ACS
Chemistry for Life®

Periodic Table of the Elements of Safety

R.A.M.P. is an acronym developed by Robert H. Hill Jr. and David C. Finster to help researchers, educators and students remember the four key elements of laboratory safety: Recognize, Assess, Minimize and Prepare.

- **Recognize** common laboratory hazards. Do this by identifying hazards and understanding why they are dangerous.
- **Assess** the risks before, during and after an experiment. Assessing risk includes evaluating how you might be exposed to the hazard and what the probable results of that exposure would be.
- **Minimize** your risk of exposure utilizing substitution, personal protective equipment, proper disposal practices and other control measures.
- **Prepare** for emergencies should they occur. Have an emergency response plan and the proper safety equipment in place. Practice emergency drills and use of equipment.

R Recognize | Hazard Communication Pictograms | Physical Hazards | Behavioral Hazards | A Assess | Risk Assessment Tools | M Minimize | Substitutions | Engineering Controls | Administrative Controls | Personal Protective Equipment | P Prepare | Response Plans

The Hierarchy of Controls is a hazard prevention and mitigation system organized along a scale from most comprehensive (hazard removal and replacement) to protection from unavoidable hazards. The hierarchy lays out a system whereby inherently safer systems are implemented before moving to higher-risk solutions.

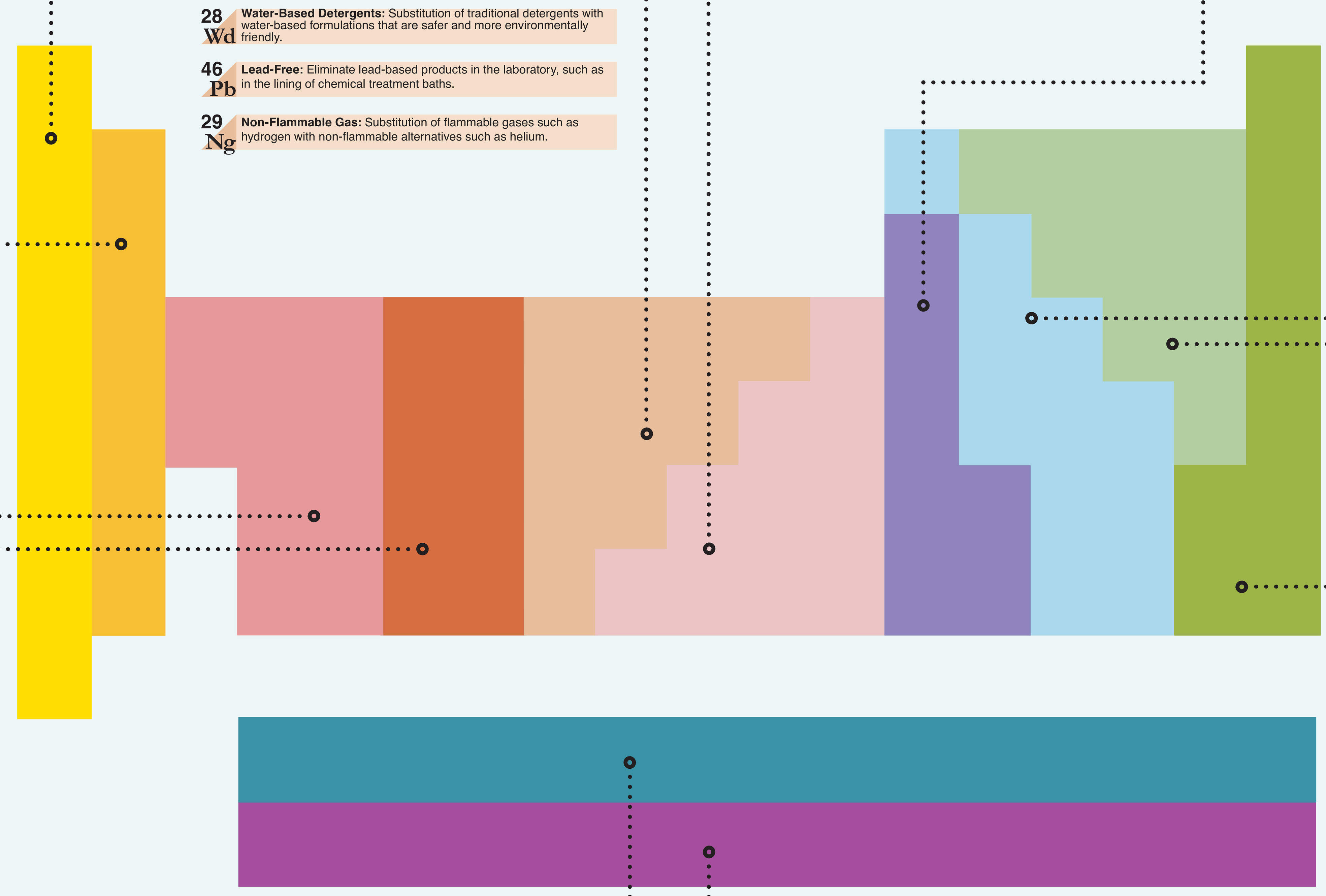
Elimination: Eliminate hazards during the design or development stage by finding safer ways to achieve project goals.

