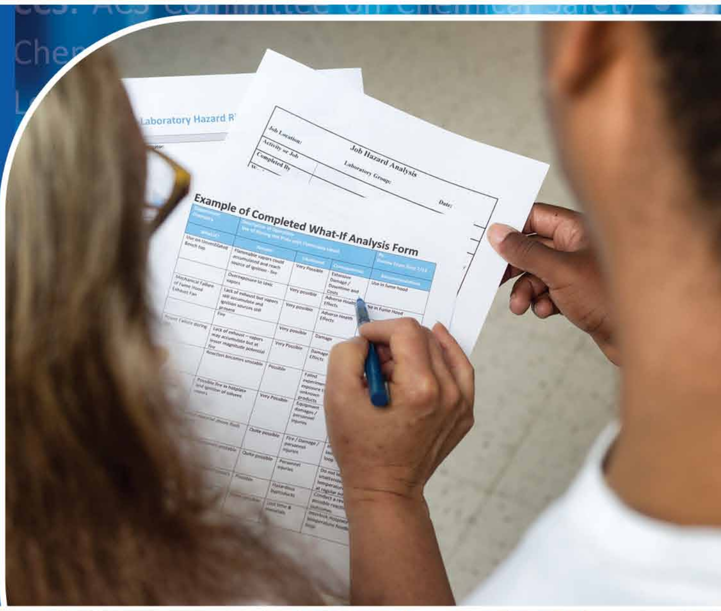
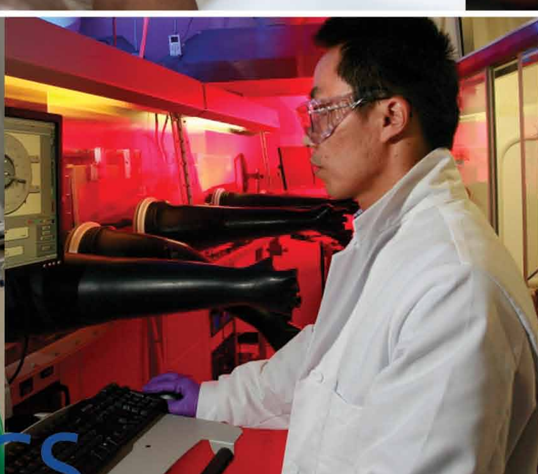
IDENTIFYING AND EVALUATING HAZARDS IN RESEARCH LABORATORIES

GUIDELINES DEVELOPED BY THE HAZARD IDENTIFICATION AND EVALUATION TASK FORCE OF THE AMERICAN CHEMICAL SOCIETY'S COMMITTEE ON CHEMICAL SAFETY





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Identifying and Evaluating Hazards in Research Laboratories

Guidelines developed by the Hazard Identification and Evaluation Task Force of the American Chemical Society's Committee on Chemical Safety

TABLE OF CONTENTS

FOREWORD

Before 2008 the U.S. Chemical Safety and Hazard Investigation Board, also known as the Chemical Safety Board (CSB),[a] was concerned about reports of significant incidents in academic laboratories. The CSB indicated this concern would likely lead to an investigation of a future serious incident in an academic laboratory.

In January 2010, a chemistry graduate student at Texas Tech University was seriously injured in an explosion. The CSB investigated this incident and issued its report in October 2011. The CSB noted: "The lessons learned from the incident provide all academic communities with an important opportunity to compare their own policies and practices to that which existed at Texas Tech leading up to the incident." The CSB report noted several factors contributed to the incident, including "Comprehensive guidance on managing the hazards unique to laboratory chemical research in the academic environment is lacking. Current standards on hazard evaluations, risk assessments, and hazard mitigation are geared toward industrial settings and are not transferrable to the academic research laboratory environment."[1]

The CSB asked the American Chemical Society (ACS) for assistance with developing guidance that would address this information gap. The ACS accepted the CSB recommendation to: "Develop good practice guidance that identifies and describes methodologies to assess and control hazards that can be used successfully in a research laboratory." The ACS assigned the responsibility for this task to the ACS Committee on Chemical Safety (CCS).

The CCS, in close coordination with the Division of Chemical Health and Safety, commissioned a task force of stakeholders and subject matter experts to create a guide for identifying and evaluating hazards, and managing the associated risks of these hazards in research laboratories.

The following factors were considered during the development of this guide:

- To provide techniques to ensure hazard information is gathered and analyzed;
- To aid researchers in recognizing the value of input from others with varying experiences;
- To provide techniques that can be used for a variety of different types of activities (routine protocols, modifications to current research, or entirely new activities); and
- To consider the variable nature of research tasks by providing tools that help researchers recognize and respond to change—both large and small.

This guide was developed for researchers without deference to where they are in their careers—undergraduate students, graduate students, postdoctoral scholars, instructors, principal investigators (PIs), technicians, or department chairs—who have varied approaches to learning and experimental design and who may require different kinds of assessment tools.

[a] See APPENDIX A for a glossary of acronyms.

ACS seeks to develop tools that are useful for colleagues working in the scientific research community. It is important that strong communication and the exchange of ideas between ACS and the research community be established and maintained, so we can clearly learn what does and does not work well. This will allow ACS to modify these techniques to be more useful. It is the sincere hope of ACS that hazard identification and evaluation techniques become incorporated into the everyday activities of the scientific research community.

ACKNOWLEDGEMENTS

The ACS Committee on Chemical Safety acknowledges the following:

- The members of CSB, for their continued dedication to providing sound investigations of chemical-related accidents across the United States which, in turn, enable us to develop better ways to protect ourselves and our colleagues.

- The members of the Hazard Identification and Evaluation Task Force, writing teams and reviewers, and ACS support staff who produced these guidelines.

- The Battelle Memorial Institute who, in keeping with its "commitment to science and technology for the greater good," provided monetary support for this project.

The individuals listed below participated as members of sub-teams that developed the methods presented in this document. The Task Force expresses its appreciation for the team members' commitment to this guide and the chemical practitioners it is intended to serve.

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EXECUTIVE SUMMARY

Written for the laboratory researcher, this document provides general information and multiple tools to identify and assess hazards in research laboratories. It may also be of value in other types of laboratories and for other types of workers. Having a good understanding of hazards allows researchers to take steps to reduce the likelihood and consequences of unwanted incidents.

The reader should be aware this document is limited in scope; as it was prepared in response to a recommendation from CSB to ACS to fill a need for better guidance on hazard assessment. It touches on many laboratory safety issues, but it is not intended to replace the many useful references on laboratory safety or safe laboratory design. Therefore, this guide is a tool to enhance laboratory safety and it provides detailed information for those who wish to explore hazard analysis in depth.

The first seven chapters provide information about various aspects of the hazard assessment process, such as:

- Definitions;
- How to identify and evaluate hazards;
- Roles and responsibilities;
- Choosing and using a technique from this guide;
- Change control; and
- Assessing implementation.

Hazard assessment is a continuous process. Once an assessment is made and well-thought-out controls are put in place, there needs to be an assessment of the effectiveness of the controls, which leads back to an updated hazard assessment.

Chapters 8–12 present five different tools that may be used to conduct hazard assessments. The five tools can briefly be described as follows:

1. **Control banding chemical uses is research laboratories:** Hazards are placed into one of several categories, so that general control strategies appropriate for those categories may be implemented.
2. **Job hazard analysis:** A methodical approach to document the work steps and hazards associated with each step.
3. **What-if analysis:** An approach that raises a series of questions to help identify things that might go wrong.
4. **Checklists:** A method that tends to be more operational in that it helps researchers remember all of the precautions they are supposed to take.
5. **Structured development of standard operating procedures (SOPs):** A comprehensive method for evaluating various aspects of research work leading to development of SOPs.

Each method provides a suggested template, which can be modified by the user to better meet specific needs. Examples are presented in the appendices to give the reader an idea about how each method might be used.

The authors attempted to keep this guide short and easy to use. However, users should be wary of shortcuts if they want to prepare sound hazard assessments.

1. SCOPE AND APPLICATION

1.1. Scope

This guide can be used by an individual researcher or an institution in the development of processes to effectively integrate the identification or recognition of hazards and the evaluation of the risks, with the aim of using this information to formulate a plan to minimize or manage the risks prior to the start of work. This guide also provides strategies for:

1. Identifying and responding to changing conditions that can affect a hazard evaluation;
2. Implementing processes in an institution not accustomed to the use of the techniques outlined in this guide; and
3. Assessing implementation of hazard identification and evaluation methodologies.

1.2. Application

This guide was written for researchers without deference to the stage in their careers—undergraduate students, graduate students, postdoctoral scholars, instructors, PIs, or departmental chairs for implementation in a scientific research laboratory. Consideration was given to the variable nature of research in the preparation of this guide and in the presentation of the techniques provided. Furthermore, this guide provides assessment approaches that are intended to be relatively easy to implement and use. While research laboratories and researchers are the primary audience for this guide, other readers may find it equally useful.

2. DEFINITIONS

Change control: The management process for requesting, reviewing, approving, carrying out, and controlling changes to agreed-upon deliverables or operational boundaries. It is sometimes referred to as "change management."

Chemical exposure hazard: A chemical for which there is evidence that acute (immediate) or chronic (delayed) health effects may occur in an exposed population. Exposure is related to the dose (how much), the duration and frequency of exposure (how long and how often), and the route of exposure (how and where a material gets in or on the body), whether through the respiratory tract (inhalation), the skin (absorption), the digestive tract (ingestion), or percutaneous injection through the skin (accidental needle stick). The resulting health effects can be transient, persistent, or cumulative; local (at the site of initial contact with a substance), or systemic (after absorption, distribution, and possible biotransformation, at a site distant from initial contact with a substance).

Chemical hygiene officer: From the Occupational Safety and Health Administration (OSHA) Laboratory Worker Standard, an employee who is designated by their employer, and who is qualified by training or experience, to provide technical guidance in the development and implementation of the provisions of the chemical hygiene plan. This definition is not intended to place limitations on the position description or job classification that the designated individual shall hold within the employer's organizational structure.

Chemical Safety Levels (CSLs): Defined levels of hazard (1 through 4), based on a risk assessment conducted by a qualified individual:

- **CSL Level 1:** Minimal health or physical hazard from chemicals. No concentrated acids or bases, toxics, carcinogens, or teratogens. Less than 4 liters of flammable liquids. No fume hood required and no general ventilation rate specified. Typical examples include: temperature-controlled rooms; K–12 science teaching and demonstration labs; research labs with chemical usage in prepackaged kits; or less than 500 milliliters (mL) of chemicals with the Globally Harmonized System (GHS) “danger” signal words, laser labs (below Class 2B), and microscopy rooms.

- **CSL Level 2:** Low health or physical hazard from chemicals. Small amounts, less than 1 liter, of concentrated reagent strength acids or bases, possesses none or limited amounts of toxic or high hazard materials. Less than 40 liters of flammable liquids stored. May need a fume hood for specific activities. Typical examples include: undergraduate chemistry or biochemistry teaching and demonstration labs, and standard biomedical research labs.

- **CSL Level 3:** Moderate chemical or physical hazard. Lab work with concentrated acids, bases, toxic, other high hazard chemicals, or cryogenic liquids. Carcinogens or reproductive toxins are handled. Corrosive, flammable, or toxic compressed gases are present in cabinets or fume hoods. Larger volumes (> 40 liters) of flammable liquids are stored in the lab. High hazards in limited quantities may be in the lab with Environmental Health and Safety (EHS) approval (for example, hydrofluoric acid, pyrophoric chemicals, or cyanides). Labs are fume hood or local exhaust intensive. Some uses of a glove box for air or water reactive chemicals. Examples include: chemistry research, pharmacology, chemical engineering, and pathology labs, as well as other chemical intensive research labs.

- **CSL Level 4:** High chemical or physical hazard. Work with explosives or potentially explosive compounds, or frequent use of larger quantities of pyrophoric chemicals. Use of large quantities or high hazard materials with significant potential for Immediately Dangerous to Life and Health (IDLH) conditions in the event of uncontrolled release or foreseeable incident. Use of glove box for pyrophoric, or air or water reactive chemicals.

  PIs and lab managers need to establish the upper limit on the quantity of high hazard materials that are used. For example, use of more than 5 grams of a pyrophoric material, or 150 mL of 2 molar t-butyllithium (in pentane) could be considered larger quantities.

Consequence: A possible result or outcome of an uncontrolled hazard.

Exposure: The concentration or amount of a particular agent (chemical, biological, electrical, electromagnetic field (EMF), or physical) that reaches a target organism, system, or subpopulation in a specific frequency for a defined duration.

Failure modes and effects analysis (FMEA): An evaluation of the means that equipment can fail or be used improperly, and the effects this failure can have on the process.[4]

Fault tree analysis (FTA): A graphical model that illustrates combinations of failures that will cause one specific failure of interest. It is a deductive technique that uses Boolean logic symbols to break down the causes of an event into basic equipment or human failure.[4]

Globally Harmonized System (of classification and labeling of chemicals) [commonly known as GHS]: A system used internationally to provide standard criteria for classifying chemicals, according to their health, physical, and environmental hazards. It uses pictograms, hazard statements, and the signal words "Danger" and "Warning" to communicate hazard information on product labels and safety data sheets in a logical and comprehensive way.

Hazard: A potential for harm. The term is often associated with an agent, condition, or activity (a natural phenomenon, a chemical, a mixture of substances, a process involving substances, a source of energy, or a situation or event) that if left uncontrolled, could result in an injury, illness, loss of property, or damage to the environment. Hazards are intrinsic properties of agents, conditions, or activities.

Hazard analysis: A term used to express the complete process of hazard identification, evaluation, and control.

Hazard control: A barrier, such as a device, measure, or limit, used to minimize the potential consequences associated with a hazard.

Hazard evaluation: The qualitative and, whenever possible, quantitative description of the inherent properties of an agent or situation having the potential to cause adverse effects.[b]

Hazard identification: The identification of the type and nature of adverse effects from an agent, operation, or equipment, which has an inherent capacity to cause in an organism, system, or (sub) population.

Hazard operability (HazOp) analysis: A technique whereby a multidisciplinary team uses a described protocol to methodically evaluate the significance of deviations from the normal design intention.[4]

Hazard statement: Assigned within the GHS classification and labeling of chemicals. Hazard statements are standardized phrases describing the hazards of chemical substances and mixtures that can be consistently translated into different languages. As such, they serve the same purpose as the well-known *R*-phrases, which they are intended to replace. Each hazard statement is designated a code, starting with the letter *H* and followed by three digits. Statements which correspond to related hazards are grouped together by code number, so the numbering is not consecutive. The code is used for reference purposes, for example, to help with translations, but it is the *actual*

[b] The definition of "hazard characterization" is adapted from the World Health Organization (WHO).

phrase which should appear on labels and safety data sheets. Note that the hazard statement is based not only on the identity of the chemical, but also on its concentration level in the product being described.

High hazard materials (to consider for used in the application of chemical safety levels): Can be defined in two ways: (1) materials which pose a high health hazard, and (2) those which pose a high physical hazard. High health hazard materials are substances with high acute toxicity (described below) and those which are known carcinogens as identified by the International Agency for Research on Cancer (IARC) Group 1 and Group 2A agents. Group 1 agents are carcinogenic to humans and Group 2A agents are probably carcinogenic to humans. Materials with the following GHS hazard statements are presumed to be a high physical hazard and subject to a risk assessment of its actual use:

- **H201:** Explosive; mass explosion hazard
- **H202:** Explosive, severe projection hazard
- **H203:** Explosive; fire, blast, or projection hazard
- **H220:** Extremely flammable gas
- **H240:** Heating may cause an explosion
- **H241:** Heating may cause a fire or explosion
- **H242:** Heating may cause a fire
- **H250:** Catches fire spontaneously if exposed to air
- **H251:** Self-heating: may catch fire
- **H252:** Self-heating in large quantities; may catch fire
- **H260:** In contact with water, releases flammable gases which may ignite spontaneously
- **H270:** May cause or intensify fire; oxidizer
- **H271:** May cause fire or explosion; strong oxidizer

Immediately Dangerous to Life and Health (ILDH) (to consider for used in the application of chemical safety levels): Any condition that poses an immediate or delayed threat to life or that would cause irreversible adverse health effects.

Job hazard analysis: A systematic approach to address hazards by looking at a task and focusing on the relationship between the laboratory worker, the task, the tools, and the work environment to identify the hazards and reduce the risks.

Laboratory: A facility where the "laboratory use of hazardous chemicals" occurs. It is a workplace where relatively small quantities of hazardous chemicals are used on a nonproduction basis.[c]

Laboratory scale: Describes work with substances in which the containers used for reactions, transfers, and other substance handling are designed to be easily and safely manipulated by one person. Excludes those workplaces whose function is to produce commercial quantities of materials.

[c] For the purposes of this guide, a laboratory can be any location where scientific research occurs.

Laboratory worker: Refers to career lab staff, PIs, undergraduate students, graduate students, postdoctoral researchers, volunteers, or visiting scholars.

Likelihood: The probability of occurrence, or how likely the complete sequence of events leading up to a consequence will occur upon exposure to a hazard. This term is often associated with descriptors, such as almost certain, likely, possible, unlikely, and rare.

Management of change analysis: An evaluation of the potential safety consequences of planned changes to experimental apparatus, materials, procedure, location or other key parameters conducted prior to implementation of the proposed changes and how identified risks should be managed.

Near miss: An event in which an injury or loss did not occur, but could have. The conditions of the event are often readily identified as precursors to an accident or loss. These events, which are sometimes referred to as a "near hit," are indicators that the existing hazard controls, if any, may not be adequate and deserve more scrutiny.

Physical hazard: A class of hazards that include cold, ergonomics, explosions, fire, heat, high pressure, high vacuum, mechanical, nonionizing radiation, ionizing radiation, noise, vibration, and so forth.

Principal investigator (PI): An individual who has primary responsibility for performing or overseeing research. In some instances, the PI may also be known as the project manager for a research project.[3]

Risk: Takes into account the probability or likelihood that a consequence will occur and the severity of the consequence should it occur. An unlikely hazard with the potential to cause death is a higher risk than an unlikely hazard which would cause temporary illness.

Standard operating procedures (SOPs): A written series of steps that can be followed to correctly and safely obtain a desired outcome. In laboratories, SOPs are typically developed for repetitive procedures which are known to have associated hazards where injury, property loss, or productivity loss could result if the steps were not followed precisely.

Structured what-if analysis (SWIF): A system-based risk identification technique that employs structured brainstorming, using predetermined guidewords and headings (for example, timing, amount, and so forth) in combination with prompts elicited from participants (which often begin with the phrases "What if…" or "How could…"), to examine risks and hazards at a systems or subsystems level.[5]

Substance with a high acute toxicity (to consider for use in the application of chemical safety levels): High acute toxicity includes any chemical that falls within any of the following OSHA-defined categories:

- A chemical with a median lethal dose (LD_{50}) of 50 milligrams (mg) or less per kilograms (kg) of body weight when administered orally to certain test populations.

- A chemical with an LD_{50} of 200 mg or less per kg of body weight when administered by continuous contact for 24 hours to certain test populations.
- A chemical with a median lethal concentration (LC_{50}) in air of 200 parts per million (ppm) by volume or less of gas or vapor, or 2 mg per liter or less of mist, fume, or dust, when administered to certain test populations by continuous inhalation for one hour, provided such concentrations or conditions are likely to be encountered by humans when the chemical is used in any reasonably foreseeable manner.
- Materials which have been assigned a GHS hazard statement, as follows:
    - **H300**: Fatal if swallowed
    - **H310:** Fatal in contact with skin
    - **H330:** Fatal if inhaled

What-if analysis: A creative, brainstorming examination of a process or operation.[4]

What-if/HazOp: A combination of what-if and HazOp techniques, deriving the benefits of both methods for a more comprehensive review.

What-if/HazOp/checklist: A combination of what-if, HazOp, and checklist analysis techniques, deriving benefits from each methodology for a more comprehensive review.

3. HAZARD IDENTIFICATION AND EVALUATION

3.1. Introduction to Hazard Identification and Evaluation

The scientific method is a foundational principle used for centuries to impress upon young scientists the need to methodically plan for, perform, and evaluate the results of experiments. Organizations with strong safety cultures also find ways to integrate the process of identifying hazards, evaluating the risks presented by those hazards, and managing the risks of hazards of the experiment to be performed into the experimental design process. This interaction is illustrated in Fig. 3–1 with the most basic elements of the scientific method represented within the circle and the basic elements of a hazard identification, evaluation, and control process in the corresponding boxes.

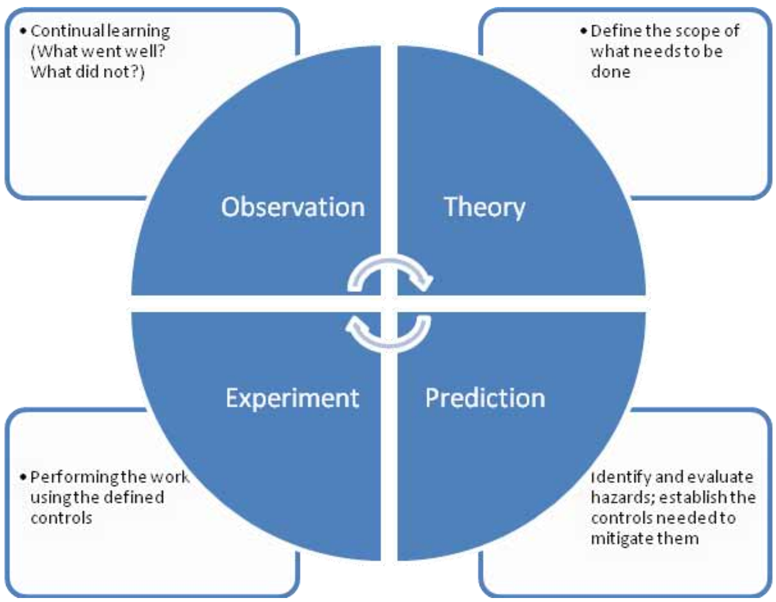

Figure 3–1: Integration of Hazard Identification, Evaluation, and Control with the Scientific Method

The research laboratory is a unique, ever-changing environment. Research experiments change frequently and may involve a wide variety of hazards (for example, chemical, physical, biological, radiological, and so forth). The individuals or teams of people conducting the experiments may be at varying stages in their academic or professional careers. Their backgrounds and experiences may vary, but hazard identification, hazard evaluation, and hazard mitigation in laboratory operations are critical skills that must be part of any laboratory worker's education. Furthermore, integrating these concepts into research activities is a discipline researchers must establish to ensure a safe working environment for themselves and their colleagues.

3.2. Key Elements of Hazard Identification and Evaluation

Defining the Scope of Work

An important, but often missed, preliminary step in hazard identification and evaluation is the identification of the task or group of tasks to be evaluated. Without this, the effectiveness of every subsequent step in the process can be compromised. Actions with significant hazards, hand offs between laboratory workers, critical skills, or specific training required for the researchers performing a task can all be missed. Conversely, the analysis of a well-defined scope of work positions the individual or team to choose the best techniques to evaluate the risks of the laboratory work, define who needs to be involved in the analysis, and create a framework that will enable easier identification of future changes.

Organizations often find merit in establishing guidelines around scope determination that fit well with the type of research activities being performed. For example, an institution may say that all tasks performed within the four walls of a given laboratory will be analyzed collectively as the "scope;" however, defined higher hazard activities, such as work with pyrophoric materials or laser system alignments, require an additional analysis covering the limited scope. Another organization may decide that every individual must complete an analysis of the tasks they will perform, which means the individual's daily activities become the "scope." Yet another organization may decide that individual tasks, such as research protocols or the steps needed to successfully operate an instrument, will be analyzed as discrete "scopes." Any of these strategies can be effective in enabling an organization to ensure all laboratory research is sufficiently analyzed.

Hazard Identification

Recognizing the existence of hazards is central to completing a sufficient analysis. Simply stated, a hazard is a potential for harm. The term is often associated with an agent, condition, or activity (a natural phenomenon, a chemical, a mixture of substances, a process involving substances, a source of energy, or a situation or event) that if left uncontrolled, could result in an injury, illness, loss of property, or damage to the environment. Hazards are an intrinsic property of the agent, condition, or activity. Table 3–1 provides a short list of hazards often identified for research activities. It is often easier to identify agents or conditions that present hazards, but it is more difficult to identify the hazards associated with an activity. Techniques are presented later in this guide to help facilitate hazard identification and evaluation. A quality that makes each of these techniques unique is the method employed in each to enable a user to identify hazards.

Table 3–1: Examples of Hazards Commonly Identified for Research Activities

Hazard Types	Examples
Agent	Carcinogenic, teratogenic, corrosive, pyrophoric, toxic, mutagenic, reproductive hazard, explosive, nonionizing radiation, biological hazard/pathogenic, flammable, oxidizing, self-reactive or unstable, potentially explosive, reducing, water reactive, sensitizing, peroxide forming, catalytic, or chemical asphyxiate

Table 3–1: Examples of Hazards Commonly Identified for Research Activities

Hazard Types	Examples
Condition	High pressure, low pressure, electrical, uneven surfaces, pinch points, suspended weight, hot surfaces, extreme cold, steam, noise, clutter, magnetic fields, simple asphyxiant, oxygen-deficient spaces, ultraviolent radiation, or laser light
Activity	Creation of secondary products, lifting, chemical mixing, long-term use of dry boxes, repetitive pipetting, scale up, handling waste, transportation of hazardous materials, handling glassware and other sharp objects, heating chemicals, recrystallizations, extractions, or centrifuging

Hazard Evaluation

The product of a hazard evaluation should be the qualitative—and sometimes quantitative—understanding of a hazard. The results of an assessment or evaluation of the risk of the hazards of a given experiment should guide the selection of risk management techniques and tools—elimination or substitution of materials; primary safety devices or engineering controls, such as chemical fume hoods; personal protective equipment (PPE); and specific procedures and processes.

