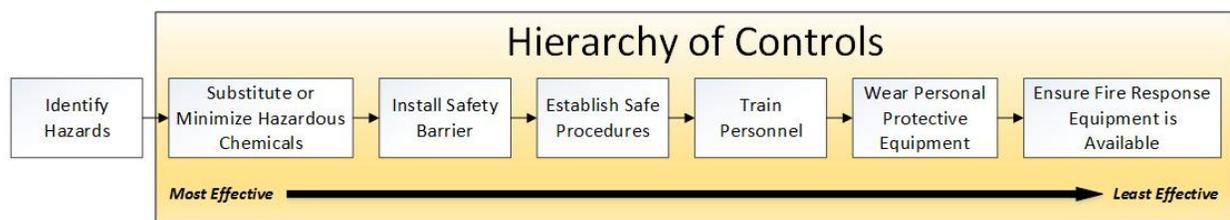


Figure 6. The effectiveness ranking of preventative measures is often referred to as the “Hierarchy of Controls.” Schematic developed from concept presented in Kletz, Trevor; Amyotte, Paul. *Process Plants: A Handbook for Inherently Safer Design*, 2nd ed; 2010.

Employers and organizational leaders (e.g, school districts, school principals, museum directors, etc.) are responsible for ensuring strict controls and effective safety programs are in place to prevent incidents. For example, leaders should require and ensure that hazard reviews are performed and that there is an effective safety training program for all personnel conducting demonstrations. Educators performing demonstrations should receive training that details the risks involved in the demonstrations and the proper use of safety precautions to minimize risks. Management should also ensure that comprehensive procedures as well as hazard reviews are updated on a regular basis or as new demonstrations are added. In both The Discovery and Denver high school incidents, if effective safety programs had been in place, the educators and demonstrators would have been aware of the hazards of methanol and also known how to safely perform demonstrations to minimize the risk of creating a large flash fire.

Resources

There are a number of online resources for educators to find safety information for educational demonstrations. The U.S. Department of Health & Human Services has a repository of resources for chemical laboratory safety, K-12 school laboratory safety, and hazard analysis at <http://sis.nlm.nih.gov/enviro/labsafety.html>. In addition, the National Science Teachers Association has resources for classroom laboratory safety at <http://www.nsta.org/safety/>. These are only two of many online resources available to educators.

Another resource for educators to learn more about hazards is from flammable chemical manufacturers. The manufacturers are knowledgeable about the flammability hazards and best practices to reduce the risk of incident during educational demonstrations. Educational institutes should contact chemical manufacturers to obtain information about the hazards of chemicals used in educational demonstrations and the best methods available to reduce those hazards.

A number of organizations promote laboratory and classroom safety and should communicate safety lessons and provide guidance to their constituents. These organizations should be proactive about distributing laboratory safety information to their members. These include:

- American Chemical Society: A congressionally chartered independent membership organization which represents professionals in all fields of chemistry and has more than 160,000 members (www.acs.org).

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- National Science Teachers Association: The largest organization in the world committed to promoting excellence and innovation in science teaching and learning and has 55,000 members (www.nsta.org).
 - National Education Association: America's largest professional employee organization that is committed to advancing the cause of public education and has 3 million members (www.nea.org).
 - American Federation of Teachers: A professional employee organization for teachers and has 1.6 million members (www.aft.org).
 - National Science Foundation: An independent federal agency that promotes the progress of science (www.nsf.gov).
 - Association of Science-Technology Centers: A nonprofit organization of science centers and museums dedicated to furthering public engagement with science (www.astc.org).
 - National Parent Teacher Association: A nonprofit association that is a strong advocate for public education, a resource for families and communities, and a voice for children (www.pta.org).
 - Association for Science Teacher Education: A nonprofit association that promotes leadership and support for educational professionals, especially science teachers (www.theaste.org).
 - American Association of Chemistry Teachers: A professional community by and for K–12 teachers of chemistry (<http://www.teachchemistry.org>).

CSB Investigation Reports are formal detailed reports on significant chemical accidents and include key findings, root causes, and safety recommendations. CSB Hazard Investigations are broader studies of significant chemical hazards. CSB Safety Bulletins are short general interest publications that provide new or noteworthy information on preventing chemical accidents. CSB Case Studies are short reports on specific accidents and include a discussion of relevant prevention practices. All reports may contain safety recommendations if appropriate. CSB Investigation Digests are plain-language summaries of Investigation Reports.

The U.S. Chemical Safety and Hazard Investigation Board (CSB) is an independent Federal agency whose mission is to ensure the safety of workers, the public, and the environment by investigating and preventing chemical incidents. The CSB is a scientific investigative organization; it is not an enforcement or regulatory body. Established by the Clean Air Act Amendments of 1990, the CSB is responsible for determining the root and contributing causes of accidents, issuing safety recommendations, studying chemical safety issues, and evaluating the effectiveness of other government agencies involved in chemical safety.

No part of the conclusions, findings, or recommendations of the CSB relating to any chemical accident may be admitted as evidence or used in any action or suit for damages. See 42 U.S.C. § 7412(r)(6)(G). The CSB makes public its actions and decisions through investigation reports, summary reports, safety bulletins, safety recommendations, case studies, incident digests, special technical publications, and statistical reviews. More information about the CSB is available at www.csb.gov.

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