Substitution: Replace the hazard with something safer.

Engineering: Isolate the hazard from the people.

Administrative: Change the way people work with procedures limiting the amount and duration of exposure.

Personal Protective Equipment (PPE): Protect the worker with personal protective equipment.



Hazard Communication Pictograms

The international Globally Harmonized System of Classification and Labelling of Chemicals includes hazard pictograms to warn of the chief hazardous properties of chemical substances.

1 **Health Hazard:** A cancer-causing agent or substance with respiratory, reproductive or organ toxicity that causes damage over time.

3 **Flame:** Flammable materials or substances liable to self-ignite when exposed to water or air (pyrophoric), or which emit flammable gas.

11 **Harmful:** An immediate skin, eye or respiratory tract irritant, or narcotic.

19 **Explosion:** Explosives, including organic peroxides and highly unstable material at risk of exploding even without exposure to air.

37 **Corrosives:** Materials causing skin corrosion/burns or eye damage on contact, or that are corrosive to metals.

55 **Oxidizing:** Chemicals that facilitate burning or make fires burn hotter and longer.

87 **Environmental Hazard:** Chemicals toxic to aquatic wildlife.

119 **Acute Toxicity:** Substances, such as poisons and highly concentrated acids, which have an immediate and severe toxic effect.

Physical Hazards

Laboratory hazards that can cause bodily harm.

4 Tp **Temperature:** Extremely high or low temperatures.

12 Pr **Pressure:** High-pressure hazards including those associated with gas cylinders and dewars.

20 Vo **Voltage:** Electrical hazards.

38 Pi **Pinch Point:** Risk of body part, hair, clothes or jewelry being caught between two objects.

56 Tr **Trip Risk:** Cords, tubing, wires, and other objects located in foot traffic areas; unmarked stairs or uneven flooring.

88 Sa **Sharps:** Needles, glass and other materials that can penetrate the skin or eyes.

Behavioral Hazards

Hazards resulting from unsafe behaviors in the laboratory.

21 Uc **Unlabeled Chemicals:** Improper or missing labels leading to misidentification of substances.

39 Hk **Poor Housekeeping:** Dirty or disorganized work spaces.

22 Ea **Eating and Drinking:** Storing, bringing, or ingesting consumables in the lab.

40 Pm **Pipetting by Mouth:** Transfer of liquids using suction by mouth.

72 Bl **Bare Legs:** Lack of a layer of clothing for protection against skin exposure.

104 Hp **Horseplay:** Playing games or roughhousing in the lab.

23 We **Wearing Earbuds:** Contributes to distraction and makes it difficult to hear if something is going wrong or if a lab partner needs help.

41 Al **Working Alone:** Inability to get help if rendered unconscious or incapacitated.

73 Os **Open-Toe Shoes:** Improper lab attire for the feet.

105 Pp **Open Undated Peroxides:** Explosion and fire risk from peroxide formation in chemicals stored too long without being tested.

Risk Assessment Techniques

Strategies for assessing and reducing risk.

24 Ol **Original Label:** Information provided on manufacturer's labels.

42 Sd **Safety Data Sheet:** Mandated information distributed for each hazardous substance with detailed information on risks, handling, exposure controls, and first aid.

74 Sm **Survey Meter:** Measures various forms of contamination in the lab environment.

106 Ts **Test Strips:** Used to test for presence of peroxides or other unwanted materials in solutions.

25 Wi **What If:** Questions used in risk analysis to identify weaknesses in planning or design.

43 Bt **Bowtie:** Method of visualizing risk using diagram outlining threats, preventative measures, outcomes and consequences.