To sufficiently understand the purpose of hazard evaluation and risk mitigation, one must understand the relationship between hazard and risk. Risk is the probability that a hazard will result in an adverse consequence. **The terms hazard and risk are not synonymous.** Because hazards are an intrinsic property of a substance or condition, they can be eliminated only by removing the agent, condition, or activity that presents the hazard. A hazard cannot be truly reduced; **however, once identified, appropriate controls can be implemented and the associated risk from the hazard can be reduced or mitigated.** For example, benzene is a human carcinogen; therefore, exposure to benzene in laboratory work poses a health risk. If one works with laboratory scale amounts of benzene in a properly functioning chemical fume hood, with practices and PPE that minimize the potential for contact or inhalation, the likelihood of exposure is low or eliminated, thereby minimizing the risk. Several of the methodologies presented in this guide encourage the use of risk rating.[d]

Selection of Hazard Controls

The purpose of conducting a hazard evaluation is to determine what hazard controls need to be put in place to allow the work to be performed safely. Hazard controls are normally discussed in terms of the "hierarchy of control"—elimination, engineering controls, administrative controls, and PPE. They are called the "hierarchy of controls" because they should be considered in this order.

The fact that risks vary with circumstances and can be compared to one another should be used in the selection of controls. Using the previous example of benzene in a laboratory operation, consider another hazard associated with benzene—flammability. The use of a few milliliters of benzene in a laboratory protocol would present a low potential for a fire, given the limited fuel. Furthermore, the

[d] See APPENDIX B for additional information on the concept of risk rating for the reader's reference.

consequences of a fire involving such a quantity may be very low. In this situation, a researcher may be well within the bounds of risk acceptable to the organization by establishing minimal standard controls, such as ensuring transfers from the stock container are made away from heat sources, using careful material handling practices, and keeping the work area free of combustible clutter, which could increase the potential consequences should the vapor flash. On the other hand, if the operation involved larger quantities of benzene (for example, transferring from stock 55 gallon drums to smaller containers for laboratory use), both the probability and consequences of a fire from the operation increase, not to mention increased probability of an individual's exposure. For a task with this increased risk, more significant controls would be necessary, such as increased general ventilation, spark protection, grounding, spill protection measures, skin and respiratory protection, and additional training.

Performing Work within Controls

A hazard identification and evaluation process will be ineffective if the results of the hazard analysis are not applied. Once an evaluation is complete and the necessary hazard controls have been identified, it is imperative that researchers understand the hazard analysis information and that they are committed to following the agreed upon controls. A number of factors need to be considered at this point. For example,

- Does the risk or complexity warrant use of SOPs to ensure all lab workers involved understand the acceptable way to complete the experiment?
- Have the lab workers received sufficient training or mentoring to perform the work independently?
- Are the administrative and engineering controls called for in the analysis in place and functioning appropriately?

When ready to begin work, investigators conduct the experiment with the identified controls in place. If unexpected conditions are found, the investigator pauses and ensures the scope of the work or the necessary controls have not changed significantly enough to warrant additional analysis. The researchers question one another about their controls, especially if they think a necessary control is not in place or it is not in use.

Continual Learning

It is equally important that time be taken after the work is completed to reflect upon lessons learned—what went as predicted or designed, as well as those things that did not go as planned. The researcher should approach the end of an experiment the same way they began, by asking questions. For example,

- Did a hazard manifest itself that was not previously identified?
- Did a control perform the way it was expected to, or should the experiment be repeated?
- Did something go exceptionally well that others could learn from?

- Did any close calls or near misses occur that indicate areas of needed improvement?

This information should be used to modify the hazard evaluation if the work is to be repeated and to inform the evaluations of similar work.

4. ESTABLISHING ROLES AND RESPONSIBILITIES

Safety in the research laboratory setting is the responsibility of all stakeholders involved in research activities throughout the institution, including administrators as well as researchers. For a hazard identification and evaluation process to be successful, everyone must know and be committed to their respective roles and obligations. The following is not intended to be a comprehensive list of roles, responsibilities, accountabilities, and authorities in the development of a culture of chemical safety, but is rather geared specifically toward the identification, evaluation, and mitigation of hazards as they exist in the research laboratory. Additional information concerning the advancement of a safety culture may be found in the ACS report, titled "Creating Safety Cultures in Academic Institutions: A Report of the Safety Culture Task Force of the ACS Committee on Chemical Safety."[2,e]

4.1. Institutional and Departmental Administration

The principal role of the administration in the development of hazard assessment and mitigation plans is to make certain that all of the tools for conducting hazard identification and evaluation are available to researchers throughout the institution, and to ensure the use of hazard identification and analysis becomes an expected and routine part of any experiment, research plan, and general performance. The administration has a responsibility to ensure researchers have the training and critical support needed to execute the analysis and mitigation process. Administrators must determine the level of risk that can be tolerated, including consequences that are not acceptable, such as injuries, death, or property loss. Assessment of the processes and procedures is vital throughout the organization, with the goal of continual improvement. The institution must foster an atmosphere where it is acceptable for a worker (regardless of rank) to question whether an analysis is complete enough or whether sufficient mitigating controls have been put in place. At the departmental level, there should be established expectations for who can authorize a research project, experiment, or task and under what conditions reauthorization needs to take place.

4.2. Principal Investigator

Many organizations produce policy documentation that defines a PI as responsible for managing sponsored research projects. The organization may even recognize this position as project director or program director. The information presented here is not meant to conflict with an organization's policies in this respect, but to define the additional responsibilities of managing laboratories where hazardous chemicals and processes are required to conduct research.

The role of the PI is paramount with regard to the development of successful strategies for the analysis and mitigation of hazards in individual research laboratories. As the content expert in matters related to the laboratory, the PI is most able to provide guidance concerning what constitutes a hazard in the performance of an experiment or research plan. Ideally, the hazard

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[e] This ACS report is available at: www.acs.org/safety

analysis will complement the development of written research procedures or protocols for the operations that will be performed. Among other responsibilities related to safety, the PI should:

- Promote a laboratory culture where safety is a valued component of research;
- Analyze proposed work tasks to identify hazards and determine the appropriate controls (engineering, administrative, and PPE) needed to sufficiently mitigate the hazards;
- Seek ways to make hazard analysis an integrated part of the research process, so that it becomes a natural part of the process;
- Include the researchers who will be performing the work in the hazard analysis process;
- Ensure the hazards and controls are clearly communicated and understood by those performing the task;
- Set the expectation that participation in the research project is contingent on an individual contributor's willingness to abide by the controls established through the hazard analysis process;
- Reach out to support personnel and subject matter experts for assistance, as needed, and defer to their expertise regardless of their position on the research team or within the organization (for example, junior staff members or safety professionals);
- Meet with research staff on a regular basis and lead by example;
- Engage in the daily operations of the laboratory and be available, as needed, to ensure workers are performing in accordance with the agreed upon controls;
- Use lessons learned from abnormal events inside and outside the research group to improve planning;
- Solicit feedback from coworkers and colleagues to improve safety and the process;
- Address risks faced by visitors, including maintenance staff, during the hazard analysis process;
- Manage change control carefully by routinely reviewing procedures and the hazard analysis to identify changes; and
- Ensure training is appropriate, effective, and documented.

Oftentimes a responsible research member, such as a co-PI or laboratory manager, may assist with the performance of the daily laboratory operations and oversee some of the chemical hygiene duties. The PI should be very selective in the assignment of this person (or persons) and ensure they have the qualifications required to assume this role. As with any other phase of research project management (budgets, ethical data collection, and so forth), chemical hygiene expectations must be clearly articulated and directed. Delegation of chemical hygiene responsibilities to other staff or faculty members should not be viewed as diminishing the responsibility or accountability of the PI.

4.3. Researcher and Laboratory Worker

Researchers and lab workers in the laboratory are on the frontline of safety. As such, they must participate most fully in the hazard analysis and mitigation process. Researchers have a right and a responsibility to ask challenging and clarifying questions to ensure the scope of work and all hazards and controls are well understood before beginning an experiment or research protocol. Researchers must have a clear understanding of needed safety measures, and they must feel comfortable in performing the upcoming experiment using identified measures to minimize risks. They must also be committed to performing their research in a manner that has been determined in the analysis. Given the constantly changing nature of the research process, it is essential the researcher or lab worker communicate changing or unexpected scope of work and conditions, so the hazard analysis can be modified, if needed. As an advocate for a strong safety culture, the researcher or lab worker has a responsibility to challenge others in the research group who are not working within the agreed upon or approved controls. Conversely, they must be willing to accept challenges from, and engage in discussions with, other coworkers concerning hazard analysis, as well as to communicate ideas for improving the control of hazards to the PI and to the research group.

4.4. Support Personnel

Support personnel (including safety or chemical hygiene officers, industrial hygienists, field surveyors, or inspectors) help to provide quality control and assurance for the processes that occur in research laboratories. The EHS staff or faculty with assigned chemical hygiene duties are essential partners in the development of a culture of safety in universities and research institutions. In addition to their regular duties (as determined by the institution and regulations), support personnel should actively participate in the hazard analysis process, as needed. Their expertise is vital, especially when asked by the research staff, in terms of checking and confirming the protocols or controls, which are developed as a result of the hazard analysis. An essential role of the safety support staff at any academic or research institution is in the area of continuing education, and in the transmission of that new knowledge both within the local EHS community, as well the community of researchers. They should ensure the research staff is up-to-date on identifying regulatory requirements and controls with which they may not be familiar, and on the development and communication of new methodologies for hazard analysis and mitigation.

5. CHOOSING AND USING A TECHNIQUE FROM THIS GUIDE

5.1. Desired Attributes of a Hazard Identification and Evaluation Tool or System

The measure of a good hazard identification and evaluation tool or system is simply that it allows a robust analysis of the various hazards of work. It enables identification of hazards, analysis of the risks presented by each hazard, followed by a selection of controls that will allow the work to be done safely. When developing the hazard analysis tools and information presented in this guidance, the task force members agreed that an identification and evaluation tool needed certain qualities before the research community could embrace it and be able to use it effectively. It was determined that tools should:

- Enable the freedom to conduct discovery science;
- Help a PI keep the research group safe;
- Work within the research environment and be connected to the research;
- Be intuitive, easy to use, and easily adaptable to a rapid pace, as needed;
- Be customizable, easy for an institution to pick up, modify, and make its own;
- Create a product that can become part of the research record, contain information the researcher values as helpful in their work, and can be shared with others; and
- Address a variety of hazards encountered in research.

Quick Start Introduction

For each of the five methodologies described in this guide, you will find a brief "Quick Start" guide. While the authors of this guide strongly suggest reading the associated text with each method prior to using that method, they recognize some individuals may prefer to tackle problems outside the linear approach used in the text.

These guides attempt to allow a user to jump into using the method as quickly as possible. It is highly recommended the main text be consulted at some point to ensure the process is being used as it was intended by the authors.

5.2. Choosing the Method Best Suited for the Research

Numerous hazard analysis techniques are used throughout various industries and institutions. The Task Force members considered several techniques and selected five that meet the attributes described in the previous paragraph and can be used in a research environment. Each technique is discussed in dedicated sections of this document, as follows:

- Section 8: Control Banding Chemical Uses in Research Laboratories
- Section 9: Job Hazard Analysis
- Section 10: What-If Analysis
- Section 11: Checklists
- Section 12: Structured Development of SOPs

A discussion is provided on how to effectively use each technique, the situations in which a researcher might find it particularly useful, and limitations and challenges for using a technique. Completed examples are provided within the section and in referenced appendices. When considering these techniques, the PI or organization must understand they are often complementary or additive. As an example, in Section 8: Chemical Safety Levels, the reader will find this technique is suitable for conducting a high-level evaluation of the hazards in a given space, but has limitations for complex, high hazard or first-time tasks. The PI may find that conducting a what-if analysis described in Section 10 for those additional tasks provides the portfolio of analysis needed to adequately manage the hazards within the PI's research group.

5.3. Suggestions for Implementing Hazard Identification and Evaluation Processes Indifferent to Technique Chosen

For a successful hazard review, the appropriate resources need to be assembled. These resources will be information in the form of knowledgeable persons and a review of safety literature on hazard properties. Where processes with higher hazard potential are to be reviewed, there is an increased need for individuals with process experience to participate in the hazard review.

Frontline laboratory workers should remember the four steps of learning:

1. Unconscious incompetence: You don't know what you don't know.
2. Conscious incompetence: You realize you don't have adequate knowledge.
3. Conscious competence: You are able to function safely and effectively.
4. Unconscious competence: You are very knowledgeable and experienced regarding the subject at hand.

Involving multiple people in a review (students, laboratory workers with varying levels of experience, peers, and support staff) is a good defense against unconscious incompetence.

Regardless of education level or experience with the hazard evaluation techniques, it is easy to be unaware of hazards with materials, equipment, and processes. When hazard evaluation is a new or emerging concept to an organization, it can be prudent to assume people are at the unconscious incompetence stage and default to proceeding carefully on a small scale, and perhaps with additional controls such as enhanced protective clothing. Additional points to consider:

- Do not expect perfection the first time a hazard evaluation technique is used, but expect improvement. This is a learning process.
- Use walk-throughs of the space where the research will be done, mock-ups, and observations of similar processes to help identify hazards. Do not just conduct the review on paper.
- Discuss previous incidents and near misses.
- Maintain open lines of communication—talk about safety in research meetings.
- Publish completed hazard evaluations, so others can use them as examples.

6. CHANGE CONTROL

It can be said that research is synonymous with change. In a research environment, the results of every experiment, the latest publication of a peer, or something as simple as the thought you had over breakfast, or a conversation in the hall can cause a researcher to modify what they plan to do when they enter their lab on any day. Unfortunately, the cause of many accidents and injuries can be traced back to unrecognized changes in the work scope or hazards. Fundamentally, when the work to be performed changes, that change must be evaluated against the current hazard analysis to determine if the hazard analysis continues to be sufficient. If this is not done, the researcher could begin the task not fully armed with the knowledge and mitigations to do the work safely.

6.1. Recognizing Change

While we all recognize change is ever-present in research, it can also be extremely difficult to recognize, especially if the change is subtle. As one becomes more accustomed to performing hazard evaluations and it becomes a habit or integral part of the way to plan an activity, the types of changes that could impact the fidelity of an analysis become more obvious. Until then, the following examples are provided for consideration in recognizing potential important changes:

- Same basic synthesis, but changing the reactant to a compound with an additional functional group;
- The need to use a different solvent in an extraction;
- The research creates a new waste stream or the need for more frequent cleanup;
- Work materials that are newer or older, involve a different concentration, or contain a trace contaminant;
- Incorporation of a new technology;
- Failure of current experimental parameters;
- Scale up;
- New piece of equipment;
- Modifications to equipment or the way the equipment is used (that is, will it be used the way the manufacturer intended?);
- Addition of a new technique;
- Creation of materials with unknown hazards;
- New person on team or losing someone with experience;
- Same task but in a new location;
- Changes in ambient conditions (more humidity, or less control of temperature);
- Something you thought would be available is not, or something you did not expect to be available is; and
- Psychological state of workers (stress, fatigue, and so forth).

6.2. Factors that Affect Recognition of Change

Everyone engaged in a research activity must be on the lookout for change, but there are certain human characteristics that make it difficult to recognize change. The concept of "unconscious incompetence" discussed in Section 5.3 affects an individual's ability to recognize change, as well. If a person does not understand the hazard or why a control was put in place, they are not likely to recognize how a change to the hazard or control could be significant. Also, while risk is measurable, it is also subject to personal interpretation. Everyone has a different risk perception. An inaccurate perception of risk can be reinforced if continuing to use a control that is perceived to be sufficient goes unchallenged.

6.3. Strategies for Enabling Recognition of and Responding to Change

Organizations have found the following strategies to be effective in recognizing and responding to significant changes in research environments:

- Require periodic reviews of hazard evaluations;
- Make the process for revisions easy;
- Establish thresholds, where important, and clearly communicate them. Some will be driven by regulations (for example, introduction of a new X-ray generating device, introduction of biological work, or use of controlled substances); others will be dependent on the expertise of the organization and work group (for example, threshold for the scale-up of energetic materials, laser alignment, and use of engineered nanomaterials). Ensure the thresholds are understood and know who has the authority to authorize tasks that exceed a threshold;
- Use peer reviews; encourage researchers not involved in the research to observe and ask questions;
- Conduct routine reviews of laboratory activities;
- Look for changing work conditions and ask questions about processes;
- Report and discuss incidents, near misses, and close calls; and
- Include information on hazards in notebooks, papers, and presentations, so the new knowledge is disseminated to a wider audience.

7. ASSESSING IMPLEMENTATION

For a hazard identification and analysis process to be effective, it must become integrated into the way research is planned and conducted. It must become “part of the fabric” of the PI, department, or institution. Effective integration and mature use of the tools takes time. Members of research teams often move, and members with less experience with the processes join the team. It is very important that implementation be routinely assessed to ensure the hazard analysis processes are being followed as designed.

Individuals and groups, who are part of an organization where this process is highly valued—and who embrace a strong safety culture—exhibit certain characteristics throughout the process of hazard identification, evaluation, and risk mitigation. An organization can assess its maturity by asking how they measure up against these attributes.

Defining the Scope

- Care is taken to identify the full scope of what needs to be done in the planning stage. Questions are addressed such as: “What steps need to be performed to complete the experiment? Who will be actively participating? What type of equipment is needed? Where will it be done? What materials are needed to complete the experiment? What is known about this experiment from literature or previous experience?”

Identifying and Evaluating Hazards

- Hazards to the investigator and risks to the environment, and the success of the experiment are identified and evaluated;
- Routes of potential exposure are identified;
- A questioning and challenging attitude is welcomed, in the name of ensuring the best analysis possible;
- Lessons are learned and implemented from investigations of incidents and near misses;
- Potential, credible accident or event scenarios are hypothesized and discussed;
- Controls are identified that will eliminate the hazard, control it, or protect the investigator in the event the thinkable or unthinkable happens;
- Regulatory requirements, which are often hazard-based, are identified;
- Tools are used to facilitate a thorough review and to lend to reasonable consistency throughout the organization; and
- While the experiment may be completed by an individual, the individual investigator calls on others to help with the process, deferring to those who may have more experience. This could be a senior investigator, a health and safety professional, or a junior student. The expertise of others is valued.

Performing the Work with the Identified Controls in Place

- Confirming the agreed upon controls are in place and functioning is completed before the work is begun. This includes a conscious evaluation of the capabilities of the individuals who will complete the work.
- Researchers conduct the experiment with the identified controls in place. If unexpected conditions are found, the investigator pauses and ensures the scope of the work or the necessary controls have not changed significantly enough to warrant additional analysis.
- Personnel question or remind investigators about their controls, especially if they are concerned that a necessary control is not in place or is not being used.
- Personnel actively seek to avoid at-risk behavior in their work and help others to identify risky behaviors in their work.

Identifying Lessons to Be Learned

- The investigator approaches the end of an experiment the same way they began—by asking questions. For example, "Did a hazard manifest itself that was not previously identified? Did a control perform the way it was expected to, or do I need another option if I repeat this experiment? Did something go really well that others can learn from? Did I recognize any close calls or near misses that can serve as a warning for identifying areas of needed improvement?"
- Hazard analysis documents are continually improving, and not something that is created once and never looked at again.

8. CONTROL BANDING CHEMICAL USES IN RESEARCH LABORATORIES

8.1. Introduction

Control banding (CB) is a systematic, qualitative strategy for assessing and managing hazards associated with chemicals in the laboratory. In this context, in addition to review of quantitative data about the chemicals being used and the conditions of the process (for example, flashpoint, operating temperature, and toxicity ratings), professional judgment is necessary to arrive at a final CB assignment to a specific laboratory process. CB is a technique used to guide the assessment and management of chemical risks in the research laboratory by focusing on a limited number of specific control measures. The assignment of these control measures is based on a group or "band" of the hazards present and the associated potential exposures, and laboratories are provided with a number or nomenclature that sums up the hazard levels involved. This is analogous to Biological Safety Levels 1–4 used in biological laboratories.

The conceptual basis of CB is the grouping of chemical hazards and exposures with similar physical and chemical characteristics, intended processes and handling, and anticipated exposure scenarios (amount of chemical used and how workers could be exposed).

Given a well-defined set of chemical processes, appropriate control strategies (that is, risk management options) are determined for each of these groupings.

In this application, a collection of five risk management options for controlling chemicals is used. These strategies include:[f]

- Providing appropriate engineering controls, such as, fume hoods and other local exhaust ventilation (LEV).
- Adhering to good management practices, including housekeeping, SOPs, and oversight.
- Seeking specialized advice when appropriate.
- Planning for credible emergency scenarios.
- Using appropriate PPE consistently.

Quick Start: Control Banding
See the cautionary statements regarding these quick start guides in Section 5.2.

What it is: An application of the industrial hygiene concept of control banding to identify, assess and communicate chemical hazards.

Target applications: Can be applied to many scales from individual research groups, complete departments, or an entire organization. These applications must be supported by a management plan that defines the hazards and control measures covered.

People involved: Partnership of institutional EHS staff, department managers, and lab supervisors.

Getting started: CSL levels must be clearly defined. See Tables 8–1 (preferred by Task Force), 8–2, and 8–3 for potential schema.

Training: Site-specific training described in the management plan is required to apply this method appropriately.

Core resources: Section 8.3 (Pros, Cons, and Limitations), APPENDIX B (Risk Rating), and APPENDIX C (Supporting Information for Chemical Safety Levels).

[f] *Source:* National Institute of Occupational Safety and Health. Qualitative Risk Characterization and Management of Occupational Hazards: Control Banding (CB): A Literature Review and Critical Analysis, Aug 2009: http://www.cdc.gov/niosh/docs/2009-152/pdfs/2009-152.pdf (accessed March 9, 2015).

8.2. Under What Scenarios Might One Consider Using the Method?

In this system, CB is applicable to research laboratories using hazardous chemicals. The controls identified by the system apply to anyone who enters the. This includes not only laboratory workers but also facilities, maintenance, and custodial personnel, and visitors.

The assignment of a control band will be influenced by the characteristics and hazards of the materials, their quantities, the chemical processes, facility, and engineering controls available. Determining potential exposures involves characterizing the processes or activities in which the chemicals or processes are used.

These control bands provide guidance for various control options and recommendations for PPE based on a qualitative assessment of the chemical hazards and exposure potentials.

8.3. Pros, Cons, and Limitations

Pros

- CB can expedite an overview of hazard controls appropriate to the research laboratory where typical processes and reactions involving chemicals are well-established.
- CB is advantageous for risk communication and training. This risk-based approach provides a reasonable, logical way to assess hazards and apply controls systematically.
- CB can also be used as a teaching tool for a variety of audiences who need to understand how protective strategies are matched to chemical hazards in a holistic way.
- Chemical safety levels from one to four, as proposed, are similar to the biosafety levels and risk levels. It is straightforward for laboratory workers, facility and maintenance personnel to understand the basic requirements for working in laboratory spaces.
- The concept of CB can be applied to other workplaces where chemicals are used that are not traditionally considered "laboratories," such as in art studios, theater shops, field stations or research stations.

Cons and Limitations

- Non-routine and high hazard activities of a laboratory require a more rigorous assessment of their unique hazards, using other techniques outlined in this document.
- CB use and nomenclature is context-dependent. For example of this challenge is presented by the GHS which uses Class 1 as its most hazardous and higher numbers to indicate lower hazards. This is the opposite of the National Fire Protection Association approach in its chemical hazard rating system, the Hazardous Material Information System (HMIS), which is used in North America, and the Biosafety in Microbiological and Biomedical Laboratories approach to biosafety levels. For this reason, a CB management plan must be written and disseminated to support its effective use.
- Careful consideration must be given to the nomenclature for a laboratory CB system to avoid increasing confusion for people outside the intended audiences. For example, emergency responders are likely to have different concerns about and strategies for specific

hazards compared to laboratory workers as they conduct work under normal conditions. It is important that the control band designations for these two groups using separate systems not be easily confused.

8.4. Suggested Approach to Establishing Chemical Safety Levels

Recognizing the previously discussed issues, an institution should take care in developing a chemical safety level approach that works best with their researchers and the type of research conducted in its laboratories. Presented in this section is one method that could be used immediately with subsequent customization for the institution.

Table 8–1 is designed to help determine a chemical safety level (CSL) that is appropriate to the chemical activities in a laboratory. This CSL provides general guidance for the best chemical safety practices appropriate to the chemical hazards of the laboratory.

In order to use this table, start with the "Conceptual Hazard Level" row and work across the row, thinking about the type of hazards present in the lab room, lab group, or process, and match the hazard to the CSL, across the top of the table. Compare the tentative CSL to the "Chemicals Used" row, to confirm proper assignment. Once the CSL is assigned, go down the table to identify the various safety measures appropriate to the lab room, lab group, or process. Remember these recommendations may be overridden by local factors; so it is important to document the reasons for these variations as they occur.

Table 8–1: Suggested Approach for Establishing Chemical Safety Levels

DESCRIPTOR OR CONTROL Scope of Assessment Possibilities Driving Consideration	**CHEMICAL SAFETY LEVEL 1**	**CHEMICAL SAFETY LEVEL 2**	**CHEMICAL SAFETY LEVEL 3**	**CHEMICAL SAFETY LEVEL 4**
CONCEPTUAL HAZARD LEVEL *(overview of risk level)* Flexible Context Dependent	Laboratory hazards equivalent to typical household use of chemicals	Laboratory hazards equivalent to academic lab settings (restricted hazardous chemical inventory; well-established procedures in place)	Moderate or varying laboratory hazards within a narrow range (open hazardous chemical inventory; evolving procedures)	Novel hazards or severe established hazards (high hazard chemicals or processes with well-established procedures)
CHEMICALS USED *(types or characteristics of chemicals used)* Lab Room None Identified	Consumer products in consumer packaging; may receive but not open chemical packages	Low concentration acids/bases, lower alcohols, solid salts, simple asphyxiant compressed gases	Typical chemical inventory for a research lab, such as flammable solvents, corrosives, inorganic salts, toxics, flammable gases. Limited amounts (mg quantities) of air or water reactive, pyrophoric materials	Air/water reactive, pyrophoric materials or pyrophoric gases. Explosives or potentially explosive compounds, highly toxic materials (in any state of matter)

Table 8–1: Suggested Approach for Establishing Chemical Safety Levels

DESCRIPTOR OR CONTROL Scope of Assessment Possibilities Driving Consideration	**CHEMICAL SAFETY LEVEL 1**	**CHEMICAL SAFETY LEVEL 2**	**CHEMICAL SAFETY LEVEL 3**	**CHEMICAL SAFETY LEVEL 4**
TRAINING REQUIREMENTS *(prerequisite for people working in the lab)* Lab Group Based on Highest Lab Hazard Rating	Observe label and warning signs	General lab safety training in addition to warning labels and signs	Laboratory hazards require laboratory-specific safety training	Laboratory access restricted to people accompanied by experienced personnel
SUPERVISION REQUIREMENTS *(safety responsibilities of lab leader(s))* Lab Room Based on Highest Active Lab Hazard Process	Awareness of work being conducted	Constant supervision or working alone based on specific restrictions	Peer presence or working alone based on specific restrictions	Peer presence
OVERSIGHT REQUIREMENTS *(expectations for institutional review of lab operations)* Lab Group Based on Highest Lab Hazard Rating	* Weekly self-inspections; ** self-audits three times per year	* Weekly self-inspections; ** self-audits three times per year	* Weekly self-inspections; ** self-audits three times per year; *** monthly drop bys; † risk-based institutional review schedule	* Daily self-inspections; ** self-audits three times per year; *** monthly drop bys; † risk-based institutional review schedule
PLANNING REQUIREMENTS *(specific requirements for planning of work)* Process Specific Based on Highest Rated Chemical Involved	Process-specific plans written and the presence of other chemicals prohibited	Written procedures including safety protocols	Written procedures including safety protocols must be peer reviewed	Written procedures including safety protocols must be reviewed by supervisor
GENERAL PPE REQUIREMENTS (EYE AND SKIN EXPOSURE) *(protection requirements to enter the room)* Lab Room Primarily Based on Physical Ratings	Coverage of legs and feet	CSL 1 PPE plus eye protection	CSL 2 PPE plus lab coat	CSL 3 plus flame resistant lab coat

Table 8–1: Suggested Approach for Establishing Chemical Safety Levels

DESCRIPTOR OR CONTROL Scope of Assessment Possibilities Driving Consideration	**CHEMICAL SAFETY LEVEL 1**	**CHEMICAL SAFETY LEVEL 2**	**CHEMICAL SAFETY LEVEL 3**	**CHEMICAL SAFETY LEVEL 4**
SPECIFIC PPE REQUIREMENTS (HAND AND RESPIRATORY PROTECTION) *(protection requirements to conduct work)* Process Specific Primarily Based on Physical Ratings	No gloves	Activity-specific gloves, such as thin nitrile, vinyl, or latex disposable gloves would be typical	Activity-specific gloves, such as thin nitrile, vinyl, or latex disposable gloves would be acceptable for an incidental small quantity splash. Neoprene or butyl rubber may be needed for immersion in solvents, or similar situation	Activity-specific gloves, such as flame resistant if using pyrophoric liquids, neoprene if using large quantities
GENERAL VENTILATION REQUIREMENTS *(facility support requirements)* Lab Room Primarily Based on Health Rating	None or low ventilation specifications	‡ Moderate ventilation, as defined by laboratory ventilation management plan	‡ High ventilation, as defined by laboratory ventilation management plan	Ventilation designed specifically for this operation
OTHER ENGINEERING CONTROLS Based on Exposure Risk		Local exhaust ventilation (snorkel)	Fume hood, local exhaust ventilation (snorkel), limited glove box use	Fume hood, local exhaust ventilation (snorkel), glove/dry box, enclosed reactor
EMERGENCY RESPONSE PROTOCOL *(expectations for response to potential hazmat emergencies)* Lab Room Primarily Based on Physical and Mechanical Ratings	Institutional-specific response protocol	Institutional-specific response protocol; people with knowledge of incident have responsibility to provide information to responders	Institutional-specific response protocol; may have advanced lab response protocol to make the situation safe while evacuating	Institutional-specific response protocol; specific pre-planning required

* Self-inspection: quick look at physical surroundings; may or may not use a formal checklist.
** Self-audit: more comprehensive review of the CSL and other documentation; use a checklist.
*** Drop-by: informal review, consult, check-in, friendly visit by an institutional representative.
† Risk-based Institutional Review: formal review of lab by an institutional representative; use a checklist, document issues for correction, escalate issues to upper management, as necessary.
‡ Contact facilities for details about the laboratory ventilation plan.

A few words need to be added about working alone in the laboratory. In the book, titled *Prudent Practices in the Laboratory,* the National Research Council defines "ALONE" as being beyond visual or audible range of another individual for more than a few minutes at a time. Accidents are unexpected by definition, and if a person is working alone when an accident occurs, his or her ability to respond appropriately could be severely impaired, and possibly result in personal injury or death and catastrophic facility damage. Indeed, working alone in any laboratory creates increased risk including not having access to basic first aid and the possibility of being unable to summon emergency assistance.

Here are some policy statements on working alone that institutions need to consider:

- Undergraduate students are not permitted to work alone in teaching or research laboratories.
- Graduate students and postdoctoral students may work alone in the laboratory only after completing all required safety training and when performing experiments approved by the PI or lab manager. Additionally, a telephone must be immediately available to the individual working alone.

PIs or lab managers must define the type of experiments that may not be conducted while working alone. For example, "Working alone with pyrophorics, air and water reactives, high hazard materials, high voltage or high power lasers, and machine tools is not allowed."

8.5. Using Raw Data to Estimate a Chemical Safety Level

The chemical safety level methodology presented by the Task Force is only one CB approach. Numerous institutions and organizations have used CB for various applications. One of the most common methods of "banding" chemicals is to use raw data for individual chemicals. Table 8–2 provides a raw data banding methodology and Table 8–3 describes the associated generic protection guidelines.

Table 8–2: Approach to Using Raw Data to Assign Chemical Safety Levels

Hazard	Fire	Reactivity	Acute Toxicity	Chronic Toxicity
CSL 1	Flashpoint above ambient temp (140 F)	No chemical changes expected in the process	All chemicals have known toxicities and OELs > 500 ppm	None known
CSL 2	Flashpoint near ambient, expected concentration < 10% LEL	No known incompatibilities between chemicals being used	All chemicals have known toxicities and 10 ppm < OELs < 500 ppm	Specific target organs or irreversible effects suspected
CSL 3	Expected concentration > 10% LEL	Chemicals with known reactions or contamination hazards present	Unknown toxicities or OEL < 10 ppm	Specific target organs or irreversible effects probable
CSL 4	Pyrophorics, air, or water reactives, etc.	High hazard reactions in use	OEL < 1 ppm	Irreversible toxicities require use of designated areas

Table 8–3: Generic Protection Guidelines for Chemical Safety Levels

	Facility	Training	Oversight	PPE	Response Protocol
CSL 1	Any room, no ventilation	Read the label	Generic self-inspection guidelines	Covered legs and feet	No unusual hazmat concern
CSL 2	Ventilated lab room	Follow the procedures	General training and check-in visits	Nitrile gloves, eye protection	Occupants respond as to general alarm
CSL 3	Lab room with local ventilation (fume hood)	Generic training for unexpected events	Process training and external audits	Appropriate gloves, eye protection, lab coat	Specific occupant responses planned before the event
CSL 4	Specifically designed lab	Practice before working with live materials	Written SOPs and specific oversight practices	Process-specific PPE	Special responder planning

8.6. Making the Chemical Safety Level Assignment

Whether using one of the methodologies described in this document or another methodology which better suits the type of work in the institution, the chemical safety level assignment should be accomplished through a partnership of institutional EHS professionals, academic department management, and individual laboratory supervisors. EHS professionals should develop and support the implementation of criteria for chemical safety level assignment based on the chemical hazards associated with the research process. Academic department management should provide general information about the type of research currently undertaken and planned for the near future. Individual laboratory supervisors should provide the laboratory-specific information about chemical inventories and processes necessary to complete the chemical safety level assignment and make the ultimate risk level designation. Specific activities will determine the scope of the assessment. Assessments must be revisited on a regular schedule or when the research process changes.

Information that Informs the Chemical Safety Level Assignment

- Chemical identity and GHS assignments;
- Chemical amounts and concentrations;
- Expected chemical reactions;
- Research processes and laboratory activities;
- Potential emergency scenarios; and
- Professional judgment of laboratory supervisor, in consultation with EHS staff.

8.7. Reminder

While control banding can be a powerful tool in situations where chemical safety information is missing, it is a system that relies on continued management and reevaluation over time. Change management is a particular concern in control banding situations because “procedure drift” is likely to occur over time in a way that crosses control banding boundaries. For this reason, we recommend annual reviews of the control banding plan to assure that it is adequate to the uses it is being put to and regular review of the control bands to which specific laboratories are assigned. To be an effective protection strategy, control banding must be a living system that engages its stakeholders on an ongoing basis,

Additional resources are available in APPENDIX C.

9. JOB HAZARD ANALYSIS

9.1. Introduction

A Job Hazard Analysis (JHA) is conducted to identify the hazard(s) associated with a particular job or task. This tool focuses on the relationship between the researcher, the task to be done, the tools needed to complete the task, and the work environment where the task will be performed. Once hazards have been identified, controls can be defined and implemented to effectively eliminate or mitigate those hazards. The acceptable risk level for any given task must be determined by the involved parties and the institution.

> **Quick Start: Job Hazard Analysis**
> *See the cautionary statements regarding these quick start guides in Section 5.2.*
>
> **What it is:** A tool that focuses on the relationship between the researcher, the task (or job) to be done, the tools needed to complete the task, and the work environment to identify potential failures, contributing factors, consequences, and likelihood of those failures.
>
> **Target applications:** Very broad. JHAs can be used for each task, each reaction or complex situations. They can be generalized for sharing.
>
> **People involved:** Typically involves those performing the task with advice from EHS, as needed.
>
> **Getting started:** A task or job must first be defined by a description statement – what is being done and why. Identify the steps/tasks; identify potential hazards per step/task using accident/near miss history, literature search, and organizational safety/EHS entities. Be sure to include physical hazards such moving parts and potential slips. Table D-2 contains example hazard types.
>
> **Training:** Minimal
>
> **Core resources:** Section 9.3 (Pros, Cons, and Limitations); APPENDIX B (Risk Rating); APPENDIX D (Supporting Information for Conducting Job Hazard Analysis).

9.2. Under What Scenarios Might One Consider Using the Method?

JHAs can be used by all researchers working in academic laboratories to analyze tasks that will be used in upcoming laboratory projects for identifying potential chemical and physical hazards, so that corrective and preventative actions or controls can be implemented. If the hazard cannot be eliminated, the risk(s) associated with the hazards can be reduced by using various methods of control. In order of priority and effectiveness, hazard controls are engineering, administrative, and PPE.[10] Requiring that lab personnel prepare a JHA *prior to project startup* is an example of an administrative control. Additional methods of control should be included in the JHA and then implemented *prior to starting work or during the task as specified*. (See APPENDIX D for various methods of control.)

JHAs are versatile tools because they can be prepared by lab personnel for the individuals working in the laboratory or for the operations that occur in a laboratory. A JHA can be written for each task or each reaction and can be as detailed, as needed. Not every activity performed in a laboratory requires a JHA, but tasks with the greatest potential for harm should receive development priority. A JHA is an exercise in detective work to track down the following:

- What can go wrong (potential pathways) with the reaction, the equipment, or in the environment?

- What would the consequences be if something did go wrong with any of the above?
- What conditions could arise that would enable something to go wrong?
- What are other contributing factors?
- Based on the answers above, how likely is it that the hazard will occur?

The risk of laboratory injuries and illnesses can be eliminated or minimized by planning research operations, establishing proper procedures based on best practices, and ensuring all researchers are trained properly at a level appropriate to their work tasks. The JHA process can be a component of the organization's chemical hygiene plan and an integral part of the laboratory health and safety culture. Individual JHAs can be defined components of written laboratory procedures that effectively integrate safety into the planned work of the laboratory.

Preparing a JHA is an excellent way to establish the implementation of best practices in your laboratory operations and identify training deficiencies. PIs and their researchers can use the findings of a JHA to eliminate or limit hazards, thus reducing risk. Reduced risk will ultimately result in fewer injuries and illnesses, more effective methodologies, and increased productivity in the laboratory. The JHA is a valuable tool to develop and provide consistent training to employees and students by supplying the written, reliable steps required to safely perform tasks. The JHA information can also be incorporated in research grant proposals to indicate to funding agencies a commitment to chemical hygiene and laboratory safety practices.

A JHA for any task must be sufficiently broad in scope to address the dynamic nature of the research, but must be specific enough to define the hazards and associated controls that apply to the task. JHA content that is too broad or general, or that is too narrow and confining, will result in the failure of laboratory workers to use the JHA tool, and to disregard what may be effective and necessary controls. The JHA should incorporate the hazards associated with the chemicals used, but not necessarily duplicate an SOP or checklist.

The JHA can reference a specific SOP or checklist as additional administrative controls for specific chemical hazards. For example, using benzene as a solvent in a process introduces a physical (fire) and a health hazard (cancer). If substitution with a less hazardous solvent is not possible, then there should be controls in place for the flammability and health risks associated with this chemical. The controls for flammability would be listed (remove ignition sources, have an absorbent on hand for spills, and so forth) and the control for the health hazard might be to refer to the laboratory SOP for using benzene prior to working with the chemical.

A JHA can be conducted on any laboratory research study. The following list gives examples of when a JHA might be appropriate:

- Research projects with the potential to cause severe or disabling injuries or illness, even if there is no history of previous accidents with the process;
- Projects that contain chemicals or processes where one simple human error could lead to a severe accident or injury;
- Research that is new to the laboratory or routine procedures that have undergone changes in processes or reaction conditions;
- Any process that is complex enough to require written instructions;
- Students who are newly introduced to laboratory work.

9.3. Pros, Cons, and Limitations

Pros

- Hazards are identified *prior to work* allowing for risk to be determined and controls to be implemented.
- Uniform instructions for controlling routine laboratory operations with known hazards. This makes training new laboratory personnel more consistent.
- Some hazards identified during the preparation of a JHA can be completely eliminated during the planning phase.
- The steps of a completed JHA translate readily into an experimental procedure.

Cons

- Process or job steps can be missed—thereby overlooking hazards—without careful attention to detail.
- Assigning risk to determine level of control can be difficult. Risk is perceived differently by individuals based on their experience, knowledge, and tolerance level.

Limitations

- Novice workers should always be guided during this process. Even experienced researchers should seek guidance when risks are being assigned to hazards outside their areas of expertise.

9.4. Job Hazard Analysis Instructions and Template

Figure 9-1: Triggers Which Might Automatically Require Completing a JHA

Recognizing the existence of hazards is central to preparing a JHA. According to the World Health Organization (WHO), hazard assessment involves two steps: 1) hazard identification and 2) hazard characterization.[11] Hazard identification is a fairly straight forward term, but the characterization of a hazard is not as easily defined. Some criteria include quantification, mechanism of action (MOA), and physical hazards for chemicals. The more information that can be included about the hazard, the more useful the JHA will be. Nearly all laboratory work requires working with some hazards, but not every hazard automatically requires the completion of a JHA. Fig. 9–1 outlines some specific triggers or severity of hazard that can assist with hazard characterization. These “triggers” show hazards in which the associated risk might be significant enough that it would be prudent to complete a JHA.

JHA Development Tactics

1) The JHA should be initiated by the people performing the work, using templates that have been established by the organization or laboratory group. It is very important that all vested parties are involved in the JHA process from the beginning because they are the people who will use the tool. Involving researchers in the process helps to minimize oversights and ensure a quality analysis product because those on the work frontline have a unique understanding of their research. Use of the JHA is more likely because there is ownership in the final product.

2) Writing a JHA should be approached in a manner similar to other aspects of a research project. Prior to writing a JHA, researchers should review accident histories within their laboratories and institutions. EHS professionals, departmental safety committees, and colleagues can be useful resources of information. Literature searches should be performed to locate related procedures and known problems with the processes or chemicals being used. Many organizations have access to “Lessons Learned” databases, some of which are publicly accessible. The key items to look for while conducting research are as follows:
   - Related accidents and occupational illnesses;
   - Losses that required repair or replacement; and
   - Any “near misses.”

Figure 9-2: JHA Preparation Tactics

3) Conduct a preliminary review of current tasks and conditions. Weekly group meetings are a perfect time to discuss hazards known to exist in current work and surroundings. Brainstorming sessions can produce ideas for eliminating or controlling those hazards. These controls should be incorporated into the JHA. A preliminary review has an added benefit in that any simple problems (that is, low time commitment or low cost) which are detected can be corrected right away. If any existing IDLH hazards are uncovered during the review, work must cease until controls can be implemented to protect the workers. Some hazards will require more study because of their complexity. Those hazards that are determined to present unacceptable risks need to be evaluated for the appropriate types of hazard controls.[g]

[g] See more information about hazard controls in APPENDIX D.

4) List, rank, and set priorities for research projects based on hazard(s). Research that involves hazards with unacceptable risks (based on high probability of occurrence and severity of consequence) should take top priority for analysis. Eliminate the hazard to mitigate the risk, whenever possible. For example, one can replace benzene with a noncarcinogenic solvent. Applying a "1–to–10" scale to hazards can be useful for this process, where an assignment of "10" represents an imminent danger.

5) Risk can be assigned using the matrices shown in APPENDIX B: Risk Rating. Assigning numerical values to risk must be done by individuals with thorough knowledge of the hazard.

6) Outline the steps or tasks. Nearly every research project can be broken down into tasks or steps, and it is important to outline these. When beginning a JHA, it might be useful to have someone perform the task and observe the steps. Novice workers should be supervised during this process if the actual reagents are used. Alternately, a laboratory worker could be observed performing a dry run of the process. Be sure to record enough information to describe each job. Avoid making the breakdown of steps so detailed that it becomes unnecessarily long, or so broad that it does not include the basic steps. Later, review the steps with the research group to ensure nothing was omitted. A JHA can be prepared as steps in a task or for the task as a whole. A typical JHA template is shown in Table 9-1.

Table 9–1: Sample Job Hazard Analysis Template

Job Hazard Analysis **Job Location: Laboratory Group: Date:**			
Activity or Job			
Completed By			
Equipment and Chemicals Required			
Work Steps and Tasks *Describe the tasks or steps involved in the work in the order performed*	**Hazards Identified for each Task/Step**	**Risk Level** *Risk Nomogram can be used (see APPENDIX B)*	**Control/Safe Work Procedures for each Task/Step** *Controls to be implemented*
Add rows, as needed			
Hazards Checklist [Note: This section can be modified, as needed. See Table D-1: Common Hazards and Descriptions in APPENDIX D.]			
Can someone be exposed to chemicals?	If so, what is the nature of the chemical hazard?		
Can someone slip, trip, or fall?	Can someone injure someone else?		
Can someone be caught in anything?	Can someone strike against or make contact with any physical hazards?		
Laboratory supervisor or PI comments			
Laboratory supervisor or PI signature		Date	
Lab worker signature		Date	

9.5. Keys to Success in Using the Method

To make a JHA useful the following questions should be addressed in a consistent manner. Addressing these questions will ensure that all hazards are identified and effective controls are implemented to target the most significant contributions to each identified hazard. A well-designed hazard scenario should address:

- Where the hazard is happening (the environment);
- Who or what it is happening to (the exposure);
- What precipitates the hazard (the trigger);
- The outcome that would occur should it happen (the consequence); and
- Additional contributing factors (fatigue, time, weather, experience, and so forth).

In addressing the above questions one should be open to new ways of approaching a hazard. So often in research one hears, "This is how I have always done this." What the investigator has to do when a hazard is identified is step back and ask, "Is this the best way to do this?" The identification of new hazards associated with familiar chemicals and processes should be evaluated as one prepares the JHA.

A completed JHA example is provided in Table 9–2. The example provided is very specific, but could easily be modified to become a generic neutralization JHA template. Hazard descriptions can be found in Appendix D.

Table 9–2: Sample Completed Job Hazard Analysis

Job Hazard Analysis **Job Location:** **Laboratory Group:** **Date:**			
Activity or Job	**Neutralizing the contents of a volumetric flask containing 350 mL of a solution of glacial acetic acid (200 mL); zinc(II) sulfate heptahydrate (10 g); potassium chloride (35 g); and water (150 mL). This procedure can be followed for neutralization of aqueous solutions where pH is the characteristic hazard. Down the drain disposal depends on federal, state, and local ordinances.**		
Completed By			
Equipment and Chemicals Required	**Stir plate; magnet; fume hood; ice; beakers; thermometer; 6 M sodium hydroxide; spill kit; waste container** **PPE required: chemical splash goggles; nitrile gloves; lab coat** **PPE optional: Face shield**		
Work Steps and Tasks *Describe the tasks or steps involved in the work in the order performed*	**Hazards Identified for each Task/Step**	**Risk Level** Risk Nomogram can be used	**Control/Safe Work Procedures for each Task/Step** Controls to be implemented
STEP 1: Add stir magnet to beaker. Transfer contents from the volumetric flask to a beaker of appropriate size (the beaker should be no more than ⅓ full)	**Inhalation, Spill, Dermal Contact** CHEMICAL (see below)	Low-to-Moderate Risk	• Work in fume hood (work behind glass with sash as low as possible) • Wear chemical splash goggles, gloves (nitrile will be sufficient for incidental exposure; remove and replace contaminated gloves), and lab coat.

Table 9–2: Sample Completed Job Hazard Analysis

			• Have a spill kit on location
STEP 2: Place beaker in an ice bath on stirring unit (no heat) and stir at a moderate rate. Suspend thermometer (0 ºC to 220 ºC capacity); if possible use a nonmercury thermometer.	Same as above	Low-to-Moderate Risk	• Same controls as above • Ensure the spill kit includes a mercury clean-up kit if using a mercury thermometer
STEP 3: Using a pH meter and electrode to monitor, add 6 M sodium hydroxide slowly to attain a pH between 5–9 Full range pH paper on a stirring rod can be used to avoid damaging a probe	Exothermic Reaction CHEMICAL (self-heating–physical hazard)	Moderate Risk	• Same controls as above • Stirring and a large enough beaker should be sufficient to dissipate the heat of neutralization • To prevent splashing, run base down a stir rod • Monitor temperature closely with the thermometer, if temperature approaches 90 ºC allow cooldown time • If heat generation cannot be controlled, lower hood sash, leave room, and notify PI or lab supervisor
STEP 4: Allow time for cooling and off-gassing and transfer to labeled waste container	Same as Steps 2 & 3	Low-to-Moderate Risk	Same controls as Steps 1 & 2

Hazards Checklist	
Can someone be exposed to chemicals? Yes	If so, what is the nature of the chemical hazard? (skin corrosion or irritation; specific target organ toxicity (single or repeated exposure)–health hazards
Can someone slip, trip, or fall? No	Can someone injure someone else? Yes
Can someone be caught in anything? No	Can someone strike against or make contact with any physical hazards? Heat can be generated and expel contents if not controlled
Laboratory supervisor or PI comments: Never neutralize in a volumetric flask. Volumetric glassware is not suitable for energetic chemical reactions due to the narrow neck which restricts heat and gas from escaping and can violently expel the contents. Never use a solid base (sodium hydroxide or potassium hydroxide) to neutralize an acid. Always work in a fume hood with glacial acetic acid. Glacial acetic acid is flammable. Evaluate the necessity for neutralization of this solution because this solution is not suitable for drain disposal due to the environmental hazards of zinc(II) sulfate on aquatic life.	
Laboratory supervisor or PI signature	Date
Lab worker signature	Date

9.6. How to Assess Effective Job Hazard Analysis Use

Because the nature of work in academic laboratories is dynamic, JHAs should be periodically reviewed to ensure they apply to the tasks being performed. The frequency of reviews will depend on the work. Even if the work has not changed, it is possible that during the review process new hazards, which were not identified in the initial analysis, are uncovered. It is particularly important to review the JHA when a near miss occurs, or if an illness or injury occurs.

There should be a periodic review of the content, effectiveness, and scope of the JHA. Once a JHA is in place and has been used in the laboratory environment, feedback from the users, such as the PI and laboratory workers, and feedback from others, such as the institution's EHS office, chemical hygiene officer (CHO), or auditors from outside agencies, can be collected and used to improve the JHA. Continuous improvement, particularly in such dynamic environments such as academic laboratories, applies to the JHA process.

Based on the circumstances, there may be indicators that the current JHA is not effective in the way it addresses known hazards. New or revised controls might be necessary. Any changes in a task's scope or the use of the laboratory-specific JHAs should be discussed with all of the group members. Laboratory workers should be trained on each new JHA. If JHAs are not being followed, then a review of the laboratory's health and safety strategy as a whole should be reviewed.

Incorporation into daily activities will promote better use. There are apps that can create JHAs on tablets and smart phones. JHAs can be incorporated into electronic notebooks. Having established JHAs available in the lab can assist in training new personnel. Using JHAs ensures nothing is overlooked and the training is consistent. Once a general JHA is developed for a process, it can be easily adapted for variations on the process. (See the sample neutralization JHA template in Table 9–2.)

Additional resources are available in APPENDIX D.

10. WHAT-IF ANALYSIS

10.1. Introduction

If you grew up in a northern climate, someone—perhaps a loved one, friend, or teacher—probably gave you some advice about driving in the snow or ice for the first time. The advice may have been to "drive like you have a raw egg between your foot and the accelerator pedal and your foot and the brake pedal." Or, you may not have received this advice and learned it on your own after an uncontrolled skid and experienced a near miss, an accident, or incident. Chances are you were in some way warned since the consequences of an incident involving a moving car can be severe. Once licensed and driving on your own you have been constantly practicing application of a hazard analysis technique.

This mental process of asking yourself about an action, its consequences, and whether there is a need to change the behavior—which is also known as a what-if analysis—is the same process you will apply to the assessment of hazards associated with an experiment or other activity in a research laboratory, just as consistently and intuitively as you would apply it in other life activities. We will describe the what-if analysis technique in this section.