75 Cl **Checklist:** Hazard mitigation through use of checklist to avoid oversights and unconscious errors.

107 Ja **Job Hazard Analysis:** Method to identify potential hazards and determine preventative measures.

Substitutions

26 Re **Remove Hazard:** Eliminate hazard or replace with non-hazardous alternative.

44 De **Prevention Through Design:** Change design to eliminate the hazard.

76 Au **Automation:** Use machines to eliminate human contact with hazard.

108 Ef **Eliminate Open Flames:** Remove hazard through design changes or substitution of other methods for heating and sterilization.

27 As **Aqueous Substitute:** Utilize water-based alternatives to toxic heavy liquids such as substituting sodium polytungstate for bromoform.

45 Pw **Powder Substitute:** Substitute liquids for toxic powdered substances that can easily become aerosolized.

77 Cr **Cryogen Free:** Provide cooling without the use of cryogenic liquids such as liquid nitrogen or liquid helium.

28 Wd **Water-Based Detergents:** Substitution of traditional detergents with water-based formulations that are safer and more environmentally friendly.

46 Pb **Lead-Free:** Eliminate lead-based products in the laboratory, such as in the lining of chemical treatment baths.

29 Ng **Non-Flammable Gas:** Substitution of flammable gases such as hydrogen with non-flammable alternatives such as helium.

Engineering Controls

109 Gb **Glove Box:** Provides enclosed, controlled environment for safe handling of laboratory samples.

78 Fr **Flammable-Safe Refrigerator:** Fire- and explosion-proof refrigerators are engineered for safe storage of volatile flammable materials and reagents.

110 Fh **Fume Hood:** Fume hoods contain and ventilate vapors, dust, gases and fumes generated within the hood.

47 Il **Interlock:** Mechanism that prevents unintended access to a location or hazard.

79 Dd **Downdraft Table:** Workbench with built-in ventilation to capture and filter dust, smoke and fumes from materials being worked on.

111 Mg **Machine Guarding:** Prevents pinch-point injuries in laboratory equipment. Also safeguards against objects falling into equipment.

30 Bs **Blast Shield:** Transparent shields guard against airborne debris and accidental sprays.

48 Sc **Secondary Containment:** Extra level of protection against spills and leakage provided by trays, absorbents and other engineered systems.

80 St **Saw Stop:** Technology that stops and retracts a rotating blade when it comes in contact with a finger or other body part.

112 So **Shut-Off Switch:** Allows for quick shut off of power to equipment in the case of a spill or other incident creating electrical risk.

Administrative Controls

13 Ws **Work Scheduling:** Setting and adhering to schedules contributes to worker safety and efficiency and may limit exposure to materials.

31 T **Training:** Comprehensive training is critical to safety operations.

49 Lt **Lock-Out Tag-Out:** Procedure to ensure equipment is properly shut off and not able to be started up again prior to the completion of maintenance or repair work.

81 Cb **Control Banding:** Risk assessment approach that groups hazards by control measure, handling procedure or characteristic.

113 S **Segregate Chemicals:** Separate chemicals by hazard class to avoid storing or mixing incompatible chemicals.

82 Sp **Standard Operating Procedures:** A written set of mandatory instructions for how to safely work with hazardous materials or operations.

114 Po **Policies:** Policies governing proper lab procedure, access and monitoring are essential to any safety operation.

Personal Protective Equipment

5 Ts **Tyvek Suit:** Head-to-toe covering for clean rooms and other environments where outside contamination must be prevented.

14 Fs **Face Shield:** Covers face and neck to offer maximum splash protection. Often used in combination with splash goggles to provide extra level of protection.

32 Lp **Long Pants:** Pants covering the entire leg to the ankle. Avoid synthetic fibers, which can melt if ignited.

50 Lc **Lab Coat:** Long-sleeved coat covering skin and clothing, sometimes made of chemical-resistant or flame-retardant material (e.g. Nomex).

33 Ct **Closed-toe Shoes:** Shoes worn in the lab must completely cover the foot and should be made of a non-porous material.

51 Ap **Apron:** When worn with lab coat, chemical-resistant aprons and smocks provide an extra layer of protection.

83 G **Gloves:** Various types offer range of protection from disposable nitrile to chemically-resistant neoprene and silver coated, depending on the chemical and duration of use.

115 Rs **Respirator:** Tight-fitting respirators are used when engineering controls are insufficient to mitigate an inhalation hazard.

52 Gg **Goggles:** Tight-fitting eyewear for protection from splash hazards.

84 Ep **Safety Glasses:** Lighter-fitting protective eyewear for protection from particulates, flying debris, or minor splashes.