"It is straightforward and easily learned, and can be used even by new or inexperienced personnel. This makes it a very useful tool for small or inexperienced organizations." R. Palluzi[13]

> **Quick Start: What-If Analysis**
> *See the cautionary statements regarding these quick start guides in Section 5.2.*
>
> **What it is:** Structured brainstorming to identify potential failures and assess associated risks.
>
> **Target applications:** Excellent for simple applications. Complex processes should be subdivided, when possible.
>
> **People involved:** A person or persons knowledgeable with the steps of the process to be reviewed. Best performed with multiple participants. New staff provides a fresh view that may be beneficial.
>
> **Getting started:** Determine scope; collect background information, including hazards associated with the chemicals and process specific data, such as flow rate; generate a complete list of questions; determine a complete list of answers, probability, and consequences; generate recommendations, either with prior step, or at end of the process.
>
> **Training:** Minimal
>
> **Core resources:** Section 10.8 (Using What-If Thinking Independently and in Teaching); APPENDIX B (Risk Rating); APPENDIX E (Supporting Information in Conducting What-If Analysis).

A what-if analysis consists of structured brainstorming to determine what can go wrong, then judging the likelihood and consequences of each scenario. The answers to these questions form the basis for making judgments concerning the acceptability of those risks and determining a recommended course of action for those risks judged to be unacceptable.[14] This analysis can be accomplished by a single individual but is best accomplished via a team approach for more complex processes and procedures. For many lab applications, the "team" may consist of the one or two members who designed the experiment, performed any maintenance on the apparatus, and facilitated their own hazard review. The what-if process will be described here in a formal sense, but it can also be performed, as appropriate, in a simpler fashion and still be of considerable value.

10.2. Under What Scenarios Might One Consider Using the Method?

A what-if analysis is a good candidate for simple research applications. Its use for more complex processes is also warranted, but needs to be applied using an organized approach that takes into account the specific needs of the review, such as the scope, complexity, single user or multiple persons involved in the process, and so forth.

Since it is based on a style of thinking that one uses regularly, it does not require extensive training, and it also lends itself well to group participation in which people with extensive experience can participate along with less experienced people. The questions, consequences, and recommended action format of this approach also works well in a research environment where teaching is the core mission. Rather than simply receiving a list of requirements to follow for a task or experiment, participants using this approach gain an understanding of the rationale behind—and subsequent appreciation for—the engineering controls, work practices, and protective equipment recommended for an operation. Concerns and controls learned through application of this method can be internalized by the participants and carried over to new tasks and experiments. Participants learn how to think critically about future processes.

For more complex processes, it is necessary to obtain a process description from the researcher, which includes a detailed equipment diagram, before beginning the hazard analysis review. The generation of drawings enables adequate review of each subsection of the process. These drawings also serve as lasting documentation for use in training new laboratory workers. The drawings and documented hazard review also serve as a discussion point for managing future changes in the experiment or process.

Assessing Existing Processes and Experiments

This technique can be used to analyze existing SOPs, which may have inherent failure modes that have not yet shown themselves. Through the use of appropriate what-if questions at each step of the SOP, this technique could help identify reasonably expected failures and reinforce the need for additional or revised engineering controls, revised work practices, or revisions to the use of PPE. However, it is highly recommended to analyze the processes and experiments before the work is conducted rather than afterward.

10.3. Limitations

One limitation of the what-if analysis is that it relies on having the right expertise to ask the right questions. However, this limitation also applies to other hazard review techniques. As we will discuss later, the addition of a HazOp deviation matrix to develop additional questions or references to a previously developed checklist of questions to the free-form what-if analysis can achieve a more robust review. The examples of what-if analyses that follow will include some questions derived from a HazOp deviation matrix.

Quick Summary of the Review Process

The review process starts when the researcher most familiar with the experimental procedure walks the team through each step of the process using a detailed equipment diagram, along with any prepared operating guidelines. As the team reviews the operation or process using a form similar to one illustrated in Table 10–1, they consider any what-if questions of potential concern. The what-if questions should relate to each step of the experimental procedure considering what may happen when the process progresses as planned and also when deviations from the intended experimental steps occur.

The review team then makes judgments regarding the probability and consequences of the what-if answers. If the conclusion of the probability and consequence is considered unacceptable, a recommendation for action or further investigation is recorded. A conclusion considered acceptable should also be recorded with "no action" listed in the recommendations section. Unless an obvious solution is at hand, it is often best to simply indicate the need for modification and proceed with the remainder of the review. Once the review is completed for the entire process, the analysis is then summarized and prioritized, and responsibilities are assigned for follow-up actions. An additional column to the sample form provided in Table 10–1 can also be added, particularly for larger systems with multiple stakeholders, listing the person or group responsible for the corrective action.

Table 10–1: Basic What-if Hazard Analysis Form

Division:	**Description of Operation:**	**By:** **Date:**

What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**

10.4. Keys to Success

Preparing for the Review

The first step is to determine what type of assistance will be needed to conduct the review. Considerations include the research staff's familiarity and experience with the experiment and apparatus to be reviewed, along with compliance with site guidelines for conducting hazard reviews. **Assembling a knowledgeable and experienced team is the key to conducting a successful what-if analysis.** Individuals experienced with the design, operation, servicing, and safety of similar equipment or facilities is essential. Inclusion of lab personnel who are new to the operation will also provide a valuable educational experience, as well as provide fresh eyes to uncover factors that those already familiar with the process may not see. The addition of research peers who have previous experience with the experimental process can be particularly helpful.

We will walk through the what-if analysis procedure using a laboratory example where a slightly more rigorous approach may be needed. A what-if analysis can be applied to all laboratory activities and often by a researcher working alone to conduct a single laboratory action. While the method below can be simplified for many tasks, the user is encouraged to take a more rigorous approach, especially in terms of documenting the review, whenever possible.

Determining the Scope of the Review

Next, one must determine the scope of the review. This review will often center on a single piece or multiple pieces of equipment used in the experimental process, which may share a common utility feed such as gas supply lines. In addition to considering the scope of the equipment review, process review scope should be considered. Often, the scope of the hazard review will not include maintenance activities because of time limitations. However, for processes in which maintenance operations may be complicated—or present safety, equipment, or process problems if not performed correctly—it may be advantageous to include this discussion in the hazard review, while the appropriate people are already assembled and the information is fresh. A clear definition of the boundaries of the analysis is a good way to begin the review.

Assembling Key Information

For an effective review, it is necessary to assemble the necessary background information and provide this information to the review team beforehand. APPENDIX D contains information concerning the chemical and physical characteristics of chemicals and gases used in the experiment or process, as well as fire, reactivity, toxicity, and other information which can be gleaned from Material Safety Data Sheets and other useful references. A list of the experimental equipment's chemical and gas compositions, operating pressures, flow rates, run times, and other applicable parameters should also be compiled and made available to the review team. It is also helpful to include any of the equipment's potential health and physical hazards, such as ionizing or nonionizing radiation, high temperature, high voltage, or mechanical pinch points, along with design safety features such as interlocks. A checklist is useful for this purpose. Prior to the review, it is helpful for the team to look at the equipment and process or view photographs of similar equipment and processes.

Figure 10-1. Picture of solvent-drying apparatus

Detailed diagrams of the equipment are perhaps the most valuable pieces of information needed for a what-if analysis. This allows for a component-by-component examination of error possibilities by breaking the process into sections and examining them one by one. These drawings are also a valuable record for future training and can serve as the basis for further analysis when changes to the process, experiment, or equipment are made. The examples to the right and below show a photograph (Fig. 10–1) of a solvent drying apparatus along with a detailed schematic drawing (Fig. 10–2) which can provide improved visibility of the parts often hidden from view and better detail for a hazard analysis.

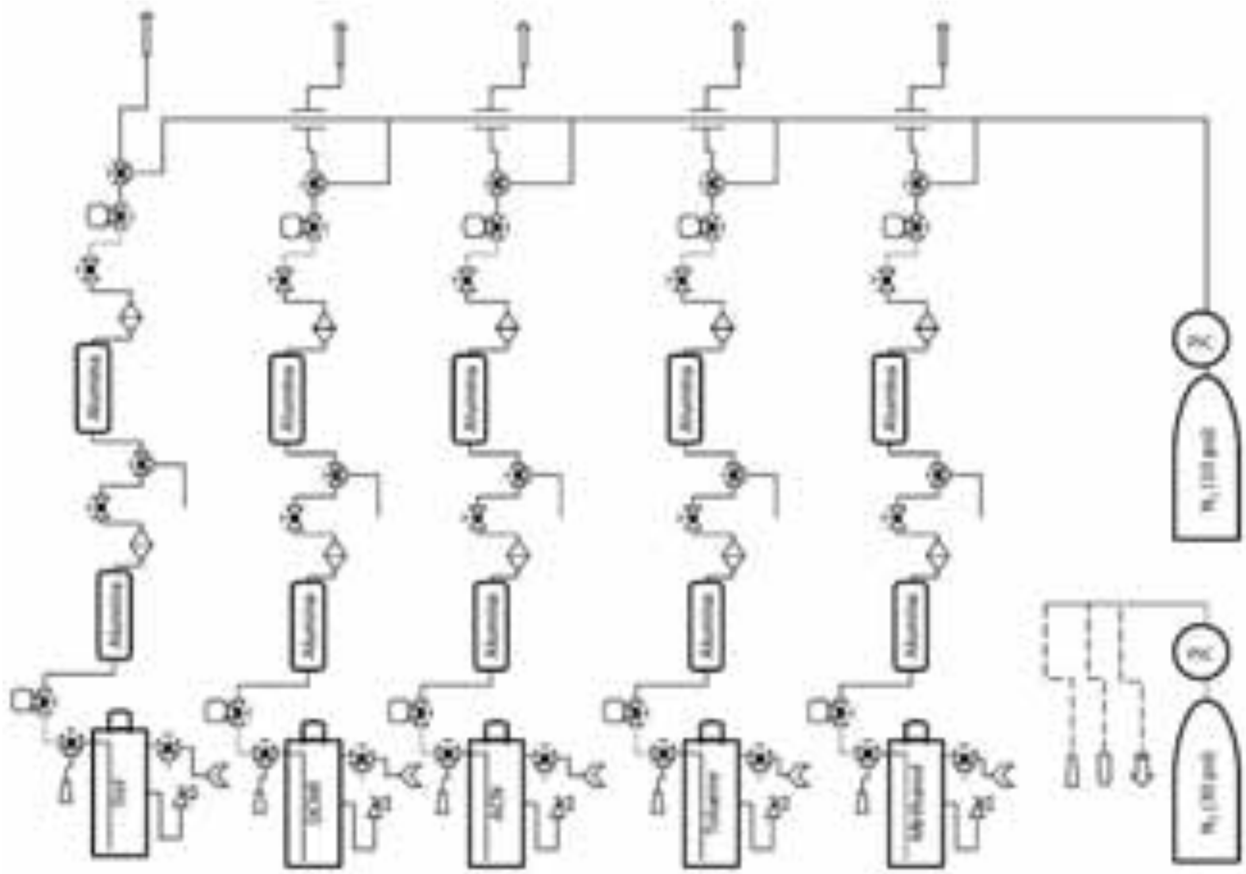

Figure 10–2. An example of a detailed equipment diagram and key

In many cases the equipment may be very basic and a detailed instrument drawing is not needed. The type and content of photos or diagrams for existing equipment can influence the selection of what-if questions. Fig. 10–3 is a diagram of a rotary evaporator.

Some questions may arise here that may not have come to mind during a review of the diagram in Fig. 10–2. For example: Did you consider materials of construction of the supply lines in Fig. 10–2? Did you consider how the connections were made? It is possible that by viewing the drawing in Fig. 10–3[h] you were more apt to consider the what-if consequences of an improper water connection. (For example, flooding—possibly severe—that affects multiple floors of the building if the apparatus does not have secondary containment, which can be a common problem in research laboratories)?

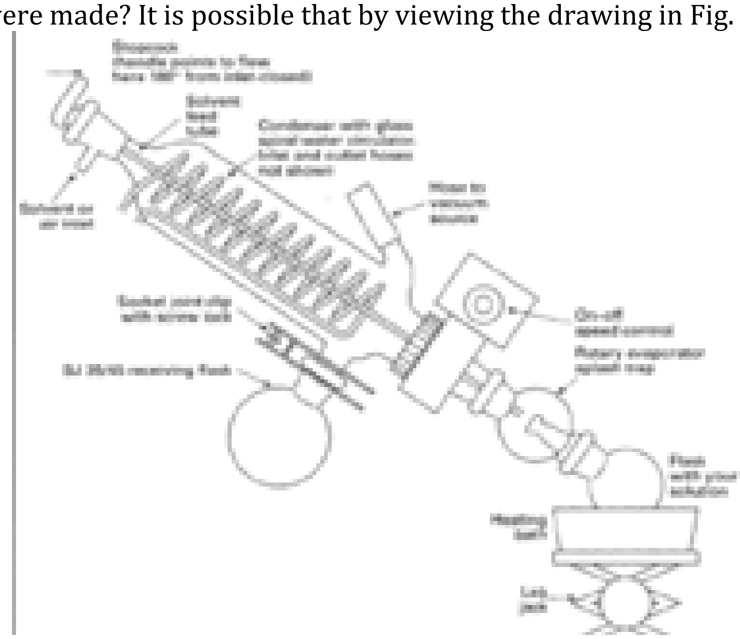

Fig.10-3: A drawing of a rotary evaporator

If critiquing a piece of equipment, which has already been constructed, a visible review of the equipment or photo, such as the one shown in Figure 10–3, may prompt additional questions and can be used to

[h] *Source:* Accessed from http://3.bp.blogspot.com/-EauZVQxlXdM/TetVKtacmgI/AAAAAAAAADU/oPHbnAdj18A/s1600/Rotary+Evaporator.png (accessed March 9, 2015).

supplement the drawings or detailed equipment diagram-based review. Later in this section we will review modifications to a simple what-if review to make it less likely to omit important questions, regardless of whether you are reviewing the use of an apparatus already constructed, or one that is in the latter stages of design and has yet to be constructed. **A review at the design stage is preferable to an after-construction review to avoid the cost and time associated with modification of completed equipment to add necessary safety features.**

Set Expectations before the Review

Progress in moving through a team hazard review can be slowed down with debates about the acceptable level of safety. As noted earlier in this section, one may wish to defer solutions to the end of the review, so time is not lost debating the best solution to the recommendations for corrective action. It may be helpful to include a short briefing at the outset of the review to establish guidelines regarding those situations which will require resolution through the use of engineering controls instead of reliance on standard practices which must be remembered by lab staff to avoid serious consequences. Based on many years of experience in the petrochemical industry, Trevor Kletz provides the following reminder regarding the need for engineering controls for certain high risk operations: “They know what they should do, want to do it, and are physically and mentally capable of doing it. But they forget to do it. Exhortation, punishment, or further training will have no effect. We must either accept an occasional mistake or change the work situation, so as to remove the opportunities for error or make errors less likely.”[15]

Conducting the Review

Once the team has reviewed the information package, the next step is to conduct the analysis. A note taker should be assigned to document the review into a format similar to the samples provided below or into a format recommended by their institution. What-if analyses templates may also include a column that indicates the name of the assigned person or job role to perform the recommended action. It is helpful to provide this clarity while the appropriate parties are all present. Listing requested dates for closure on follow-up actions on the review form may also be desired. It may be useful to record the meeting to assist the note taker. Hazard review documentation should be saved for future use for training purposes or for reference when experiment changes occur. Computer software is available to aid in documenting frequent or more complex reviews.

A review team leader, or facilitator, walks the team through the review process, with group members proposing various what-if questions. The leader should keep the team moving forward, occasionally tabling some items as “further investigation needed” and resisting efforts from the team to dive into detailed and time-consuming problem solving on an individual item rather than identifying the item as “needing action.”

The review team moves through the experimental process, step-by-step and component-by-component, to determine likely sources of errors and failures, based on the experience of the review team and lessons learned from homework completed in advance of the review.

What-if questions should include possible human errors of omission or commission, equipment component failures, and deviations from the planned experimental sequence, including, but not limited to: the loss of utilities and other changes in critical parameters, such as temperature, pressure, time, and flow rate. Review of the HazOp deviation matrix, later in this section provides the basis for additional deviation questions. It may be helpful to prepare a list of some questions that should be routinely asked in advance of the review, as well as questions which prompt consideration of SOPs and behaviors which should be continually reinforced.

Examples of What-If Questions

Human Factor-Driven What-If Questions

What-if questions to consider should include those that stem from human errors, which you should always assume will occur, regardless of training and experience. Some sample scenarios associated with human errors include:

Material too concentrated	Material too diluted
Valve/stopcock not opened	Valve/stopcock not closed
Valve opened in wrong sequence	Valve closed in wrong sequence
Inert gas purge omitted	Unintended materials mixed

Additional human errors may include: readings missed or ignored, warnings missed or ignored, or errors in diagnosis. Poor layout of instructions or instrumentation, and inadequate understanding of human factors will often be a contributing factor to human errors.[16] These questions can drive consideration of either written SOPs or a decision for interlocks, automated sequences, or other engineering controls when these errors could have a severe impact.

Utility Driven-What-If Questions

The following questions concern utilities, which are key to the support of the experiment or process.

What if?	Drives consideration of:
Power is lost	Automatic shutoffs and emergency power
Power is restored automatically after loss	Manual restarts
Laboratory ventilation is lost	Automatic shutoffs, emergency power, and redundant mechanical exhaust fans

Experimental Equipment or Ancillary Equipment-Driven What-If Questions

Consideration of failure of materials or components may result in decisions for additional controls or changes to higher rated or alternative types of materials and components.

What if?	Drives consideration of:
Unexpected over-pressurization	Pressure relief devices and barriers, and PPE
Glassware breaks during reaction	Spill control and PPE
Failure of equipment cooling	Alarms, automatic shutoffs, and emergency shut-off procedures

Personal Protection-Driven What-If Questions

This should be included since, despite best efforts with hazard reviews and training, incidents will occur.

What if?	Drives consideration of:
Body impacted by liquids or solids	Physical barriers
Exposure to vapors or gases	PPE and ventilation
Exposure to respirable particles	Use of wet contamination control methods, ventilation controls, and respiratory protection

Miscellaneous Issues

The team may add additional questions prior to the review based on experience or the nature of the process to be reviewed. Later in this section, we discuss the means to generate additional questions related to deviations from the expected experimental procedure.

The potential to fail to ask the right questions is one of the shortcomings of a free-form what-if analysis. This technique can be modified to include a checklist of questions, such as those noted above, one might always want to include for a certain type of experiment or process.

When using a checklist for developing a what-if question set or using checklists in the manner described in Section 11, a reference checklist should be routinely updated with new questions based on lessons learned from incidents at your site and at other research institutions. Many incidents have been compiled in lessons learned databases or have been included in experimental summaries available online.

10.5. Hazard Operability Analyses

A what-if approach can be further modified to include questions about deviations in important parameters to identify the effects of deviations from normal events. This is known as a HazOp analysis. For example, after referencing the Deviation Matrix table below, the team conducting a what-if analysis for an experiment, which involves heating a material to a certain temperature, may also include the likelihood and consequences of the various deviations from the designated heating time, such as "loss of" heat, "too much" heat, or "too little" heat. The HazOp methodology incorporates deviations from the usual SOP through development of additional questions, such as:

- If something is provided, what if it is lost (power, heating, cooling, purge gas, inerting gas, stirring, and so forth)?
- If something is provided, what if you have too much or too little (heating, cooling, gas pressure, system pressure, system vacuum, and so forth)?
- If you have valves or stopcocks, which must be actuated, what if you have forgotten to open or close, or you opened or closed at the wrong time or sequence?
- If something is incompatible with your experiment or process (air, oxygen, moisture, and so forth), what happens if your process sees it?

Use of HazOp methodology reduces the likelihood of the review team missing an analysis of the potential for, and consequences of, some circumstances worthy of consideration.

First, let's define the HazOp methodology in more detail. HazOp questions can be, in a simplistic view, deviations from the usual process. HazOp questions add an assessment of what may happen when deviations from the usual process occur. You can incorporate them as additional what-if questions or, if conducting a highly detailed review, you could compile them as a separate HazOp review. Refer to a matrix for appropriate HazOp questions to add to your review. Table 10–2 includes parameters on one axis and guide words on the other axis. Placing the parameters and guide words side-by-side can reveal, for example, too much heat. Deviation matrices can be constructed, such as the one below provided by David Leggett, which can assist in providing applicable process deviation conditions for the review team to consider.[17]

Table 10–2: HazOp Study Deviations Created from Design Parameters and Guide Words

	Guide Words for HazOp Deviations						
Parameter	**More**	**Less**	**No**	**Reverse**	**As well as**	**Part of**	**Other than**
Flow	Higher flow	Lower flow	No flow	Reverse flow	Extra material in stream	Misdirected flow	Loss of flow control
Pressure	Higher pressure	Lower pressure	Vacuum		Explosion		
Temperature	Higher temperature	Lower temperature					
Level	Higher level	Lower level	Empty	Loss of containment			Different level
Time	Too long/too late	Too short/too soon	Missed hold time				Wrong time
Utilities	Too much flow, pressure, etc.	Partial loss of utility	Complete loss	Utility feeds reversed	Utility contaminated		Wrong utility hookup
Reaction	Fast reaction/runaway	Slower reaction	No reaction	Back reaction	Unexpected reaction(s)	Incomplete reaction	Wrong recipe
Quantity	Too much added	Too little added	None added	Material removed	Additional chemical		
Composition		Impure or contaminated	Unknown purity		Contaminant added	Contaminant present	Wrong chemical
Agitation	Mixing is too fast	Mixing is too slow	No mixing	Phase forms			Loss of agitator control
Phase	Additional phase forms	Loss of a phase	Loss of all phases	Emulsion forms	Rag layer forms		
PPE		Insufficient PPE	PPE not used			Extra PPE needed	Incorrect PPE, wrong glove
Inerting	Higher pressure	Lower pressure	None	Inerting lost		Insufficient inerting	

Source: Leggett, D. J. Hazard Identification and Risk Analysis for the Chemical Research Laboratory, Part 2. Risk Analysis of Laboratory Operations. *Journal of Chemical Health and Safety.* Elsevier Science, Inc.: Amsterdam, Sept–Oct 2012; Vol. 19, No. 5; pp 25-36.

10.6. Completing the What-If Analysis

After the review team has finished generating a list of what-if questions for the portion of the process under review, the team answers the question: "What would be the result of that situation occurring?"

Next, the team considers the likelihood and consequence of the what-if situation. The team develops a recommendation based on the probability and consequences. In some cases, where probability is very low, consequences are not severe, and the action to correct the condition would involve significant cost and time, the team may note a "no recommendation" response. In other cases, the need for corrective action may be obvious.

10.7. Examples of What-If Analyses

Table 10–3 shows the results of a what-if analysis for the use of a stirring hotplate with flammable liquid. Table 10–4 shows the results of a what-if analysis for a toxic or flammable small gas cylinder in a fume hood.

Table 10–3: Flammable Liquid Example

Department: Chemistry	**Description of Operation: Use of stirring hotplate with flammable liquid**			**By: Review Team Date:**
What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Use on unventilated benchtop	Flammable vapors could accumulate and reach source of ignition fire	High	Extensive damage/downtime and costs	Use in fume hood
	Overexposure to toxic vapors	High	Adverse health effects	Use in fume hood
Mechanical failure of fume hood exhaust fan	Lack of exhaust but vapors still accumulate and ignition sources still present	Moderate	Adverse health effects	Interlock hotplate power to exhaust monitor
	Fire	Moderate	Damage	Use explosion proof hotplate
Power failure during use (see also loss of heat and loss of stirring below)	Lack of exhaust, vapors may accumulate but at lesser magnitude, potential fire	Very high	Damage/health effects	Connect exhaust fan to emergency power
	Reaction becomes unstable	Very high	Failed experiment, exposure to unknown products	Conduct a review of all possible reactions and outcomes
Hotplate malfunction, electrical arcing	Possible fire in hotplate and ignition of solvent vapors	Moderate	Equipment damage/personnel injuries	Check electrical connections (plugs and wires); pretest

Table 10–3: Flammable Liquid Example

Department: Chemistry	Description of Operation: Use of stirring hotplate with flammable liquid			By: Review Team Date:
What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
(switch/ thermostat)				hotplate before starting; use explosion proof hotplate
Hotplate malfunction, supplies too much heat	Heat material above flash point	Moderate	Fire, damage, personnel injuries	Interlock hotplate to temperature feedback loop
	Reaction becomes unstable	Moderate	Personnel injuries	Do not leave reaction unattended; check temperature of reaction at regular intervals
	Unintended reaction occurs	Moderate	Hazardous byproducts	Conduct a review of all possible reactions and outcomes
Hotplate malfunction; supplies too little heat; if no heat, see loss of power above	Reaction unsuccessful	Moderate	Lost time and materials	Interlock hotplate to temperature feedback loop
	Reactants degrade/ evaporate	Moderate	Lost time and materials; hazardous byproducts	Do not leave reaction unattended; check temperature of reaction at regular intervals
Loss of Stirring	Superheating of portion of flask contents	Very high	Vessel fails/fire	Interlock hotplate to temperature feedback loop
	Unintended reaction occurs	High	Hazardous byproducts	Conduct a review of all possible reactions and outcomes
	Reaction unsuccessful	High	Lost time and materials	Do not leave reaction unattended; check temperature and stirring of reaction at regular intervals
Spill from container being heated	Flash fire	High	Fire/damage/ personnel injuries	Do not handle hot vessel
	Reaction unsuccessful	High	Lost time and materials	Do not leave reaction unattended
Heating period is too long	Open container boils dry	High	Failed reaction	Connect hotplate to timer and temperature feedback loop
	Vessel breaks	High	Vessel fails/fire	See above
	Reaction unsuccessful	High	Lost time and materials	Do not leave reaction unattended

Table 10–3: Flammable Liquid Example

Department: Chemistry	**Description of Operation: Use of stirring hotplate with flammable liquid**			**By: Review Team Date:**
What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Heat period is too short	Unreacted starting material	High	Hazardous byproducts	Connect hotplate to timer and temperature feedback loop
	Unstable products	High	Personnel injuries	Conduct a review of all possible reactions and outcomes
	Reaction unsuccessful	High	Lost time and materials	Do not leave reaction unattended
Container breaks	Flash fire	High	Fire/damage/ personnel injuries	Check container for signs of prior damage or use new container
Residual process gas in equipment when opened	Vessel breaks	High	Fire/Damage/ personnel injuries	Do not use a closed container; use container with a pressure relief device
	Vessel cannot be opened	High	Lost time and materials	See above
	Unintended reaction occurs	High	Hazardous byproducts	Conduct a review of all possible reactions and outcomes

Table 10–4. Hazardous Gas Example

Department: Chemistry	**Description of Operation: Use of toxic or flammable gas in small cylinder in fume hood**			**By: Review Team Date 7/12**
What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Power to exhaust fan is lost	Possible exposure to toxic gas if gas flow continues	Very high	Serious	Provide emergency power and normally closed gas valve
Mechanical failure of exhaust fan?	Same as above	Moderate	Serious	Same as above and consider connection to multiple fans
Regulator fails or creeps, and allows full cylinder pressure to apparatus	Apparatus or tubing failure and gas release if not able to handle full cylinder pressure	Low	Serious	Use flow restricting orifice in cylinder valve to limit flow or install excess flow shutoff valve; consider gas monitor that is interlocked to shut down gas flow

Table 10–4. Hazardous Gas Example

Department: Chemistry	**Description of Operation: Use of toxic or flammable gas in small cylinder in fume hood**			**By: Review Team Date 7/12**
What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Cylinder regulator gauge blows	High pressure gas release and possible exposure	Low	Serious	Same as above
Gas leak downstream of regulator; hood face at 18 inches	Lower pressure gas release but potential exposure which increases with gas flow rate	Moderate	Serious	Same as above
Gas leak downstream of regulator; hood face at 30 inches with operator at hood	Same as above but high potential for exposure	Moderate	Serious	Same as above and restrict hood opening while gas flowing via interlock, or stop and consider use of a self-contained breathing apparatus (SCBA) if access during flow is necessary
Cylinder contains wrong contents	Potential exothermic reaction or if not, ruined experiment and apparatus	Low	Serious	Check cylinder tag, not just cylinder stencil
Cylinder pressure is incorrect	Regulator gauge could fail; rapid release of high pressure gas	Low	Serious	Same as above (see also https://www.aiha.org/get-involved/VolunteerGroups/LabHSCommittee/Pages/Compressed-Gas-Incidents.aspx (accessed March 9, 2015))
Apparatus contains oxygen when gas is introduced	Explosion potential if gas hits flammable range and ignition source is present	Moderate	Serious	Assure purge with inert gas before introducing flammable gas if ignition source may be present (consider automation)
Residual process gas in equipment when opened	Potential exposure to toxic gas	Moderate	Serious	Same as above; test atmosphere or use SCBA

10.8. No Single Format or Approach to What-If and HazOp

In APPENDIX E, Leggett[17] provides tables E-1 and E-2 as excellent examples of use of a SWIF and HazOp analyses of a Wolff-Kishner Reaction. In these examples, what-if and HazOp are provided as separate tables. In tables 10–5 to 10–9, column heading *C* refers to consequences (severity), column heading *F* refers to frequency, and column heading *R* refers to risk rankings, which are defined in the table notes. These tables illustrate an interesting approach for hazard assessment in a research setting, whereby the experimental procedure steps and the hazard assessment of each corresponding step are integrated.

10.9. Using What-If Thinking Independently and in Teaching

Rules and regulations sometimes do not cover all situations that might occur in a research laboratory. Individuals must assess and make the right decisions independently on many occasions. The following are examples of noncomplex decisions one might make in a research environment related to personal safety. These actual incidents are useful for teaching.

Table 10–5: Entering an Empty Lab (Example)

The first involves entering a lab which is empty. Hill and Finster report instances of explosions from over-pressurized containers which may be delayed.[18]

This example illustrates the value of a lessons learned database. Once people understand explosions can occur in empty labs, they are more likely to choose the right course of action regarding the use of protective equipment.

Division: **Chemistry**	**Description of Operation:** **Entering empty laboratory**	**By:** **Date:**

What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Enter empty laboratory without wearing protective glasses	Explosion possible in empty lab from delayed failure of over-pressurized containers or equipment	Low	Extreme severity if explosion while lab is entered and protective equipment not used	Always wear eye protection when entering a lab, even when void of apparent work in progress

Table 10–6: Management of Change (Example)

The next example illustrates the essential principle of an important safety concept called "management of change." A management of change analysis should be conducted before changes to the experimental apparatus, materials, or procedure are implemented to evaluate whether the planned changes present new risks and how any new risks should be managed.

A moisture removal column, consisting of a plastic housing loaded with desiccant located downstream of a gas regulator, was relocated to another gas system running at significantly higher pressure.

Division: **Chemical Engineering**	**Description of Operation: Removal of desiccant column from one gas system and placement on another**	**By:** **Date:**

Table 10–6: Management of Change (Example)

What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Column is not rated for pressure of new system	Column could explode	Probable, if no lower rated component in gas stream	Severe	Assure column is rated for cylinder pressure or install an overpressure device with relief pressure below pressure rating of column

Table 10–7: Inert Materials and Nonchemical Effects (Example)

It is useful to provide examples when inert materials and nonchemical effects are involved, such as a blowout of a window in an ultrahigh vacuum system due to pressure buildup during backfill with nitrogen.				
Division: **Materials Science**		**Description of Operation:** **Backfill of nitrogen into ultrahigh vacuum system**		**By:** **Date:**
What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Nitrogen backfill exceeds atmospheric pressure	Windows in vacuum system could blow out if moderate positive pressure is applied. (The system can see very low negative pressure but only modest positive pressure.)	Very likely at modest positive pressure	Severe, if personnel located in front of window at time of failure; equipment damage and downtime	Install pressure relief on nitrogen backfill line based on understanding of window failure pressure and backfill pressure requirement

Table 10–8: Lockout or Tagout Principle (Example)

Here is an example which illustrates the important principle of lockout or tagout for hazardous energy sources, for example, electricity, pressure, or steam.				
Division: **Engineering**		**Description of Operation:** **Equipment using hazardous gases is no longer being used**		**By:** **Date:**
What if?	**Answer**	**Probability**	**Consequences**	**Recommendations**
Parts are scavenged from a discontinued module of a multi-module processing unit while other modules are still in use	Components essential for preventing hazardous gas supply to scavenged module could be inadvertently removed	Moderate	Severe	Use proper lockout procedures on isolation component on discontinued module

Table 10–9: Material Substitution (Example)

<table>
<tr><td colspan="5">In this final example, a nonflammable hydrogen mixture was replaced with pure hydrogen and an explosion resulted. This incident highlights the need for an effective management of change procedure.</td></tr>
<tr><td colspan="2">Division:
Chemistry</td><td colspan="2">Description of Operation: Glove box use of nonflammable hydrogen mixture</td><td>By:
Date:</td></tr>
<tr><td>What if?</td><td>Answer</td><td>Probability</td><td>Consequences</td><td>Recommendations</td></tr>
<tr><td>Hydrogen mixture is replaced with pure hydrogen</td><td>Ignition of explosive mixture possible if experimental design is not appropriate for use of a flammable gas mixture</td><td>Moderate</td><td>Severe</td><td>Assure appropriate management of change procedures are in place to re-evaluate setup for flammable gas use</td></tr>
</table>

10.10. Measures of Success with this Approach

Successful use of a hazard review methodology can be measured in numerous ways. One measure of success is the identification of hazards which would not have been identified without the review. Other measures of success include improved understanding of reasons for precautions, which have a more lasting effect on the student or employee. The lasting documentation of experimental apparatus and hazard review findings can be used for training of future students and employees. The review documents will also serve as a sound basis for comparison when future changes to the procedure, materials, or equipment are planned and the management of change analysis is conducted.

Debriefing of participants at the conclusion of the what-if analysis is another measure of success, which may include positive feedback, such as improved understanding of “nonsafety” but process quality issues that were highlighted and resolved through the use of the hazard analysis technique.

A longer term measure would include analysis of incidents that may occur despite the implementation of a what-if analysis. **This type of careful root cause analysis of the cause of failure—and understanding why it was not caught during the review process—is critical to improving the review process and indicating the need for use of an additional or revised hazard assessment technique.**

Once laboratory personnel have conducted a detailed review or perhaps multiple simple reviews, the what-if analysis “way of thinking” can become a habit, carrying over into the professional activities of students and research staff.

10.11. Realizing Limitations and Seeking Assistance

In this section, we discussed a methodology, with a few variations, that can be applied to large processes and smaller experiments or tasks. Academic and private research institutions often engage in a wide array of processes which can range from simple operations performed on the benchtop or in a fume hood to complex engineering or physics labs where large and highly complex equipment may be involved. For this reason, one or more hazard review techniques or an approach adaptable for the situation at hand is needed.

The reader should also realize that methodologies, including, but not limited to, techniques such as FTA and FMEA are not described in this publication but may be appropriate for certain highly complex equipment in which the consequences of failure may be severe. The graduate, postdoctoral student, or PI should consult with EHS staff members when they suspect their experiment or process may be complicated enough to require additional assistance from site personnel, outside assistance, or the use of more complex review methodologies. See publications, such as the American Institute of Chemical Engineers' *Guidelines for Hazard Evaluation Procedures,* 2nd ed., for further information on appropriate hazard review methods for various applications.

Additional resources are available in APPENDIX E.

11. CHECKLISTS

11.1. Introduction

A properly constructed checklist can be an effective tool for assessing hazards and implementing safe work practices. Of the hazard identification and evaluation methods reviewed in this guide, checklists are the most prevalent method used by researchers and safety professionals. As researchers are familiar with the checklist concept and methodology, there will be less of a learning curve and time required to implement and complete a new safety checklist versus a different hazard evaluation methodology.

An important benefit to the checklist methodology is its ability to quantify risk and provide scalability across an organization. This allows the researcher and the organization to conduct a comparative risk assessment to identify specific processes or research operations that present higher degrees of risk to the organization. This is critical to help prioritize and allocate limited available resources, such as budget or time, to the higher risk areas.

In its basic form, a "safety" checklist can be a list of high risk materials, operations, or critical safety equipment. This basic checklist may not appear to be a hazard assessment. However, completing this checklist can help users identify "high" hazard operations or missing or inoperable safety equipment the researcher may not have previously recognized. Once this initial screening is completed, additional hazard assessments (for example, checklists, job hazard assessments, or what-if analyses) may be needed to further assess the specific higher risk work activities and identify appropriate exposure control methods. In a more complex and integrated format, a checklist can begin to incorporate aspects of a job hazard assessment, what-if analysis, or SOPs into a more structured checklist to help guide the user in completing a risk assessment and identifying the appropriate exposure control methods.

This section will provide clarification of the steps involved in developing effective checklists, as well as examples of behavior and process-based safety checklists compiled from peer academic research institutions.

Quick Start: Checklists

See the cautionary statements regarding these quick start guides in Section 5.2.

What it is: Structured process to assess hazards and quantify risk. Most common method used by researchers and safety professionals.

Target applications: Can be used to evaluate processes, behaviors or both. Scalable across organization.

People involved: Should include both professionals and technical staff in a collaborative process.

Getting started: Determine purpose, audience, and who will use tool. Develop concise procedures and checklist items, including allowable responses. Beta test with departmental, professional, and technical staff.

Training: Verify users understand the intent of each checklist item.

Core resources: Table 11-1 (A checklist for creating checklists); Section 11.3 (Benefits and Limitations of Checklists); Sections 11.8–11.12 (Types of Checklists); APPENDIX B (Risk Rating); APPENDIX F (Supporting Information for Use of Checklists).

11.2. Applicability and Uses for Checklists

A checklist is a type of informational job aid used to reduce failure by compensating for potential limits of hazard recognition, human memory, and attention to specific details. A checklist helps to ensure consistency and completeness in carrying out a task from an individual user or multiple users within a work group or institution. However, a checklist is considered to be a "finite" tool because the common expectation but potential pitfall for the checklist user is to limit the scope or assessment to the specific questions listed rather than a holistic hazard analysis for the process being evaluated. It is thus critical in the checklist development process to:

- Clarify an explicit checklist scope;
- Collaborate with professionals knowledgeable in both the work tasks, such as a PI, and hazard assessments, such as a safety professional;
- Identify and obtain the required departmental and institutional support to implement the checklist and, if necessary, stop unsafe work practices and behavior;
- Identify critical work flows to successfully complete the task;
- Identify potential hazards associated with the work flow steps;
- Establish appropriate safe work practices (that is, administrative controls, engineering controls, and PPE);
- Integrate safe work practices into the critical work flow;
- Establish triggers to recognize changes in work practices, identify new hazards, and report accidents and near misses;
- Develop concise procedures and checklists;
- Test the checklist "in the field" with the researchers;
- Modify and finalize the checklist; and
- Educate the checklist user, PI, and work group. Depending on the scope and scale of the checklist, departmental and institutional leadership may need education and training on their roles and checklist goals to successfully implement the checklist.

Checklist Scope and Complexity

When developing a checklist, the full scope of the process being evaluated must be considered and defined. Depending on the extent and complexity of the scope, a series of smaller, more manageable checklists may need to be developed. This was evident in Dr. Peter Pronovost's initial line infection checklist which did not look to address all risks and hazards associated with patient care in intensive care units (ICUs). Rather a smaller, finite scope was established to address the risks associated with this clinical process. A "Checklist for Creating Checklists"[8] provided in Table 11–1 identifies critical factors for developing effective checklists.

Understanding the Audience and Checklist User

A key step to developing an effective checklist scope is to determine the purpose of the checklist, its audience, and ultimately the checklist user. This serves a few important functions, including knowledgeable collaboration, checklist scope or context, and institutional support.

- **Knowledgeable collaboration:** It is important to understand and identify your audience to solicit their knowledge, expertise, and participation in the checklist development process. Professionals, as well as technicians, from these areas should be a part of the checklist development process to better define critical work flows and subsequent hazard assessments associated with the checklist scope. While the professionals have the subject matter expertise to identify the critical work flows, the technicians may have more operational experience to elaborate on the day-to-day challenges in conducting the work and may be able to share accident and near miss details important to the overall hazard assessment and checklist development. This should result in a more thorough hazard assessment and a reduced likelihood that significant hazards and risks are not overlooked.

- **Checklist scope or context:** It helps to identify the goal of the checklist and the context for which the checklist is sculpted. For example:

  "Is this a checklist for a user to implement a defined work task with integrated safety protocols?" or

  "Is this a checklist for a user to conduct a more holistic hazard assessment of a new, undefined task or set of tasks?"

Table 11-1. A checklist for creating checklists

Content-Related Checks

- Involve the professionals who do the work (e.g., surgeons, nurses) in creating the checklist
- Keep the checklist short
  - Five to nine items is the rule of thumb, but the number of items will vary depending on the situation.
  - Paper checklists should fit on one page
- Incorporate "Killer Items"—or the steps that are most dangerous to skip and are sometimes overlooked.
- Use simple, exact wording and language that is familiar to team members.
- Include communication checks at important junctures (e.g., at the start of surgery), which prompt team members to share their expertise in identifying, preventing, or solving problems.
- Ensure the checklist is easy to read (e.g., use sans serif type, use both upper- and lower-case text, avoid distracting colors, graphics, or colors).

Procedure-Related Checks

- Determine whether you want to implement a "Do-Confirm" checklist (i.e., first complete the tasks, then pause to run the checklist), or a "Read-Do" checklist (i.e., read the checklist item by item while completing the tasks).
- Authorize a specific team member to kick off the checklist and ensure the team completes it (e.g., the circulating nurse kicks off the "WHO Safe Surgery" checklist).
- Set up a clear procedure for when to use the checklist (e.g., when the patient is wheeled into preop).
- If the checklist is longer than a few items and/or relates to a multistep process (e.g., a surgery), identify clear pause points, or times when the team must pause to complete specific sections of the checklist.
- Test the checklist in a real-world environment. Revise, as needed, and keep testing until the checklist works for team members.

Source: Gawande, A. *The Checklist Manifesto: How to Get Things Right;* Metropolitan Books/Henry Holt and Company LLC: New York; 2009.[8]

If the checklist is for a defined work task with integrated safety protocols, the checklist would typically be more “process-based” in nature. Dr. Pronovost’s checklist is an example of a process-based checklist in which the work task can be well defined, such as placing lines into patients, and the specific safety protocols are explicit, such as five critical steps. If the checklist requires a more holistic hazard assessment, for example, a new or undefined task, or a broad set of tasks, the checklist may need to be more “behavior-based” in nature.

- **Institutional support:** Depending on the nature of the checklist and the relationship between the checklist audience and users, developers may need to obtain institutional support to ensure the checklists are properly implemented. Additionally, if the checklist user is a subordinate to a member of the checklist audience, such as a PI or senior laboratory staff member, there will likely be apprehension for the subordinate to stop the work if the checklist is not completed properly. This was a critical component in Dr. Pronovost’s implementation of the ICU line infection checklist. By obtaining hospital administration support, the nurses were empowered to stop the procedure if critical steps were missed.

Process-Based Checklists

Process-based checklists are designed to address safety hazards associated with a specific work task that can be well defined. A process-based checklist establishes a finite, explicit set of steps for the checklist user to implement. For the process-based checklist to be successful, the developers must have sufficient knowledge of the process to identify the critical work flow for which the hazard assessment is based. Relevant safety protocols are then established and explicitly integrated into the checklist. If any of these steps are incomplete or insufficient, the checklist user could be at risk.

Behavior-Based Checklists

Behavior-based checklists are designed to conduct a more holistic hazard assessment for new or undefined tasks, or a broader spectrum of work tasks. A behavior-based checklist establishes hazard assessment criteria for the checklist user to evaluate their anticipated work flow (for example, will this task involve acutely toxic, pyrophoric, or explosive materials). The “cause-and-effect” concept of the behavior-based checklist is to identify potential high hazard, high risk work practices that would trigger the implementation of exposure control methods and safe work practices, such as source controls, administrative controls, engineering controls, and PPE.

For the behavior-based checklist to be successful, the developers must have sufficient knowledge of the overall anticipated spectrum of hazards present and the work activities conducted in the category of work area (for example, teaching laboratory as compared to synthetic chemistry laboratory). The developers must then establish the appropriate set of hazard assessment criteria to be evaluated in the checklist. The challenge is to establish an appropriate level of granularity to trigger the proper “cause-and-effect” response without overwhelming the checklist user with irrelevant questions and information. The utilization of chemical hazard control banding to categorize “like” laboratories or work areas can help define the scope for behavior-based checklist development and its intended audience.

Combined Process-Based and Behavior-Based Checklists

A common combined use of behavior-based and process-based checklists is to use the behavior-based checklist as a means to conduct a higher level, broader risk assessment for the PI’s research activities. If certain work activities are identified as being of higher risk, then a process-based checklist can be specifically developed to mitigate the associated risks.

However, it is not the intention of this checklist methodology summary to imply that checklists must solely be process-based or behavior-based. Rather, circumstances may often dictate that a process-based checklist incorporate behavior-based checks and vice versa. While a process-based checklist is centered on a well-defined work flow, behavior-based checks may be needed to identify process changes or the introduction of new hazards. Conversely, while a behavior-based checklist may be intended to assess a broader spectrum of *anticipated* activities in a work area, process-based checks may need to be included for work activities *known* to be present (for example, proper chemical waste management and labeling).

11.3. Benefits and Limitations of Checklists

As previously referenced, developing an effective checklist requires five components:

1) A clearly defined scope;
2) Collaboration with those knowledgeable in the work activities (for example, the investigator) and the implementation of safe work practices (for example, safety professionals);
3) Developing concise procedures and checklists;
4) Checklist testing and training; and
5) The support of departmental or institutional administration.

Checklist Benefits

The benefits to an effectively developed checklist include:

- The checklist methodology is commonly used in society and laboratories and, as such, the learning curve for implementing a checklist is less than other hazard analysis techniques.
- A “finite” list of questions or assessment categories helps laboratory users more familiar with laboratory operations assess and implement specific safe work practices.
- A standardized checklist allows institutions to compare and contrast various laboratories and operations to identify high risk operations and allocate resources.

Checklist Limitations

Potential limitations to the use of checklists include:

- Appropriate staffing and resources are needed to initially develop the checklist. The inability to effectively develop any of the above-listed five components can inhibit the effectiveness of the checklist and its ability to yield the required implementation of a safe work practice.
- Future checklist users and developers need to routinely reevaluate the checklist scope to ensure it is still appropriate for the work being evaluated. Have new operations or hazards been introduced that were not previously part of the scope and not included in the checklist?
- By its nature and design, a checklist is considered to be a finite tool which asks the user an explicit series of "questions." The common expectation but potential pitfall for the checklist user is to limit their scope or assessment to the specific questions listed rather than a holistic hazard analysis for the process being evaluated.
- A traditional "Yes/No" checklist may further limit the finite nature of the checklist by oversimplifying the scale and severity of the hazard present. In an effort to address this limitation, many checklists are incorporating hazard analysis elements for users to rate the potential "Severity of Consequences" and the "Probability of Occurrence." This is further discussed in APPENDIX B.

Checklist-Specific Benefits and Limitations

In addition these overall checklist methodology benefits and limitations, Section 11.7 on the *Keys to Successful Implementation and Use of Checklists* provides checklist-specific benefits and limitations for the example checklist reviewed.

11.4. Hazard Analysis Checklists

Traditional checklists use "Yes," "No," and "Not Applicable" scales for the checklist questionnaire. This can potentially over simplify the scale and severity of the hazard present. To address this issue, many checklists now include degrees of the "Severity of Consequences" and the "Probability of Occurrence" (described in APPENDIX B) to identify a more accurate representation of the risk associated with an entire laboratory's operations, a laboratory-specific operation, or a chemical-specific operation.

Figure 11-1: Example Exposure control Methods

11.5. Exposure Control Methods

As the risk level increases, the researcher or the organization will need to implement specific exposure control methods to mitigate the hazard outlined in APPENDIX B (Table B-4). Exposure control methods will traditionally look to minimize the risk of exposure by first assessing the source of the hazard to determine if viable, less hazardous alternatives are available. This "removes" the hazard from the laboratory before any researcher has the potential to become exposed. If this is not feasible, the second area of assessment is the pathway in which researchers store, handle, and use the material. This may be through the use of administrative controls or engineering controls to educate and improve the efficient, safe use of the material or isolate the hazard "away" from the researcher. The third area of assessment is for the receiver to determine what PPE would be required to minimize the risk of exposure. Specific examples of exposure control methods include, but are not limited to:

- **Source controls:** Remove or reduce the hazard through product substitution, purchasing premixed solutions, using less hazardous physical forms of the material.
- **Administrative controls:** Develop a process-based checklist for SOPs, restrict access to the materials or laboratory, obtain hazard-specific training, or contact the safety department for assistance.
- **Engineering controls:** Use chemical hoods, splash shields, enclosed balances, glove box, anaerobic chambers, or needle safe devices.
- **Personal protective equipment:** Wear personal attire to minimize uncovered skin, items such as chemical resistant gloves, double glove techniques, standard laboratory coats, fire resistant laboratory coats, face and eye protection, or respiratory protection.

11.6. Assessing the Effective Use of Checklists

Individual User

The individual user's effective use of a checklist can be assessed by routine review and auditing of the checklist by the investigator or other senior laboratory staff member within the work group. Training of the individual user is a key component to ensure a checklist's effective use. The training should provide instruction on identifying hazards and risks, procedures to document and ensure the timely resolution of deficiencies if observed, and proper implementation of exposure control methods. Additional institutional control can be established by having an entity, such as an EHS office or a Chemical Safety Committee, review the individual user checklists for thoroughness and accuracy.

Work Group

A work group's effective use of a checklist can be assessed by a routine review and auditing of the work group operations in the laboratory, for example. This must be conducted by the investigator, as well as their designated senior staff, to ensure a comprehensive assessment of the hazards has been completed and reflects current operations. The internal assessment should include the holistic laboratory hazard assessment of all laboratory operations and the operation-specific or chemical-specific hazard assessments, as necessary. The internal work group assessment would ensure the prescribed safe work practices from the comprehensive laboratory, operation-specific, and/or chemical-specific hazard assessments are being maintained.

The department or institution should also conduct external audits of the work group to confirm the thoroughness and accuracy of the various hazard assessments and the effective implementation of the safe work practices. If areas for improvement are noted, these should be immediately addressed by the investigator.

Departmental

A department's effective use of a checklist can be assessed by a comparative risk assessment and analysis of checklists for the work groups within the department. This analysis can either be administered by the department or most likely through the involvement of a centralized institutional office, such as EHS or a Chemical Safety Committee. The centralized institutional office can help provide expertise assessing high hazard areas that present an increased risk to the department. The collaboration between the department and the centralized institutional office can help identify priorities the department needs to address.

The key influences at the departmental level may include centralized support for the implementation of various safety programs, peer review and collaboration on critical safety initiatives, or shared use of safety equipment not readily available in all laboratories. Peer review can also be an important aspect for research collaboration and transferring knowledge among the work groups. An investigator may be a subject matter expert in a specific type of operation or in the safe use and handling of a high hazard chemical. The subject matter expert can help train and influence work groups and individuals with less experience. Additionally, certain safety programs, such as laboratory coat services, biosafety cabinet, and other safety equipment certifications, may be more cost-effective and efficient at a higher level of granularity than at the work group level.

Institutional and Administrative

An institution's effective use of a checklist is similar to a department's in that it should conduct comparative risk assessments and analysis of checklists for the work groups and departments. This analysis would most likely be through the involvement of a centralized institutional office, such as an EHS or a Chemical Safety Committee. The centralized institutional office can help provide expertise assessing high hazard areas and identify work groups or departments that present an increased risk to the institution. Institutional resources can then be properly prioritized and allocated to the areas of highest concern. If warranted, institutions may develop core facilities and shops to provide centralized services and access to equipment. In this environment, the associated hazards can be more readily controlled and facility managers can help train and ensure users are knowledgeable in the safe operation of the equipment.