116 Uv **UV Protection:** Eyewear and skin covering to prevent damage from ultraviolet rays.

Response Plans

6 Ll **Lessons Learned:** Following any incident or near-miss, analyze the root causes and share lessons learned to avoid similar incidents.

7 Am **Amalgam Powder:** Key component of a mercury spill kit. When mixed with water, the powder solidifies the spilled mercury into a scoopable mass.

15 Fe **Fire Extinguisher:** With proper training, appropriate for fighting small, incipient stage fires.

8 Ca **Calcium Gluconate:** Gel used in first aid treatment for exposure to hydrofluoric acid.

16 Pg **Polyethylene Glycol:** Substance used in first aid treatment for exposure to phenol.

34 Ew **Eye Wash:** Flushing with water is the primary first aid for chemical exposure to the eyes.

9 Sk **Spill Kit:** Used for response to various types of spills.

17 Fa **First Aid Kit:** Keep on hand for treatment of minor injuries. Be sure to report any injury to your supervisor, teacher, principal investigator, or lab manager, no matter how small.

35 Rp **Response Plans:** Emergency response protocols should be developed and available in every lab, including emergency contact numbers and detailed instructions for specific scenarios.

53 Sh **Safety Shower:** Must be located within 100 feet or 10 seconds from any chemical use area.

Green Chemistry

85 Ch **Chemical Substitutes:** Substitute safer materials for polluting or toxic substances whenever possible.

117 C **Cold Storage:** Updating refrigerators, cleaning door seals and filters, disposing of unneeded materials and consolidation of chemicals and reagents are all good ways to reduce energy costs.

2 Cs **Close Sash:** Close the sash on a fume hood when not in use to reduce electricity consumption in the lab.

10 Mf **Mercury Free:** Eliminate the use of mercury in experiments whenever possible to avoid the need to dispose of this hazardous metal.

18 Rq **Reduce Quantity:** Reduce the amount of materials and resources used when possible.

36 Mw **Minimize Waste:** Find alternatives to disposal such as sharing, redistribution and recycling.

54 Wc **Water Conservation:** Conserve water by using flow-reducing valves, reducing rinse cycles and running dishwashers only when they are full.

86 Ms **Microscale:** Scaling down experiments saves time and resources, cuts down on storage needs and promotes safety in the lab.

118 Eo **Efficient Ordering:** Utilize good inventory practices to reduce the amount of materials purchased and stored.

Safety Heroes

57 Pe **Pliny the Elder:** Ancient Roman philosopher described the use of loose-fitting animal bladder skins to protect workers in mines from lead oxide dust, the first recorded instance of use of a protective device to reduce exposure to airborne contaminants.

58 Lv **Leonardo da Vinci:** Credited with the idea for an air-purifying respirator made of wet woven cloth, designed to protect sailors from a weapon utilizing toxic dust.

59 Pc **Paracelsus:** Swiss physician, alchemist, and astrologer, father of toxicology. Credited with the adage, "the dose makes the poison."

60 Pj **Powell Johnson:** African-American inventor received "eye protector" patent in 1880 "for use of furnace men, puddlers, firemen, and others exposed to glare of strong light."

61 Wh **William Stewart Halsted:** First chief of surgery at Johns Hopkins Hospital, invented rubber surgical gloves in order to prevent medical staff from developing dermatitis from surgical chemicals.

62 Ah **Alice Hamilton:** Physician and scientist, expert in field of industrial health and considered the founder of industrial hygiene.

63 Rc **Rachel Carson:** Biologist and environmentalist whose book Silent Spring highlighted the dangers of DDT and other pesticides to wildlife. Carson's call for independent oversight of chemical use influenced the founding of the EPA.

64 Hs **Herbert Stokinger:** Toxicologist who lead the American Conference of Governmental Industrial Hygienists committee that produced the Threshold Limit Values (TLVs).

65 Gs **Glenn Seaborg:** Nobel Prize-winning chemist and American Chemical Society president. The ACS Division of Chemical Health and Safety was founded with his support.

66 Jh **James Hodgson:** US Secretary of Labor helped shape the Occupational Safety and Health Act of 1970, established the Occupational Safety and Health Administration (OSHA) to administer the Act.