11.7. Keys to Successful Implementation and Use of Checklists

The keys to the successful implementation and use of checklists will depend on the intended scope of work activities to be assessed and the knowledge of the users completing the checklist assessment. Users must determine if the scope of their work activity is a full laboratory operations assessment, a more defined laboratory process or operation, or potentially a specific chemical hazard. Based on the understanding of the assessment scope, the proper users must be identified who are familiar with the work activities associated with the checklist. The checklist users must then be trained on the proper use of the checklist and provided the necessary resources to implement necessary changes identified during the successful completion of the checklist.

The training of the checklist users becomes increasingly more critical if others within the work group, department, or institution are assessing and comparing the checklist results. As checklist results are added up through the organization, effective training is critical to ensure the checklist results are consistently, accurately, and comparatively represented among users and between the different work groups and departments.

The following sample checklists and risk assessment tools are being made available for institutions and users to adopt and modify for their operations. A brief overview; target audience; checklist applicability and use; and benefits and limitations for each checklist are summarized in the associated sections, while the complete checklists can be found in APPENDIX F.

- Traditional Laboratory Safety Checklist (Section 11.8)
- Laboratory Hazard Risk Assessment Matrix (Section 11.9)
- Laboratory Process Risk Assessment Matrix (Section 11.10)
- Laboratory Process Risk Assessment Checklist for a Process Using a Chemical (Section 11.11)
- Chemical Hazard Assessment Tool for High Hazard Chemicals (Section 11.12)

Laboratory Safety Checklist Sections

In general, the checklists are organized into the following Laboratory Safety Sections to help users organize and facilitate their assessments. Depending on the specific nature and scope of the assessment, sections may be omitted or expanded.

- Training and Documentation;
- Spill and Emergency Planning;
- Personal Protective Clothing, Equipment, and Engineering Controls;
- Chemical Safety and Exposure Assessment;
- Biological Safety and Exposure Assessment;
- Radiation Safety and Exposure Assessment;
- Compressed and Cryogenic Gas Safety and Exposure Assessment;
- Equipment and Physical Hazards Exposure Assessment;

- General Laboratory Safety and Exposure Assessment; and
- Waste Management.

11.8. Traditional Laboratory Safety Checklist

The complete checklist is available in APPENDIX F (Table F-1).

Applicability and Use

This laboratory safety checklist is a more traditional checklist, including an explicit series of questions (see excerpt in Figure 11-2) for the user to confirm the item's completion, availability, or applicability. This checklist is designed to assess the full spectrum of laboratory safety operations and materials used in association with the Laboratory Safety Checklist sections identified above.

Laboratory Information
Laboratory Director/Principal Investigator:
Location:

Traditional Laboratory Safety Checklist	**Yes**	**No**
Training and Documentation		
Up-to-date inventory maintained for all hazardous materials?		
Chemical Safety Data Sheets (SDS) maintained and readily available at all times employees are present?		
Workplace hazard assessment and certification completed?		
Employees know the location of chemical inventory, SDS and related reference material?		
Employees received institutional safety training (typical provided by Environmental Health and Safety office) and supplemental laboratory-specific safety training for the hazards present in the laboratory?		
Employees familiar with physical and health hazards of chemicals in work area?		
Employees able to describe how to detect the presence or release of hazardous materials?		
Employees know how to protect themselves and others from effects of hazardous materials?		
Employees familiar with Chemical Hygiene Plan (or equivalent)?		

Figure 11-2: Excerpt from Table F-1 in APPENDIX F

Target Audience

The target audience is a laboratory manager or other senior laboratory staff member who is familiar with the overall operation of the laboratory but may not be the subject matter expert on a specific laboratory operation or chemical usage.

Benefits and Limitations

The benefits of this Traditional Laboratory Safety Checklist include:

- Comprehensive assessment of multiple aspects of laboratory safety;
- Straightforward, explicit questions that most laboratory managers and senior laboratory staff should be able to answer with a moderate amount of training, and
- User variability is minimized based on limited "Yes," "No," "N/A" options.

The limitations of this Traditional Laboratory Safety Checklist include:

- A checklist with a finite number of explicit questions may inadvertently overlook a hazard present in the laboratory;

- A “Yes,” “No” questionnaire may oversimplify the scale and severity of the hazard present; and
- Requires a secondary assessment and use of another tool to address the severe hazards of a process or chemical used in the laboratory.

11.9. Laboratory Hazard Risk Assessment Matrix

The complete checklist is available in APPENDIX F (Table F-2).

Laboratory Information
Laboratory Director / Principal Investigator: **Location:**

Hazard and Exposure Category	How could you be exposed to this hazard?	Given the exposure, what is negative outcome?	Severity of Consequences		Probability of Occurrence		Risk Rating (CV*OV)
			What is the expected harm?	(CV) Value (1,5,10,20)	Existing Control Measure In Place	(OV) Value (0,1,2,3,4)	
Training and Documentation							

Figure 11-3: Excerpt from Table F-2 in APPENDIX F

Applicability and Use

This laboratory hazard risk assessment checklist (see excerpt in Figure 11-3) uses a comparative analysis of the “Severity of Consequences” and “Probability of Occurrence” for each checklist item to assign a risk rating. This example risk assessment matrix uses a weighted scale as outlined in APPENDIX B, “Example Hazard Risk Rating with Weighted Scaling” (Table B-6). The risk rating is then used to identify higher risk materials, laboratory operations, and overall laboratory operations. This risk assessment checklist is designed to assess the full spectrum of laboratory safety operations and materials used in association with the Laboratory Safety Checklist sections identified above.

Target Audience

The target audience is a more senior laboratory manager or other senior laboratory staff members who are familiar with the overall operation of the laboratory. The person may not be the subject matter expert but the user must have sufficient technical knowledge to properly rate the “Severity of Consequences” and “Probability of Occurrence” on a specific laboratory operation or chemical usage.

Benefits and Limitations

The benefits of this Laboratory Hazard Risk Assessment Matrix include:

- Comprehensive assessment of multiple aspects of laboratory safety;
- Behavior-based hazard and exposure category assessments minimize potential for missed hazards upon completion of the checklist; and
- Scaling and use of "Severity of Consequences" and "Probability of Occurrence" values provide greater differentiation of risks based on actual laboratory operations.

The limitations of this Laboratory Hazard Risk Assessment Matrix include:

- User variability is increased based on the effective rating of "Severity of Consequences" and "Probability of Occurrence."
- Higher degree of user training is required to consistently and accurately rate "Severity of Consequences" and "Probability of Occurrence" among users and operations.
- Requires secondary assessment and use of another tool to address the severe hazards of a process or chemical used in the laboratory.

11.10. Laboratory Process Risk Assessment Matrix

The complete checklist is available in APPENDIX F (Table F-3).

Applicability and Use

This laboratory process risk assessment tool uses a comparative analysis of the "Severity of Consequences" and "Probability of Occurrence" for a specific laboratory process to assign a risk rating. This example risk assessment matrix (see excerpt in Figure 11-4) uses a weighted scale as outlined in APPENDIX B, "Example Hazard Risk Rating with Weighted Scaling" (Table B-6). The risk rating is then used to identify aspects of the laboratory operation that represent higher risks. The checklist user can then assess and implement appropriate safe work practices to mitigate the risk, such as administrative controls, engineering controls, and PPE).

Laboratory Process and Procedure Overview
Laboratory Director / Principal Investigator:
Location:
Process Title:
Description:

Hazard and Exposure Category	**How could you be exposed to this hazard?**	**Given the exposure, what is negative outcome?**	**Severity of Consequences**		**Probability of Occurrence**		**Risk Rating (CV*OV)**
			What is the expected harm?	**(CV) Value (1,5,10,20)**	**Existing Control Measure In Place**	**(OV) Value (0,1,2,3,4)**	
Training and Documentation							
Specialized training requirements for material hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Specialized training requirements for equipment / process hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Figure 11-4: Excerpt from Table F-3 in APPENDIX F

Target Audience

The target audience for this Laboratory Process Risk Assessment Matrix is a senior laboratory staff member who is familiar with the laboratory operation being assessed. The person should be the subject matter expert to properly rate the "Severity of Consequences" and "Probability of Occurrence" for the specific laboratory operation.

Benefits and Limitations

The benefits of this Laboratory Process Risk Assessment Matrix include:

- Comprehensive assessment of a specific laboratory operation;
- Behavior-based hazard and exposure category assessments minimize potential for missed hazards upon completion of the checklist; and
- Scaling and use of "Severity of Consequences" and "Probability of Occurrence" values provides greater differentiation of risks based on actual laboratory operations.

The limitations of this Laboratory Process Risk Assessment Matrix include:

- User variability is increased based on the effective rating of "Severity of Consequences" and "Probability of Occurrence."
- Higher degree of user training is required to consistently and accurately rate "Severity of Consequences" and "Probability of Occurrence" among users and operations.
- Hazard assessment is solely focused on an operation and should be used in conjunction with a holistic laboratory assessment tool to identify other potential hazards present in the laboratory.

11.11. Laboratory Process Risk Assessment Checklist for a Process Using a Chemical

The complete checklist is available in APPENDIX F (Table F-4).

Laboratory Process Risk Assessment Checklist Overview								
Laboratory Director / Principal Investigator: Location: Process Title: Description:								
Laboratory Process Risk Assessment Checklist	How could you be exposed to this hazard?	Given the exposure, what is negative outcome?	Severity of Consequences		Probability of Occurrence		Risk Rating (CV*OV)
			What is the expected harm?	(CV) Value (1,5,10,20)	Existing Control Measure In Place	(OV) Value (0,1,2,3,4)	
Training and Documentation							
Specialized training required for the process or material hazards?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Specialized procedures developed for the safe completion of this operation?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	

Figure 11-5: Excerpt from Table F-4 in APPENDIX F

Applicability and Use

This Laboratory Process Risk Assessment Checklist is a traditional checklist, which includes an explicit series of questions regarding a particular laboratory process. The user must confirm the items completion, availability, and applicability.

Target Audience

The target audience for this Laboratory Process Risk Assessment Checklist (see excerpt in Figure 11-5) is a senior laboratory staff member who is familiar with the laboratory operation being assessed. The person should be the subject matter expert to properly assess the specific laboratory operation.

Benefits and Limitations

The benefits of this Laboratory Process Risk Assessment Checklist include:

- Finite assessment of a specific laboratory operation;
- Straightforward, explicit questions that most senior laboratory staff members should be able to answer with a moderate amount of training; and
- User variability is minimized based on limited “Yes,” “No,” and “N/A” options.

The limitations of this Laboratory Process Risk Assessment Checklist include:

- A checklist with a finite number of explicit questions may inadvertently overlook a hazard associated with the process.
- A “Yes,” “No” questionnaire may oversimplify the scale and severity of the hazard present.
- A hazard assessment is solely focused on an operation and should be used in conjunction with a holistic laboratory assessment tool to identify other potential hazards present in the laboratory.

11.12. Chemical Hazard Assessment Tool for High Hazard Chemicals

The complete checklist is available in APPENDIX F (Table F-5).

Applicability and Use

This Chemical Hazard Assessment Tool (see excerpt in Figure 11-6) is used to assess the hazards of a specific high hazard chemical and identify the necessary safe work practices. The qualification for a high hazard chemical may vary

HIGH HAZARD SUBSTANCE (HHS) CHECKLIST	
High Hazard Classification: ☐ High Acute Toxicity ☐ Carcinogen ☐ Reproductive Toxin ☐ Air Reactive / Pyrophoric ☐ Water Reactive ☐ Explosive / Unstable	
Physical state/concentration:	
Maximum quantity kept on hand:	Estimated rate of use (e.g., grams/month):
Toxicity: LD_{50} Oral (Rat)______ LD_{50} Skin (Rabbit)______ Other______ Reactivity and Incompatibility:	
SIGNIFICANT ROUTE(S) OF EXPOSURE (CHECK ALL THAT APPLY)	
☐ Inhalation ☐ Skin contact ☐ Percutaneous injection ☐ Eye contact ☐ Ingestion	
ADDITIONAL MATERIALS FOR REVIEW (ATTACHED)	
☐ Safety Data Sheet (SDS) ☐ Laboratory/Experimental Protocol ☐ Other:	
EXPOSURE CONTROLS	
Ventilation/Isolation: Personnel must work under/in the following equipment to minimize personal exposure: ☐ Chemical hood ☐ Glove box/AtmosBag ☐ BioSafety Cabinet ☐ Balance Enclosure ☐ Other (list): If Glove box or AtmosBag, identify gas environment:	
Personnel Protective Equipment (PPE)/Clothing: Laboratory coats, close-toed shoes, clothing that covers the legs and gloves (disposable latex or nitrile) are the minimum PPE requirements for all personnel working in the laboratory. Identify additional PPE requirements for work with HHS: Protective clothing: ☐ Disposable laboratory coat ☐ Fire-resistant laboratory coat (e.g., Nomex) ☐ Others (list): ______	

Figure 11-6: Excerpt from Table F-5 in APPENDIX F

between institutions. The enclosed tool includes explosive, unstable, pyrophoric, water reactive, high acute toxicity, carcinogens, and reproductive toxins as high hazard chemicals. The Chemical Hazard Assessment Tool is used to develop the laboratory-specific high hazard operating procedure to identify safe work practices for the particular high hazard chemical, including administrative controls, engineering controls, and PPE. The Chemical Hazard Assessment tool can then be used to help train laboratory staff.

Target Audience

The target audience for this Chemical Hazard Assessment Tool is a senior laboratory staff member who is familiar with the laboratory use of the high hazard chemical being assessed. The person should be the subject matter expert to properly assess and identify the safe work practices associated with the high hazard chemical. Secondary users are the other laboratory staff members who require training on the safe use of the high hazard chemical.

Benefits and Limitations

The benefits of this Chemical Hazard Assessment Tool include:

- Comprehensive assessment of a specific high hazard chemical;
- Serves as the laboratory-specific high hazard operating procedure for the safe handling and use of the high hazard chemical;
- Depending on the frequency of use of the high hazard chemical at the institution, subject matter expert knowledge and training can be shared with other less experienced laboratories prior to use of the high hazard chemical;
- Identifies staff authorized or unauthorized to use the high hazard chemical; and
- Identifies the requirements for staff training, available resources, administrative controls, engineering controls, and PPE.

The limitations of this Chemical Hazard Assessment Tool include:

- High degree of user knowledge and potential safety personnel interaction to complete the laboratory-specific high hazard operating procedure.
- High degree of laboratory-specific customization may limit ability to use the resource in other laboratory spaces.
- Hazard assessment is solely focused on the specific use of a high hazard chemical in a certain methodology and should be used in conjunction with a holistic laboratory assessment tool to identify other potential hazards present in the laboratory.
- Additional hazard assessments for the same high hazard chemical may be required if the material is used in varying forms, concentrations, and methodologies.

Checklist Example

A completed sample of this Chemical Hazard Assessment Tool for High Hazard Chemicals is available in APPENDIX F (Table F-6). This tool assesses the safe handling and use of sodium cyanide powders in laboratories. Note the sample omits laboratory- and institution-specific information, not pertinent to the example.

12. STRUCTURED DEVELOPMENT OF STANDARD OPERATING PROCEDURES

12.1. Introduction

Structured development of Standard Operating Procedures (SOPs) is a comprehensive approach to evaluating the safety challenges presented by a scientific experiment or process. Every aspect of an experiment must be thought out in advance so that the goal—discovery science done safely—is achieved by identifying the risks of harm and controlling the hazards inherent in all steps of an experimental process. Each step is analyzed separately to identify failure points. Then, they are evaluated collectively to determine if combinations of the elements could impact safety, and further reviewed to try to predict what could go wrong and to assess the impact of a safety failure.

This method of analysis can be used for *any* occupational task or job analysis (for example, the same methods work well for designing experimental protocols in general); however, the matrix and instructions are designed to help shape the inquiry and planning that would reveal safety issues related to a scientific protocol. The constant changes that are part of carrying out scientific inquiry require evaluation of both what has been changed and how the other aspects of the process might have been affected.

Quick Start: SOPs

See the cautionary statements regarding these quick-start guides in Section 5.2.

What it is: Comprehensive, structured approach to identify failure points of both individual hazards and combinations of those hazards. Can incorporate previous four methods. Requires more time and expertise than other methods.

Target applications: Any scenario where hazardous materials, equipment, or processes are identified.

People involved: Those experienced with the prior methods including supervisors, professional, and technical staff.

Getting started: Identify hazards and create process steps (address obvious and pressing issues before attempting a comprehensive evaluation); evaluate hazards and steps individually; and repeat evaluation for combinations of hazards and steps. Create SOPs based on process results.

Training: Can be complex due to complications in evaluating hazard combinations.

Core resources: Section 12.3 (Pros, Cons, and Limitations); Section 12.4 (Using the Template); Section 12.6 (Sample Scenario); APPENDIX G (Supporting Information for Structured Development of SOPs).

Using a hazard analysis matrix, the lab worker reviews the risks associated with the use of hazardous materials, hazardous processes, and hazardous equipment, as well as the impact of various conditions, such as the adequacy of facilities, worker knowledge and experience, and proposed hazard mitigation measures.

12.2. Under What Scenarios Might One Consider Using the Method?

This method may be used in all scenarios where hazardous materials, equipment, or processes have been identified, but could be streamlined for simple experiments, well-tested experiments, or those that are unchanging.

12.3. Pros, Cons, and Limitations

The structured development of SOPs approach works because it requires a comprehensive evaluation of any experimental process. It can be used by any laboratory worker. If instilled in students as part of their course of study, it will provide exercises in critical thinking that will serve the laboratory worker well in scientific inquiry and in understanding how to evaluate the potential risks of any endeavor. It can incorporate multiple well-described hazard analysis methods: task analysis (or JHA), what-if, checklists, control banding (by supervisors), and others. Because this method may be more thorough and tedious than other assessment methods, it is recommended that laboratory workers first gain experience with other, simpler hazard assessment methods before trying this one.

Because the method calls for reevaluation of all steps of an experiment when changes are made, experienced laboratory workers will have more insight into some aspects of risk assessment and produce a better hazard analysis. It could be time-consuming for an inexperienced laboratory worker, thus supervisory review is highly recommended. Most laboratory workers are trained in simple approaches to hazard analysis that may not adequately address the safety challenges they face; thus, they may be resistant to using this more time-consuming method.

As with any of the methods, the value of this method is related to both the amount of time spent preparing the assessment and the comprehensiveness of the assessment criteria used. This method has been designed to help the user assess the most likely hazards to be encountered; however, the researcher should always be prepared for the possibility that some hazard has been overlooked.

12.4. Using the template

Using Table 12–1 as a model (not a fill in the blank questionnaire) to identify and assess hazards, the laboratory worker should do the following: create a list of steps or tasks in a column. The following steps and tasks are identified in Table 12–1:

- Regulatory concerns;
- Human factors;
- Facility;
- Materials;
- Equipment and labware;
- Processes;

- Effect of change in design or conditions;
- Possibility for additive or synergistic effects, or unknown effects;
- Effluents and waste management;
- Availability of PPE;
- Emergency response resources; and
- Potential failure points or routine activities with high risk of harm.

Next, the model shows a column with typical hazards or issues related to the steps and tasks. Additional columns are added to the table to help the laboratory worker identify and evaluate hazards in a structured manner.

12.5. Keys to Success

Use of this assessment tool can be intimidating if one feels a need to fill in every box in the table. It is suggested that the list of topics and example issues be used first for a quick screen to identify the most obvious and pressing issues. However, once those have been identified and addressed, a more thorough review should be conducted to ensure nothing has been overlooked and to ensure the identified issues have been fully addressed.

Table 12–1 (columns 1–5): Structured Development of SOPs—Work from Detailed Scientific Protocol

Evaluate Each Step or Task	Hazard Identification(Known and potential hazards/Safety constraints and restrictions)	Specific Issues Identified	Risk Assessment(What is most likely to go wrong/what are the most severe consequences even if unlikely?)	Literature search and consultation with experienced supervisors for lessons learned	Strategies to Eliminate, Control, or Mitigate Hazard
Regulatory Concerns	Understanding applicability, cost constraints, lack of options, delays, require assistance, permits				CHP, OSHA carcinogen regulations, controlled substances DEA regulations, permits for select agents and/or radioactive materials, etc.
Human Factors	Inexperienced worker, new experiment, work hours, follows directions, medical conditions, effect of errors, effect of cold or fatigue, language barrier				Reiterative training, enforce lab rules, supervision, ascertaining worker knowledge, ensure worker is well-informed, practice small, SOPs, buddy system
Facility	Lighting, hand wash sink, egress, electrical circuits, ventilation, emergency equip., code adherence, confined space, storage arrangements, sturdy shelves				Ensure proper environment and conditions**–can use checklist**
Materials	Biological, Radiological, Chemicals; for chemicals--flammability, toxicity, PEL, Physical data, reactivity, corrosivity, thermal & chemical stability, inadvertent mixing, routes of exposure				Eliminate, substitute or reduce amt.? Detection and warning methods? Use of administrative, engineering or PPE controls (expand)
Equipment and Labware	Materials integrity, maintenance, piping, electrical, relief systems, ventilation systems, safety mechanism				Integrity check, right tool for job, maintenance, correct use, troubleshoot, normal and emergency operations delineated
Process	Unsafe quantity or concentration, unsafe temp, pressure, flow or composition, deviations, potential for runaway reaction				Change process, small tests, test runs without hazard present, acquire expert assistance, secondary controls, emergency response actions
Effect of change in design or conditions	More energetic or toxic, increase potential for release, hazards of scale up				Assume and prepare for increased risks, identify these in order of potential, require review by experts, require continuous monitoring, install safeguards, warning systems, shutdown mechanisms and remote monitoring
Possibility for additive or synergistic effect or unknown effects	Lack of expertise or knowledge, newly synthesized materials, untested or unfamiliar equipment, materials or processes				
Effluents and waste management	Challenges to proper disposal, potential for exposure or contamination, hazardous releases to air or water				Must be resolved before experiment, proper disposal containment and methods for experiment waste
Availability of PPE	Inadequate PPE or shielding for hazard, cost factors, worker compliance, lack of alternatives				Design experiment to reduce reliance on PPE, combine control methods, prohibit use of inadequate PPE
Emergency Response resources	Inadequate or unavailable, lack of knowledge about emergency procedures				Buddy system, alarms, ensure availability of equipment & personnel, emergency drills & training, spill kits, AED
Potential failure points or routine activities with high risk of harm	Weighing toxic materials on lab bench, opening an autoclave, hard to close caps, lack of "kill" switch				Review and change work practices, extensive training, instructions to address unexpected failures, breakage

Table 12–1 (columns 6–10): Structured Development of SOPs–Work from Detailed Scientific Protocol

Evaluate Each Step or Task	**Strategies to Eliminate, Control, or Mitigate Hazard (Column 5 duplicated from previous page for ease of use)**	**Suggested strategies to address identified hazards (Plan A)**	**Ask again (What could go wrong? Consider atypical or less likely events/Identify possible failure points or known failures of prior strategies)**	**Plan B to Eliminate, Control or Mitigate**	**Will Standard Precautions be Adequate? (Develop written criteria)**
Regulatory Concerns	CHP, OSHA carcinogen regulations, controlled substances DEA regulations, permits for select agents and/or radioactive materials, etc.				
Human Factors	Reiterative training, enforce lab rules, supervision, ascertaining worker knowledge, ensure worker is well-informed, practice small, SOPs, buddy system				
Facility	Ensure proper environment and conditions—**can use checklist**				
Materials	Eliminate, substitute or reduce amt.? Detection & warning methods? Use of administrative, engineering or PPE controls (expand)				
Equipment and Labware	Integrity check, right tool for job, maintenance, correct use, troubleshoot, normal and emergency operations delineated				
Process	Change process, small tests, test runs without hazard present, acquire expert assistance, secondary controls, emergency response actions				
Effect of change in design or conditions	Assume and prepare for increased risks, identify these in order of potential, require review by experts, require continuous monitoring, install safeguards, warning systems, shutdown mechanisms and remote monitoring				
Possibility for additive or synergistic effect or unknown effects					
Effluents and waste management	Must be resolved before experiment, proper disposal containment and methods for experiment waste				
Availability of PPE	Design experiment to reduce reliance on PPE, combine control methods, prohibit use of inadequate PPE				
Emergency Response resources	Buddy system, alarms, ensure availability of equipment and personnel, emergency drills & training, spill kits, AED				
Potential failure points or routine activities with high risk of harm	Review and change work practices, extensive training, instructions to address unexpected failures, breakage				

12.6. Sample Scenario

In this section we demonstrate how to use the structured development of SOPs method. An excerpt from the completed matrix is provided in Table 12–2 and the complete example is provided in APPENDIX G. We used a red font to highlight the information added to the template as the hazard analysis is carried out. Once the template is complete, the information is used to prepare an SOP. An example is also provided in APPENDIX G.

A lab worker proposes to use carbon monoxide for a new process in a laboratory hood. This chemical presents several hazards. According to GHS criteria, there is a health hazard because carbon monoxide is acutely toxic (category 3) and there is a physical hazard because it is an extremely flammable gas (category 1). The immediate risk assessment must address the potential for fire or explosion. The type of equipment, tubing and connections, the process and the specific hazards of carbon monoxide must also be considered before the risk assessment is complete. The potential for fire or explosion primarily arises if there is a leak or gas flow controls fail and a source of ignition is present. In addition to these hazards, there is also physical hazard related to the uncontrolled release of the compressed gas or explosion due to equipment failure from the high pressure.

Table 12–2: Excerpt from Completed Example of Matrix

Evaluate Each Step or Task	Hazard Identification (Known and potential hazards/Safety constraints and restrictions)	Specific Issues Identified	Risk Assessment (What is most likely to go wrong? What are the most severe consequences even if unlikely?)
Regulatory Concerns	Understanding applicability, cost constraints, lack of options, delays, require assistance, permits	Fire codes for flammable compressed gases limits storage amounts and conditions, regulators, tubing, connections and may require special storage, alarms, etc. Fire code requires conditions for safe egress. Compressed gases are regulated by NFPA and OSHA. NFPA and IFC also regulate toxic gases (see below).	Improper storage can lead to a leak or high vol. gas release. Improper connections can lead to a leak or static buildup. Emergency response may be impeded by lack of shut off valves or kill switches. Lack of fire alarms/suppression could result in catastrophic fire damage. For flammable gas CO, regulatory concerns relate to flammability, toxicity, and gas under pressure (see below).
Human Factors	Inexperienced worker, new experiment, work hours, follows directions, medical conditions, effect of errors, effect of cold or fatigue, language barrier	Relatively new graduate student from overseas with limited command of English. New experiment for this student.	Student may misunderstand parts of scientific procedure/safety procedures. Student may not have been adequately prepared or trained. Student may not be able to acquire emergency help.

List hazards for all materials, equipment, processes, conditions, human factors, and so forth.

- **Materials:** Gas under pressure subject to sudden release, highly flammable, potentially explosive, flammability and explosion may be increased by presence of oxidizers, characteristics of specific gas must be considered (would flame be visible, molecule size influences tubing choice, gas is highly toxic). Is gas a mixture and concentration appropriate for the use? Has cylinder been maintained and stored as required by National Fire Protection Association (NFPA) code and manufacturer's recommendations? Has a safe amount been acquired (minimum amount required for experiment)? Gas requires storage in a gas cabinet due to toxic properties.

- **Equipment:** Is it explosion proof? Can the equipment be placed in fume hood? Does use of the equipment in fume hood block exhaust of flow? Is the equipment suitable for gas? Has the equipment been maintained? Is the equipment failure testable? Are shutoff mechanisms available at the point-of-use? Has the cylinder been secured? Have proper tubing and connections been installed and tested?
- **Processes:** Is the process under pressure or vacuum? Does the process require heating? Does the process volume increase potential for a leak or could it result in a higher potential for injury or damage? Can the process be tested using a smaller volume of gas?
- **Facility and conditions:** Are remote shutoff mechanisms required? Is an emergency power source required and effective? Is a flammable gas detector or alarm required or advisable? Is a toxic gas alarm required or advisable? Remove unnecessary materials or objects that might impede free access to the equipment.
- **Human factors:** Is a laboratory worker experienced in the use of the equipment, the process and the gas? Can the experiment be monitored at all times or automatically shut down? Does the laboratory worker recognize warning signs of equipment failure, tubing failure or other factors that could lead to an accident? Is the laboratory worker trained for emergency response? Is the laboratory worker working with a trained coworker? Is the laboratory worker affected by illness, fatigue, or other stresses? Is the laboratory worker able to clearly communicate with coworkers and emergency personnel? Have coworkers been advised of experiment? Are disabilities accounted for by the laboratory or experiment design? Is there an internal transport procedure (cylinder secured, and so forth)?
- **Personal protective equipment:** Is the laboratory worker wearing flame resistant clothing and lab coat? Is the laboratory worker wearing impact resistant eye protection? Is the laboratory worker wearing proper PPE when transporting or setting up the cylinder?
- **Regulatory concerns:** Are the facility and experiment in compliance with NFPA codes (the Safety Office can obtain these) for the flammable gas to be used?

Consider Facility Requirements and Constraints

- Does the experiment pose a risk to other facility operations?
- Are lighting and other work conditions adequate? Is there a risk of static buildup due to low humidity?
- Are emergency response measures in place (fire extinguishers, safety shower, automatic fire alarms, and fire suppression)? Will emergency responders be able to locate and access the lab? Have emergency responders been advised of the experiment and materials present?
- Is safe egress available? Does the experiment location impede egress or emergency response actions?
- Have combustible materials been removed from the work area?

Review Literature, Consult Experienced Lab Workers, and Look for SOP or other Guidance Material

- Consult Safety Data Sheet for specific hazards of gas to be used;
- Consult NFPA codes (the Safety Office can obtain these) for control requirements for gas in storage and use, including tubing and connectors, and emergency response equipment and facilities requirements;
- Consult with experienced lab workers or compressed gas vendor regarding appropriate handling;
- Review the literature for lessons learned; and
- Review the experiment for what could go wrong—what are the most likely failures? What failures, even if unlikely, could lead to a catastrophic event?

Determine Broad Strategies for Controlling Hazards and List Specific Safety Measures

- **Regulations:** Have NFPA or other applicable codes (the Safety Office can obtain these) been reviewed for gas storage limitations, lab construction and emergency response requirements, compressed gas storage and use, special requirements for certain gases?
- **Substitute or use small amounts:** Order the smallest amount of gas required and use a nonflammable mixture, if possible. Substitute a less hazardous gas (or process), if possible. Use of lecture size or small volume cylinders enables storage in a fume hood. Carbon monoxide must be stored in a continual flow exhaust cabinet. Nontoxic flammable gases may, under certain conditions, be used on the open bench, but are preferably used in the fume hood or gas cabinet. Order carbon monoxide with a flow restrictor in the cylinder valve where low flow rates will be used.
- **Use of equipment, tubing, and connections:** Select regulator and tubing appropriate for gas; enclose equipment, tubing and gas cylinder in a fume hood or gas cabinet; secure cylinder and test connections (pressure hold test and leak tests or flammable gas detector); minimize amount of tubing and number or connections, ensuring that tubing cannot be pinched or kinked; make sure there is a shut off valve at the point-of-use and a second shutoff if the gas is remote from the equipment. If multiple gas lines are used, label tubing to remove confusion (which gas is in which line). Check the maintenance schedule of the equipment; follow the manufacturer's operating procedure; the laboratory worker must be familiar with the correct operation of the equipment, warning signs of trouble, and emergency shutdown measures. Have a "kill switch" available in the laboratory, if appropriate.
- **Ensure there is no potential source of ignition:** Outlets and power strips must be external to the fume hood. If flames are used, make sure there is a mechanism for emergency shutoff. Check if equipment is intrinsically safe or can be made so.
- **Emergency response:** Perform experiment in laboratory with fire alarms, fire suppression; have a fire extinguisher readily available and know when and how to use it; make sure coworkers are available to assist, if necessary.
- **Write an SOP** (step by step procedure with detailed safety measures and warnings): Make sure the appropriate research was performed to understand the hazards and identify safety measures, including a review of past incidents. Consult with coworkers, vendors, or other

experts. Include warning or trouble signs, and what to do to avert a lab accident. Submit SOP for review by supervisor and other laboratory workers.

- **Prepare for the experiment:** Remove any combustible material from the area around the experiment; remove any unnecessary materials or objects that are in the vicinity of the experiment; make sure there is a clear emergency egress; have available appropriate attire and PPE; have a plan to monitor the experiment. Review the hazards and make sure measures have been taken to reduce risk. Address other laboratory or facility operations that might affect this experiment or be affected by it. Practice using nonhazardous materials or using a scaled down process.
- **Unsafe conditions:** Do not perform an experiment in low humidity, with inadequate space or lighting, or in a cluttered or cramped area. Do not perform while working alone or without emergency response personnel, if needed. Do not perform an experiment if rushed, fatigued, or ill. Do not proceed if there is evidence of a gas leak or a tubing or equipment failure. Report any incidents or concerns to a supervisor.

As noted above, once all of the information has been collected and thoroughly evaluated, the laboratory worker can prepare an SOP. A sample SOP for this example is shown in APPENDIX G.

12.7. Assessing the Effective Use of this Assessment Method

The effectiveness of this method is dependent on how much energy laboratory workers put into it. This tool is designed to stimulate conversations about hazards, so a thorough hazard assessment can be conducted. Users can create their own base template to meet their specific needs and update the template depending on their personal experiences.

This method is not recommended for users who want a “quick-and-dirty” solution.

12.8. How to Incorporate this Tool into Daily Activities

This tool may be used to give a broad look at daily activities; instructions related to the use of a specific hazardous material, process, or equipment should also be incorporated into the review. The structured approach gives one confidence that potential hazards have been examined from a variety of angles, so laboratory workers have the confidence that they are working safely. When new or modified procedures are required, this tool will give laboratory workers the confidence that a thorough safety review was conducted.

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APPENDIX A: GLOSSARY OF ACRONYMS

ACS	American Chemical Society
BSL	Biological Safety Level
CB	control banding
CCS	ACS Committee on Chemical Safety
CHAS	ACS Division of Chemical Health and Safety
CHO	chemical hygiene officer
CSB	Chemical Safety Board (U.S. Chemical Safety and Hazard Investigation Board)
CSL	Chemical Safety Level
CV	severity of consequences value
EHS	Environmental Health and Safety
EMF	electromagnetic field
FTA	fault tree analysis
FMEA	failure modes and effect analysis
GHS	Globally Harmonized System
Hazmat	hazardous materials
HazOp	hazard and operability analysis
HMIS	Hazardous Material Information System
IARC	International Agency for Research on Cancer
ICU	intensive care unit
IDLH	Immediately Dangerous to Life and Health
JHA	Job Hazard Analysis
Kg	kilogram
LC	legal concentration
LEL	lower explosive limit
LD	legal dose
Mg	milligram
mL	milliliter
MOA	mechanism of action
NIOSH	National Institute of Occupational Safety and Health
NFPA	National Fire Protection Association
OEL	occupational exposure level
OSHA	Occupational Safety and Health Administration
OV	probability of occurrence value
PI	principal investigator
PPE	personal protective equipment
PPM	parts per million
RR	Risk Rating
SDS	Safety Data Sheet
SOP	standard operating procedure
SWIF	structured what-if analysis
WHO	World Health Organization

APPENDIX B: RISK RATING

Risk is the probability that a hazard will result in an adverse consequence. Assessing risk along with potential hazards can be helpful in determining the proper mitigation strategy and determining priorities. Many risk assessments use degrees of the "Severity of Consequences" and the "Probability of Occurrence" to identify a more accurate representation of the risk associated with an entire laboratory's operations; a laboratory-specific operation; or a chemical-specific operation. Additionally the increased use of risk ratings and scaling can help individual user, the work group (for example, laboratory), the department, and/or the institution determine where additional resources are required. This may include when and where investigators need to develop laboratory-specific operational hazard assessments and chemical-specific hazard assessments.

Severity of Consequences

The severity of consequences pertains to the impact to personnel safety, resources, work performance, property and/or reputation associated with the failure to properly implement or execute the issue being assessed. For example, the severity of consequence for a laboratory measuring the pH of ground water samples would be low in the event of a "failure" that caused an employee to be exposed to the ground water. Conversely, the severity of consequence for a laboratory conducting electroplating research with cyanide baths would be very high in the event of a "failure" that caused an employee to be exposed to cyanide.

Table B-1: Severity of Consequences with Standard Linear Scaling

Severity of Consequences with Standard Linear Scaling identifies the example impacts to personnel safety, resources, work performance, property damage, and institutional reputation associated with each rating. For educational purposes, Severity of Consequences in Table B-1 is arbitrarily scaled 1 to 4 with 4 being the highest severity. Later in this section, "Weighting Scaling and Institutional Variation," will further discuss the importance of selecting an appropriate value scale that meets the institution's priorities and risk management.						
Consequence Value (CV)		**Impact to…**				
Rating	**Value**	**Personnel Safety**	**Resources**	**Work Performance**	**Property Damage**	**Reputation**
No Risk	1	No injuries	No Impact	No Delays	Minor	No impact
Minor	2	Minor injuries	Moderate impact	Modest Delays	Moderate	Potential damage
Moderate	3	Moderate to life impacting injuries	Additional resources required	Significant delays	Substantial	Damaged
High	4	Life threatening injuries from single exposure	Institutional resources required	Major operational disruptions	Severe	Loss of Confidence

Probability of Occurrence

The probability of occurrence pertains to the likelihood that the failure to properly implement or execute the issue being assessed could occur. For example, if the laboratory measuring the pH of ground water samples handles hundreds of samples daily, there is a higher probability that a container could spill and expose an employee to ground water. Conversely, if the laboratory conducting research on electroplating with cyanide baths only uses the bath monthly, the probability of the occurrence happening would be low.

Table B-2: Probability of Occurrence with Standard Linear Scaling

Probability of Occurrence with Standard Linear Scaling identifies the percent probability an issue will occur associated with each rating. For educational purposes, Probability of Occurrence in Table B-2 is arbitrarily scaled 1 to 4 with 4 being the highest probability. The following section on Institutional Variation will further discuss the importance of selecting an appropriate value scale that meets the institution's priorities and risk management.

Occurrence Value (OV)		Probability of Occurrence	
Rating	**Value**	**Percent**	**Description**
Not Present	0	0%	Item/operation is not present in laboratory.
Rare	1	1–10%	Rare
Possible	2	10–50%	Possible
Likely	3	50–90%	Likely
Almost Certain to Certain	4	90–100%	Almost Certain to Certain

Risk Ratings, Risk Levels, and Expectation of Response

The laboratory hazard risk rating is calculated by multiplying the Severity of Consequences Value (CV) by the Probability of Occurrence Value (OV).

Risk Rating (RR) = Severity of Consequences Value (CV) x Probability of Occurrence Value (OV)

The calculated Risk Rating value will increase as the associated Severity of Consequences and Probability of Occurrence increase. The calculated hazard risk ratings are intended to help the user and institution categorize risk into varying degrees of risk or Risk Levels as demonstrated in Table B-3 using standard linear scaling.

Table B-3: Example Hazard Risk Rating with Standard Linear Scaling (Values 1–4)

		Severity of Consequences (CV) Impact to Personnel Safety, Resources, Work Performance, Property and/or Reputation			
		CV = 1	**CV = 2**	**CV = 3**	**CV = 4**
Probability of Occurrence (OV)	**OV = 4**	**RR = 4 LOW**	**RR = 8 HIGH**	**RR = 12 CRITICAL**	**RR = 16 CRITICAL**
	OV = 3	**RR = 3 LOW**	**RR = 6 MEDIUM**	**RR = 9 HIGH**	**RR = 12 CRITICAL**
	OV = 2	**RR = 2 LOW**	**RR = 4 LOW**	**RR = 6 MEDIUM**	**RR = 8 HIGH**
	OV = 1	**RR = 1 LOW**	**RR = 2 LOW**	**RR = 3 LOW**	**RR = 4 LOW**
	OV = 0	**RR = 0 Not Applicable—The Material or Process is Not Present in the Laboratory**			

Based on the Risk Level, users and institutions can establish priorities and allocate resources towards the higher risk operations. Table B-4 is an example matrix of risk levels and expectation of response of the user and/or institution.

Table B-4. Risk Level and Response Expectations

Risk Level	Expectation of Response
Low	Acceptable Risk Level Monitor and Manage
Medium	Tolerable Risk Level Implement corrective action and consider additional controls
High	Tolerable Risk Level with Strict Controls and Oversight Implement mitigating and corrective actions with routine monitoring and oversight.
Critical	Intolerable Risk Level Implement mitigating and corrective actions. Engage higher levels of management

Weighted Scaling and Institutional Variation

The primary goal of the hazard risk rating is to help differentiate the critical and high hazard risk from the low risk activities at an institution. Institutions will need to evaluate their specific priorities to help establish suitable Severity of Consequences and Probability of Occurrence values; the calculated Risk Ratings; and the resultant assignment of Risk Levels and Expectation of Response by the user.

Table B-3 used standard linear scaling for the Probability of Occurrence (0–4) and Severity of Consequence (1–4) and evenly distributes risk levels across the matrix. However this scaling would rate the activity with the certain probability (OV=4) of no risk (CV=1) the same risk level (RR=4) as an activity with the rare probability (OV=1) of being exposed to a lethal material or operation (CV=4). **Most would ascertain that any activity with the potential of being lethal is not a low risk regardless how low the probability.**

Table B-5. Severity of Consequences with Weighted Scaling

Consequence Value (CV)		Impact to...				
Rating	**Value**	**Personnel Safety**	**Resources**	**Work Performance**	**Property Damage**	**Reputation**
No Risk	1	No injuries	No Impact	No Delays	Minor	No impact
Minor	5	Minor injuries	Moderate impact	Modest Delays	Moderate	Potential damage
Moderate	10	Moderate to life impacting injuries	Additional resources required	Significant delays	Substantial	Damaged
High	20	Life threatening injuries from single exposure	Institutional resources required	Major operational disruptions	Severe	Loss of Confidence

In order to provide a better stratification of risk levels, a modified or weighted scaling system can be used to place greater emphasis on higher consequence work activities. Table B-5 uses weighted scaling for the Severity of Consequences. The weighted scaling assigns a disproportionately higher value for the moderate and high Severity of Consequences. Table B-6 represents the recalculated hazard risk ratings using the weighted Severity of Consequences.

This method now reassigns "High" and "Critical" risk levels to all high Severity of Consequence operations and materials. As a result of this reassignment, appropriate levels of attention and action by the user and the institution can be assigned to the higher risk and higher consequence operations. It is the Institution's responsibility to determine the scaling and assignment of risk levels that best suits their priorities and available resources.

Table B-6: Example Hazard Risk Rating with Weighted Scaling

		Severity of Consequences (CV) Impact to Personnel Safety, Resources, Work Performance, Property and/or Reputation			
		CV = 1 **No Risk**	**CV = 5** **Minor**	**CV = 10** **Moderate**	**CV = 20** **High**
Probability of Occurrence (OV)	**OV = 4**	**RR = 4** **LOW**	**RR = 20** **HIGH**	**RR = 40** **HIGH**	**RR = 80** **CRITICAL**
	OV = 3	**RR = 3** **LOW**	**RR = 15** **MEDIUM**	**RR = 30** **HIGH**	**RR = 60** **CRITICAL**
	OV = 2	**RR = 2** **LOW**	**RR = 10** **MEDIUM**	**RR = 20** **HIGH**	**RR = 40** **HIGH**
	OV = 1	**RR = 1** **LOW**	**RR = 5** **LOW**	**RR = 10** **MEDIUM**	**RR = 20** **HIGH**
	OV = 0	**RR = 0** **Not Applicable—The Material or Process is Not Present in the Laboratory**			

Tools for Risk Rating–Nomograms

In addition to previously described methods, there are software and web applications available to semiquantitatively measure risk. Nonagrams, such as the one shown in Figure B-1, can be useful for visualizing risk severity as a result of manipulating probability and exposure and consequence.[i]

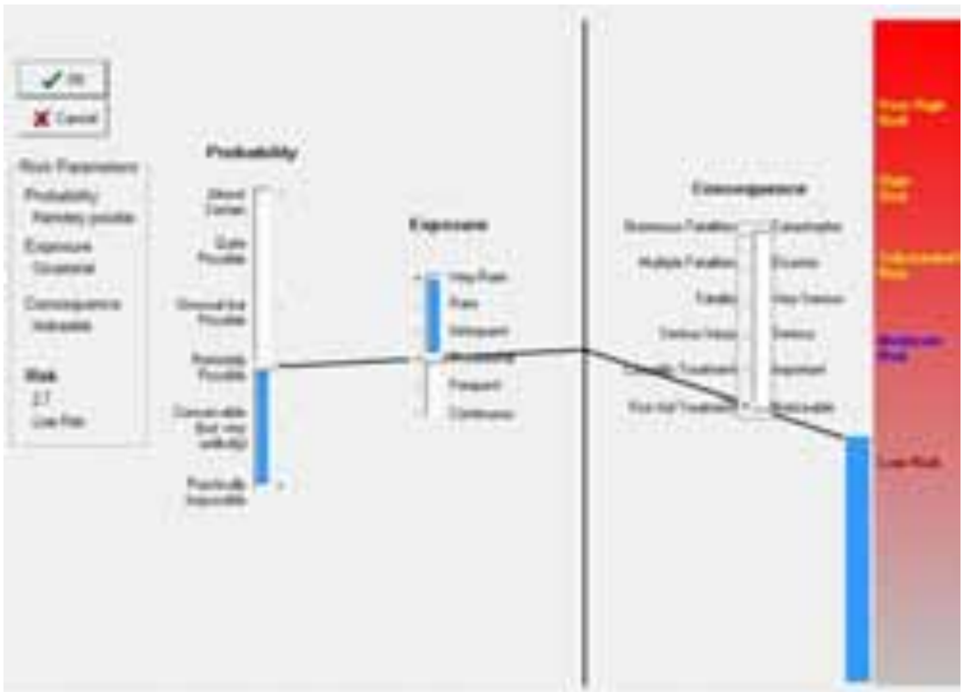

Figure B-1: Risk Severity

[i] The Electronic Risk Score Calculator nomogram may be downloaded from the Health and Safety Risk Management Web site at: http://www.safetyrisk.com.au/free-safety-and-risk-management-downloads-page-1/

APPENDIX C: SUPPORTING INFORMATION FOR CHEMICAL SAFETY LEVELS

Helpful Links

- Several institutions have made information related to control banding publically available.
- The California Nanosafety Consortium of Higher Education has published a "Nanotoolkit" which provides a control banding approach to "Working Safely with Engineered Nanomaterials in Academic Research Settings." This toolkit is available at http://www.ehs.uci.edu/programs/sop_library/Nanotoolkit.pdf (accessed on September 3, 2013).
- The University of California San Diego has created an application based on control banding called the "Chemical Hazard Use Application." Information is available at http://blink.ucsd.edu/safety/research-lab/chemical/chua.html#CHUA%27s-hazard-control-plan-temp (accessed on September 3, 2013).
- The National Institute of Occupational Safety and Health maintains a Web site dedicated to control banding. The site is currently located at http://www.cdc.gov/niosh/topics/ctrlbanding/ (accessed on September 3, 2013).

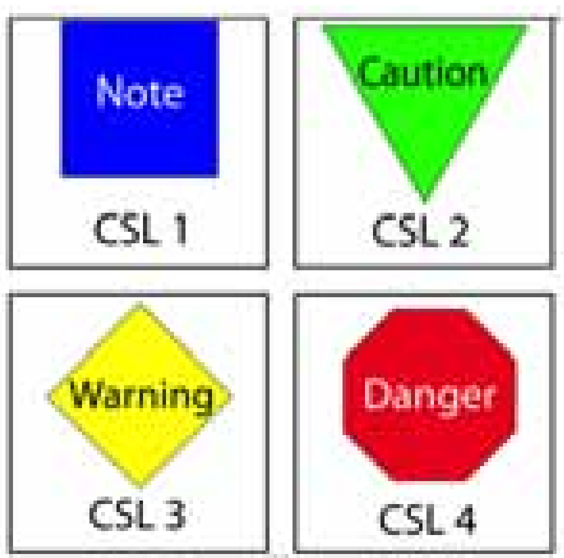

Figure C-1: Potential Pictograms to Communicate Chemical Safety Level Ratings

APPENDIX D: SUPPORTING INFORMATION FOR CONDUCTING JOB HAZARD ANALYSIS

Various Methods of Control Used in a JHA[10]

Engineering Controls—Reduce or remove the hazard

- Elimination/minimization: Hazards are reduced or removed by:
    - The initial engineering design of the facility, equipment, or process or
    - Substituting processes, equipment, materials or other components.

- Isolation: Hazards are reduced or removed by separation in time or space
    - Enclosure of the material or process in a closed system
    - Transporting hazardous materials when fewer workers are present
    - Guarding and shielding

- Ventilation
    - Removal or redirection hazards local and exhaust ventilation.
    - Ventilation with fume hoods

Administrative Controls—Minimize laboratory worker's exposures

- SOPs, other hazard analysis tools, and hazardous work permits (these can be incorporated into JHA)
- Using "best work practices" including, good personal hygiene, good housekeeping, and regular maintenance
- Limiting exposure by scheduling reduced time in the laboratory
- Alerting laboratory workers to hazards using alarms and signage
- Never working alone (buddy system)
- Ensuring that laboratory workers are properly trained as required by standards

Personal Protective Equipment—Worn by laboratory workers to protect them from the laboratory environment

- Protective clothing, safety goggles, respirators, and hearing protection. Referred to as PPE. Respirator use requires specific training and health monitoring. PPE is acceptable as a control method when,
    - Engineering controls are not feasible or they do not totally eliminate a hazard
    - As a temporary control while engineering controls are being developed
    - If engineering and administrative controls cannot provide sufficient protection
    - In emergency situations

Summary

The use of one control method over another which is higher in precedence can be appropriate for providing protection if the hazard cannot be eliminated. The reality is that if the hazard cannot be eliminated, controlling it may require a combination of all control methods being used simultaneously. The effectiveness of PPE is highly dependent on the proper selection, use, and fit of the PPE. Additionally, always remember that PPE is the last line of defense between the worker and exposure. With no other controls are in place, there will be exposure if PPE fails.