67 Jy **Jay Young:** Chemistry educator and one of the founders of the modern discipline of chemical health and safety, authoring and revising the original versions of several seminal lab safety publications

68 Hf **Howard Fawcett:** Co-organizer and first chair of the ACS Division of Chemical Health and Safety (CHAS), published four influential books and numerous papers on safety. In his honor, the CHAS Award was renamed the Howard H. Fawcett Chemical Health and Safety Award in 1998.

69 Hl **H.K. Livingston:** First chair of the ACS Committee on Chemical Health and Safety (1963).

70 Lb **Leslie Bretherick:** Chemist and author of standard reference guide to dangerous chemical reactions, Bretherick's Handbook of Reactive Chemical Hazards, now in its 8th edition.

71 U **You?:** Every lab worker can be a hero if they adhere to the Elements of Safety!

Safety Martyrs

89 Fm **Fluorine Martyrs:** 19th century chemists died or were severely injured trying to isolate fluorine French chemist Henri Moissan was the first to isolate it after being poisoned several times. Irish chemists Thomas and George Knox nearly died. Belgian chemist Paulin Louyet and French chemist Jerome Nickles died, even though aware of the hazards.

90 Cd **Clarence Dally:** An assistant to Thomas Edison, Dally investigated the medical diagnostic potential of radiation. After years of testing this technology with insufficient protective equipment, Dally succumbed to metabolic skin cancer and became the first known American fatality due to x-ray exposure.

91 Rg **Radium Girls:** The Radium Girls were female factory workers at US Radium Corporation beginning around 1917, who contracted radiation poisoning from painting watch dials with self-luminous paint. Told that the paint was non-hazardous, they utilized unsafe work practices.

92 Mc **Marie Curie:** Pioneering researcher on radioactivity, discovered radium and polonium. Curie died in 1934 from aplastic anemia contracted from long-term exposure to radiation.

93 Ce **Candalario Esquibel:** First of seven employees at Los Alamos National Laboratory killed in lab accidents in the 1950s. Died in explosion involving thallous azide, which detonates when heated or subjected to shock.

94 Jp **Janet Parker:** Medical photographer died of smallpox in 1978 after being accidently exposed to a strain of the virus in a lab. As a result, all known stocks of smallpox were destroyed or transferred to one of two WHO reference laboratories with BSL-4 facilities.

95 Bd **Bhopal Disaster:** Union Carbide pesticide plant in Bhopal, India, released methyl isocyanate gas, exposing more than 500,000 people. More than 4000 people died within two weeks. Considered the worst industrial accident in history, it led the U.S. to pass Right to Know and Hazard Communication legislation.

96 Ar **Andrew Riley:** Killed at SRI International in 1992 in explosion involving Dewar flask containing a palladium electrode immersed in deuterium oxide. Was part of a team conducting research into cold fusion.

97 Kw **Karen Wetterhahn:** American chemist specializing in toxic metal exposure spilled a few drops of dimethyl mercury on her hand while wearing latex gloves. Months later she died from mercury poisoning. Her death in 1996 led to new understanding of the type and level of protection required for handling highly toxic metallic compounds.

98 Eg **Elizabeth Griffin:** Research assistant at Emory University died in 1997 of herpes B virus contracted from an infected macaque monkey. A foundation set up in her name promotes evidence-based biosafety and biosecurity practices around the world.

99 T2 **T2 Laboratories:** Explosion from methycyclopentadienyl manganese tricarbonyl (MCMT) production at T2 Laboratories in Jacksonville, FL killed four employees injured 32. A root cause: lack of experience/understanding of reactive chemical processes, which led to better integration of reactive hazard awareness into US curricula.

100 Ss **Sheharbano "Sheri" Sangi:** Research assistant at UCLA who suffered burns from a fire ignited from using a plastic syringe to transfer pyrophoric tert-butyl lithium. The severe burns caused her death. This marked the first criminal case resulting from an incident in an academic lab.

101 Tx **Texas Tech:** Chemistry lab explosion in 2010 seriously injured graduate student working with a high-energy metal, nickel hydrazine. First academic laboratory accident to be investigated by the US Chemical Safety Board, leading to more focus on physical hazards of chemicals, and deeper scrutiny of laboratory safety in academia.

102 Md **Michele Dufault:** Yale University student who died from asphyxiation when her hair became caught in a lathe while working alone in an academic laboratory machine shop. Her death in April 2011, weeks before graduation, led many colleges and universities to adopt new safety standards in the laboratory.

103 Nu **Not You:** Don't be the next martyr – assess the risks and practice science safely.

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PRINCETON UNIVERSITY

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