Table D-1: Common Hazards and Descriptions

The information in this table is useful in describing the hazards identified in the JHA. The list is comprehensive, but not all inclusive. The "chemical" descriptions are from 29CFR1910.1200.[12] All other hazard descriptions are from the OSHA publication, *Job Hazard Analysis*.[10]		
HAZARD TYPE		
General	**Specific Hazard or Consequence (GHS Criteria)**	**Specific Description**
Chemical	Acute toxicity (Health Hazard)	*Acute toxicity* refers to those adverse effects occurring following oral or dermal administration of a single dose of a substance, or multiple doses given within 24 hours, or an inhalation exposure of 4 hours.
Chemical	Aspiration hazard (Health Hazard)	*Aspiration* means the entry of a liquid or solid chemical directly through the oral or nasal cavity, or indirectly from vomiting, into the trachea and lower respiratory system.
Chemical	Carcinogenity (Health Hazard)	*Carcinogen* means a substance or a mixture of substances which induce cancer or increase its incidence. Substances and mixtures which have induced benign and malignant tumors in well-performed experimental studies on animals are considered also to be presumed or suspected human carcinogens unless there is strong evidence that the mechanism of tumor formation is not relevant for humans.
Chemical	Corrosive to metals (Physical Hazard)	A substance or a mixture that by chemical action will materially damage, or even destroy, metals is termed "corrosive to metal."
Chemical	Explosive (Physical Hazard)	An *explosive chemical* is a solid or liquid chemical which is in itself capable by chemical reaction of producing gas at such a temperature and pressure and at such a speed as to cause damage to the surroundings. Pyrotechnic chemicals are included even when they do not evolve gases.
Chemical	Flammable gas, liquid, solid, or aerosol (Physical Hazard)	Flammable gas means a gas having a flammable range in air at 20 °C and a standard pressure of 101.3 kPa. Flammable liquid means a liquid having a flash point of not more than 93 °C. Flammable solids are solids that are readily combustible, or may cause or contribute to fire through friction. Readily combustible solids are powdered,

Table D-1: Common Hazards and Descriptions

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HAZARD TYPE		
General	**Specific Hazard or Consequence (GHS Criteria)**	**Specific Description**
		granular, or pasty substances which are dangerous if they can be easily ignited by brief contact with an ignition source, such as a burning match, and if the flame spreads rapidly. Aerosols are any gas compressed, liquefied or dissolved under pressure within a non-refillable container made of metal, glass or plastic, with or without a liquid, paste or powder. The container is fitted with a release device allowing the contents to be ejected as solid or liquid particles in suspension in a gas, as a foam, paste or powder or in a liquid or gaseous state. Aerosols are classified as flammable if they contain any component classified as flammable according to the GHS criteria for flammable liquids, flammable gases, or flammable solids.
Chemical	Gas under pressure (Physical Hazard)	
Chemical	Germ cell mutagenicity (Health Hazard)	A *mutation* is defined as a permanent change in the amount or structure of the genetic material in a cell. The term *mutation* applies both to heritable genetic changes that may be manifested at the phenotypic level and to the underlying DNA modifications when known (including, for example, specific base pair changes and chromosomal translocations). The term *mutagenic* and *mutagen* will be used for agents giving rise to an increased occurrence of mutations in populations of cells and/or organisms.
Chemical	Organic peroxides (Physical Hazard)	An organic peroxide is an organic liquid or solid which contains the bivalent -0-0- structure and may be considered a derivative of hydrogen peroxide, where one or both of the hydrogen atoms have been replaced by organic radicals.
Chemical	Oxidizing gas, liquid, or solid (Physical Hazard)	Oxidizing gas means any gas which may, generally by providing oxygen, cause or contribute to the combustion of other material more than air does. An oxidizing liquid or solid is a substance which, while not necessarily combustible, may, generally by yielding oxygen, cause or contribute to the combustion of other material.
Chemical	Pyrophoric liquid or solid (Physical Hazard)	A pyrophoric liquid is a liquid which, even in small quantities, is liable to ignite within five minutes after coming into contact with air. A pyrophoric solid is a solid which, even in small

Table D-1: Common Hazards and Descriptions

The information in this table is useful in describing the hazards identified in the JHA. The list is comprehensive, but not all inclusive. The "chemical" descriptions are from 29CFR1910.1200.[12] All other hazard descriptions are from the OSHA publication, *Job Hazard Analysis*.[10]		
HAZARD TYPE		
General	**Specific Hazard or Consequence (GHS Criteria)**	**Specific Description**
		quantities, is liable to ignite within five minutes after coming into contact with air.
Chemical	Reproductive toxicity (Health Hazard)	*Reproductive toxicity* includes *adverse effects on sexual function and fertility* in adult males and females, as well as *adverse effects on development of the offspring*. Some reproductive toxic effects cannot be clearly assigned to either impairment of sexual function and fertility or to developmental toxicity. Nonetheless, chemicals with these effects shall be classified as reproductive toxicants.
Chemical	Respiratory or skin sensitization (Health Hazard)	Respiratory sensitizer means a chemical that will lead to hypersensitivity of the airways following inhalation of the chemical. Skin sensitizer means a chemical that will lead to an allergic response following skin contact.
Chemical	Self-heating substance (Physical Hazard)	A self-heating substance is a solid or liquid, other than a pyrophoric substance, which, by reaction with air and without energy supply, is liable to self-heat. This endpoint differs from a pyrophoric substance in that it will ignite only when in large amounts (kilograms) and after long periods of time (hours or days).
Chemical	Self-reactive substance (Physical Hazard)	Self-reactive substances are thermally unstable liquids or solids liable to undergo a strongly exothermic thermal decomposition even without participation of oxygen (air).
Chemical	Skin corrosion or irritation (Health Hazard)	Skin corrosion is the production of irreversible damage to the skin; namely, visible necrosis through the epidermis and into the dermis, following the application of a test substance for up to 4 hours. Skin irritation is the production of reversible damage to the skin following the application of a test substance for up to 4 hours.
Chemical	Specific target organ toxicity (single or repeated exposure) (Health Hazard)	*Specific target organ toxicity - single exposure, (STOT-SE)* means specific, nonlethal target organ toxicity arising from a single exposure to a chemical.
Chemical	Substances which, in contact with water emit flammable gases (Physical Hazard)	Substances that, in contact with water, emit flammable gases are solids or liquids which, by interaction with water, are liable to become spontaneously flammable or to give off flammable gases in dangerous quantities.
Electrical	*Shock/Short Circuit*	*Contact with exposed conductors or a device that is incorrectly or inadvertently grounded, such as when a metal ladder comes into contact with power lines. 60Hz alternating current (common house current) is very dangerous because it can stop the heart.*

Table D-1: Common Hazards and Descriptions

The information in this table is useful in describing the hazards identified in the JHA. The list is comprehensive, but not all inclusive. The "chemical" descriptions are from 29CFR1910.1200.[12] All other hazard descriptions are from the OSHA publication, *Job Hazard Analysis*.[10]		
HAZARD TYPE		
General	**Specific Hazard or Consequence (GHS Criteria)**	**Specific Description**
Electrical	*Fire*	*Use of electrical power that results in electrical overheating or arcing to the point of combustion or ignition of flammables, or electrical component damage.*
Electrical	*Static/ESD*	*The moving or rubbing of wool, nylon, other synthetic fibers, and even flowing liquids can generate static electricity. This creates an excess or deficiency of electrons on the surface of material that discharges (spark) to the ground resulting in the ignition of flammables or damage to electronics or the body's nervous system.*
Electrical	*Loss of Power*	*Safety-critical equipment failure as a result of loss of power.*
Ergonomics	Strain	*Damage of tissue due to overexertion (strains and sprains) or repetitive motion.*
Ergonomics	Human error	A system design, procedure, or equipment that is error-provocative. (A switch goes up to turn something off).
Excavation	Collapse	*Soil collapse in a trench or excavation as a result of improper or inadequate shoring. Soil type is critical in determining the risk associated with this hazard.*
Fall	Slip/Trip	*Conditions that result in falls (impacts) from height or traditional walking surfaces (such as slippery floors, poor housekeeping, uneven walking surfaces, exposed ledges, etc.)*
Fire/Heat	Burn	*Temperatures that can cause burns to the skin or damage to other organs. Fires require a heat source, fuel, and oxygen.*
Mechanical/Vibration	Chaffing/Fatigue	*Vibration that can cause damage to nerve endings or material fatigue that can result in a critical safety-critical failure.*
Mechanical	Failure	*Equipment failure typically occurs when devices exceed designed capacity or are inadequately maintained.*
Mechanical	Caught-by/ Caught-in	*Skin, muscle, or a body part exposed to crushing, caught-between, cutting, tearing, shearing items or equipment.*
Noise	Hearing Damage	*Noise levels (> 85 dBA 8 hr TWA) that result in hearing damage or inability to communicate safety-critical information.*
Radiation	Ionizing	*Alpha, Beta, Gamma, neutral particles, and X-rays that cause injury (tissue damage) by ionization of cellular components.*
Radiation	*Non-Ionizing*	*Ultraviolet, visible light, infrared, and microwaves that cause injury to tissue by thermal or photochemical means.*
Struck By	Mass Acceleration	*Accelerated mass that strikes the body causing injury or death. (Examples are falling objects and projectiles.)*
Struck Against		*Injury to a body part as a result of coming into contact of a surface in which action was initiated by the person. (An*

Table D-1: Common Hazards and Descriptions

The information in this table is useful in describing the hazards identified in the JHA. The list is comprehensive, but not all inclusive. The "chemical" descriptions are from 29CFR1910.1200.[12] All other hazard descriptions are from the OSHA publication, *Job Hazard Analysis*.[10]		
HAZARD TYPE		
General	**Specific Hazard or Consequence (GHS Criteria)**	**Specific Description**
		example is when a screwdriver slips.)
Temperature Extreme	Heat/Cold	*Temperatures that result in heat stress, exhaustion, or metabolic slow down such as hyperthermia/hypothermia.*
Visibility	Limited	*Lack of lighting or obstructed vision that results in an error or other hazard.*
Weather	Phenomena	*Created by snow, rain, wind and or ice.*

APPENDIX E: SUPPORTING INFORMATION FOR CONDUCTING WHAT-IF ANALYSIS

Table E-1: Sample Portion of a Worksheet from a SWIF Analysis of a Wolff-Kishner Reaction

Synthesis Step			Relevant SWIF Categories			
What-If Scenario	**Consequence(s)**	**Safeguard(s)**	**C**	**F**	**R**	**Recommendation(s)**
In a suitable fume hood set up a nitrogen purged multi-neck flask			SWIF Category: 6			
N_2 is lost during this step?	Possible air ingress to flask; possible flammable atmosphere (FL ATM)	None at present	4	3	MJ	Consider adding no-flow alarm on N_2 line for continuous inserting; consider measuring O_2 conc. in head space after one-time inserting
Add an agitator to the flask			SWIF Category: 1, 2, 3, 4, and 6			
Stirrer assembly detaches from mountings?	Probably break glass vessel; loss of containment; possible fire	Monthly inspection of agitator mounting	4	2	MD	No additional recommendations
Unstable motion of the agitator shaft/paddle?	Possibly break glass vessel; possible loss of containment	Agitator motion checked before starting reaction	3	3	MD	No additional recommendations
Agitation rate is too fast or too slow?	Wrong reaction rate	Chemist monitors reaction regularly	2	4	MD	No additional recommendations
Electric motor is an ignition source	Fire/Explosion if FL ATM forms in hood?	None at present	5	2	MD	Electric motor must be explosion proof
Add a reflux condense			SWIF Category: 1 and 6			
Condenser water is not cold enough?	Failure to condenser volatiles; possible FL ATM in hood; possible fire/explosion	Chemist monitors reaction regularly	3	3	MD	Consider high T alarm placed in vapor space above condenser
Water flow to condenser decreases or stops?	Failure to condenser volatiles; possible FL ATM in hood	Chemist monitors reaction regularly	3	4	MJ	Consider installing an alarm for No/Low Flow of water

Table E-1: Sample Portion of a Worksheet from a SWIF Analysis of a Wolff-Kishner Reaction

Synthesis Step			Relevant SWIF Categories			
What-If Scenario	Consequence(s)	Safeguard(s)	C	F	R	Recommendation(s)
The loss of cooling water is not noticed by chemist?	Possible FL ATM in hood; possible fire/explosion	None at present	5	2	MJ	Shut down reactor heating system on No Flow of water
Add a Dean Stark trap to the flask			SWIF Category: 1 and 5			
Water from the Dean Stark trap back-flows into the reactor?	Flash evaporation of water if reaction T > 125C; possible loss of containment; possible fire	Chemist monitors reaction regularly	4	2	MD	Match size of Dean Stark trap with expected volume of water from reaction
Install and set a temperature controller for reactor			SWIF Category: 2 and 3			
Temperature controller incorrectly set up or fails	Failure to control reaction temperature; possible runaway reaction; possible loss of containment	Chemist monitors reaction regularly	4	3	MJ	Determine if runaway is possible; consider using redundant T controller if true
Runaway reaction occurs before evasive action can be taken?	Probable loss of containment; possible fire/explosion	None at present	5	3	S	Determine if runaway is possible; consider using redundant T controller if true; do not perform overnight runs for this reaction

Note: Risk rank categories are S–severe; MJ–major; MD–moderate; MR–minor; ML–minimal. from Leggett[17]

Table E-2: Sample Portion of a Worksheet from a HazOp Analysis of a Wolff-Kishner Reaction **From Leggett[17]**

Synthesis Step							
Deviation	Deviation/Upset	Consequence	Safeguards	C	F	R	Recommendation(s)
Install and set a temperature controller							
Other than Step	The set-point for the T controller incorrectly set	The reaction T exceeds set point T; possible runaway reaction; possible loss of containment	Chemist monitors reaction regularly	4	3	MJ	Determine if runaway is possible; consider using redundant T controller if runaway can occur; do not perform overnight runs for this reaction
Higher temperature	Temperature controller fails	The reaction T exceeds set point T; possible runaway reaction; possible loss of containment	Chemist monitors reaction regularly	4	3	MJ	
More reaction	A runaway reaction occurs before evasive action can be taken	Probable loss of containment; possible fire/explosion	None at present	5	3	S	
Suspend the ketone (85 g) in diethylene glycol (2 L)							
Less PPE	The chemist is exposed to diethylene glycol	Low toxicity LD50 (rat) = 12,000 mg/kg (data from Chemical Hazard Review form)	Standard PPE	2	3	MR	
	The chemist is exposed to ketone	No data available; assume toxic by ingestion	Standard PPE	2	3	MR	
Place the flask in a room temperature oil bath then add KOH (70 g)							
Less PPE	The chemist is exposed to KOH	Moderately toxic LD50 (rat) = 273 mg/kg.(data from Chemical Hazard Review form)	Standard PPE + lab safety goggles	3	3	MD	
As well as reaction	There is a high heat of solution between NaOH solid and EG	Possible unexpected heating of glycol–no concern	Standard PPE+ lab safety goggles	3	3	MD	
Gradually add 80% solution of hydrazine hydrate (65 mL)							
Less PPE	The chemist is exposed to these reagents	Extremely hazardous and highly toxic LD50 (rat) 60 mg/kg; IDLH 50 ppm (data from Chemical Hazard Review form)	Standard PPE + lab safety goggles	5	3	S	Require use of full face respirator when handling N2H4
More reaction	The addition rate of 80% hydrazine is too high	Higher reaction rate than expected; possible to exceed heat removal capacity	None at present	3	2	MR	Consider using small scale reaction to determine impact of higher concentration or addition rate of N2H4 Consider adding flow

Table E-2: Sample Portion of a Worksheet from a HazOp Analysis of a Wolff-Kishner Reaction From Leggett[17]

Synthesis Step							
Deviation	Deviation/Upset	Consequence	Safeguards	C	F	R	Recommendation(s)
							restrictor in N2H4 line
Other than flow	Control of the hydrazine flow is lost	Higher reaction rate than expected; possible runaway reaction if all N2H4 is added at once	None at present	4	2	MD	
Heat the reaction mixture slowly heated to 200 8C over about 3–4 h allowing water to collect in the Dean–Stark trap							
Reverse flow	Water from the Dean Stark trap back-flows into the reactor	Flash evaporation of water if reaction T > 125 8C; possible loss of containment; possible fire	Chemist monitors reaction regularly	4	2	MD	Ensure capacity of trap matches expected volume of water

Note: Risk rank categories are S–severe; MJ–major; MD–moderate; MR–minor; ML–minimal (*Source:* Leggett[17]).

APPENDIX F: SUPPORTING INFORMATION FOR USE OF CHECKLISTS

Table F-1: Traditional Laboratory Safety Checklist (Example)

Laboratory Information
Laboratory Director/Principal Investigator: **Location:**

Traditional Laboratory Safety Checklist	Yes	No	N/A	COMMENTS
Training and Documentation				
Up-to-date inventory maintained for all hazardous materials?				
Chemical Safety Data Sheets (SDS) maintained and readily available at all times employees are present?				
Workplace hazard assessment and certification completed?				
Employees know the location of chemical inventory, SDS and related reference material?				
Employees received institutional safety training (typical provided by Environmental Health and Safety office) and supplemental laboratory-specific safety training for the hazards present in the laboratory?				
Employees familiar with physical and health hazards of chemicals in work area?				
Employees able to describe how to detect the presence or release of hazardous materials?				
Employees know how to protect themselves and others from effects of hazardous materials?				
Employees familiar with Chemical Hygiene Plan (or equivalent)?				
Spill and Emergency Planning				
Employees familiar with the fire safety and building evacuation procedures including evacuation routes, nearest fire exits, fire alarm pull stations, and fire extinguishers?				
Emergency procedures and phone numbers clearly posted?				
First aid materials readily available?				
Are any "antidotes" or special first aid materials required and available (e.g., Hydrofluoric Acid = Calcium Gluconate)?				
Spill cleanup materials available and laboratory staff familiar with their use?				
Safety shower and eye wash accessible within 10 seconds and unobstructed (e.g., no closed doors)?				
Safety shower tested and documented within past year?				
Eye wash tested, flushed, & documented at least monthly?				
Fire alarm pull stations, strobes, speakers, and fire extinguishers unobstructed and visible?				
Exits clearly marked and unobstructed?				
Personal Protection Clothing, Equipment and Engineering Controls				
Personnel wear shoes that fully cover feet and full length clothing to protect legs?				
Long hair confined? Jewelry, lanyards and other loose articles are confined or removed?				
Lab coats of appropriate material available and worn?				
Appropriate gloves available and worn?				
Goggles, face shields, are of appropriate type and worn?				
Respirators available and used in the laboratory? If yes…				
Respirator training, fit test and medical evaluation completed for				

Table F-1: Traditional Laboratory Safety Checklist (Example)

employees?				
Respirators cleaned, stored, and inspected regularly?				
Chemical hood available? If yes…				
Chemical hood free of clutter?				
Chemical hood inspected within last 12 months and capable of drawing at least 100 LFPM (or more if appropriate)?				
Chemical hoods equipped with air flow indicator?				
Perchloric acid operations conducted in specialized wash down chemical hoods?				
Biological Safety Cabinet available? If yes…				
Biological Safety Cabinet free of clutter and surfaces decontaminated?				
Biological Safety Cabinet certified within last 12 months?				
Mechanical pipetting used, no mouth suction?				
Chemical Safety				
Are chemicals used in this area? If yes…				
Appropriate labels are found on all hazardous chemical containers?				
Containers are in good condition (e.g., labels intact, metal cans free of rust) and closed when not in use?				
Containers properly segregated by hazard class (e.g., flammables away from oxidizers, acids separate from bases, incompatible acids separated)?				
Storage of chemicals above eye level is avoided?				
Flammable liquids stored in OSHA/NFPA approved cabinets and safety containers?				
Flammables liquids requiring refrigeration stored in either explosion proof or flammable resistant refrigerators and freezers (i.e., no regular refrigerators)?				
Ignition sources avoided when using/storing flammables?				
Corrosives stored in acid cabinets or other appropriate cabinets?				
Peroxide formers properly labeled and inventory tracked?				
Picric acid sufficiently wet?				
Large containers (4L or greater) stored near the floor?				
Bottle carriers or carts utilized when transporting hazardous chemicals between work areas?				
Proper signs delineate designated areas where high hazard chemicals are used?				
Designated area properly cleaned and decontaminated?				
Biological Safety				
Are biological materials used in this area? If yes…				
Biological materials are not stored in hallways in unlocked freezers or refrigerators.				
Biohazard signs are posted in labs handling infectious materials (BSL2 and higher).				
Disinfectants are on hand for sanitizing bench tops and treating spills.				
Biological safety cabinet(s) was certified within the last 12 months.				
Ionizing and Non-Ionizing Radiation Safety				
Are radioactive materials used in this area? If yes…				
Pure beta emitters (e.g., P-32, P-33, S-35, C-14)?				

Table F-1: Traditional Laboratory Safety Checklist (Example)

Gamma and x-ray emitters (e.g., I-125, I-131, Cr-51, Na-22)?				
Volatile, gaseous radioisotopes (e.g., I125) or aerosol/dust generating laboratory operations (e.g., vacuum flasks)?				
Sealed sources?				
Irradiators?				
X-ray generating equipment (Electron Microscope, X-ray diffraction, Diagnostic X-ray, Computed Tomography)?				
Is the proper shielding available for the types of radioisotopes being used?				
Are appropriate meters available for radioactive material used and are meter(s) calibrated?				
Are radiation workers provided personal monitoring when required?				
Are all appropriate signs posted? (Radiation Labels, Notice to Employees and Emergency Procedures)				
Are all spaces and items which store, handle or use radioactive materials properly labeled with "Radioactive Material", "Radiation Area" or other applicable hazard warning labels?				
Are radioactive materials secured/locked against unauthorized access from nonauthorized users?				
Is non-ionizing radiation used in the area? If yes…				
Laser – Class 1?				
Laser – Class 2?				
Laser – Class 3a?				
Laser – Class 3b?				
Laser – Class 4?				
Personal protective equipment (e.g., eye protection) or shielding available specific to the Class lasers used?				
Laser hazard warning signage posted?				
(Laser, Electromagnetic)				
Compressed and Cryogenic Gas Safety				
Are compressed gas cylinders used in this area? If yes…				
Cylinders stored upright and properly secured at all times?				
Caps properly secured when cylinders are not in use?				
Regulators always used, proper regulators used for type gas, pressure bled when not in use?				
Cylinders in good condition and clearly marked?				
Flammables stored separately from oxidizers, toxics in secure area, etc.?				
Cylinders of flammable gases stored in ventilated enclosures?				
Cylinders moved on cylinder trucks with regulators removed and caps secured?				
Cylinders of toxic gases (e.g., NFPA health hazard 3 or 4 and 2) stored and used in continuously ventilated enclosures?				
Cryogenic gas cylinder pressure relief values in proper working condition?				
Oxygen monitor available in areas with increased likelihood of oxygen deficient atmospheres?				
Equipment and Physical Hazards Safety				
Are equipment safety signs posted and in good condition?				
Are all guards and shields in place and secured?				

Table F-1: Traditional Laboratory Safety Checklist (Example)

Are safe work practices (long hair tied back, no loose clothing, etc.) being adhered to by all equipment users?				
Is equipment in good repair with evidence of proper maintenance?				
Are electrical cords in good condition, out of travel paths, and free of any cracks or breaks in insulation?				
Is proper PPE available and being used by equipment operators?				
Is a tagging system in place to prevent use of damaged equipment?				
Is access to the equipment restricted?				
Have all users been trained to operate this equipment?				
Are any additional or new hazards present at or around the equipment?				
Have there been any modifications to the equipment?				
General Laboratory Safety				
Smoking, eating, and drinking prohibited in lab?				
Lab is maintained secure; door is locked when no one is in lab?				
Appropriate warning signs posted near lab entrance?				
Unobstructed aisles maintained at least 36 in. wide throughout?				
Lab benches and work areas free of clutter?				
Shelves and cabinets in good condition?				
Shelves have seismic restraints, e.g., lips or wires?				
Shelves and cabinets secured to walls?				
Storage above eye level minimized and items restrained from falling?				
Refrigerators and freezers clearly labeled "Not for Storage of Food for Human Consumption"?				
No storage of food or drink in refrigerators, unless dedicated for such and clearly labeled?				
Waste Management				
Wastes are not discarded via trash or drain disposal unless specifically approved by the appropriate institutional authority (e.g., Environmental Health and Safety)?				
Is hazardous chemical waste generated in this area? If yes…				
Chemical inventory management/ordering system in place and checked before ordering new chemicals?				
Waste containers tightly closed unless actively adding or removing waste?				
Waste storage area has communication equipment readily available?				
Satellite Accumulation Area (SAA) is located at or near where waste is generated?				
Maximum SAA storage capacity not exceeded (55-gallons per hazardous waste stream)?				
Waste containers are in good condition (not leaking, rusted, bulging or damaged)?				
Each container is marked with the words “Hazardous Waste”?				
Each container is marked with full chemical names identifying the contents stored inside (no abbreviations or formulas)?				
Waste containers are kept closed unless adding waste?				
Waste containers storing liquid hazardous waste at or near sinks and drains are stored within secondary containment?				

Table F-1: Traditional Laboratory Safety Checklist (Example)

Secondary containment is in good condition (e.g., free of cracks, gaps and impervious to leaks)?				
Is sharps waste (e.g., needles, syringes, scalpel blades, or other instruments that has the potential to cut, puncture, or abrade skin) generated in this area? If yes…				
Sharps wastes are immediately discarded into proper puncture resistant containers?				
Sharps containers are readily available and managed appropriately (e.g., not overfilled)?				
Is biological waste generated in this area? If yes…				
Biological waste liquids decontaminated (if applicable) prior to drain disposal?				
Biological waste solids discarded as regulated medical waste and autoclaved or disinfected as appropriate?				
Is radioactive waste generated in this area? If yes…				
Is mixed waste (e.g., scintillation vials and any other radioactive and hazardous chemical waste mixture) generated in this area?				
Are the radioactive waste containers properly labeled?				

Table F-2: Laboratory Hazard Risk Assessment Matrix

Laboratory Information
Laboratory Director / Principal Investigator: **Location:**

Hazard and Exposure Category	How could you be exposed to this hazard?	Given the exposure, what is negative outcome?	Severity of Consequences		Probability of Occurrence		Risk Rating (CV*OV)
			What is the expected harm?	(CV) Value (1,5,10,20)	Existing Control Measure In Place	(OV) Value (0,1,2,3,4)	
Training and Documentation							
Personnel are appropriately trained (hazard communication, waste handling, process and chemical specific hazards and risks and mitigation, emergency procedures)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Personnel are aware of all activities in the lab and associated hazards and risks				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Average experience of lab personnel				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
SDSs and other hazard documentation are available as appropriate				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Hazard communication program is in place				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-2: Laboratory Hazard Risk Assessment Matrix

Process-specific risk assessment has been conducted for all processes and processes optimized				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Process-specific risk assessments are reviewed periodically				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Average value of process-specific risk assessment for all processes				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Spill and Emergency Planning							
Emergency response equipment is available and appropriate (spill kits, showers, etc.)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Means of egress				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate emergency response materials available and accessible				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
What is the worst thing that could happen in the lab?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Personal Protection Clothing, Equipment and Engineering Controls							
Skin / Hand Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Eye / Face Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Respiratory Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-2: Laboratory Hazard Risk Assessment Matrix

Eye Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Cut or Puncture Hazards from Sharp Objects				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Chemical Safety							
Hazard level of materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Amount of hazardous materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Adequate space and proper types of storage for materials				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Condition of containers and contents				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate material segregation				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate security measures are in place				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Current Comprehensive Inventory				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Containers are appropriately labeled				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Biological Safety							
Hazard level of materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Amount of hazardous materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-2: Laboratory Hazard Risk Assessment Matrix

Adequate space and proper types of storage for materials				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Condition of containers and contents				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate material segregation				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate security measures are in place				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Current Comprehensive Inventory				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Containers are appropriately labeled				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Radiation Safety							
Hazard level of materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Amount of hazardous materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Adequate space and proper types of storage and shielding for materials				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Condition of containers and contents				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate material segregation				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate security measures are in place				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-2: Laboratory Hazard Risk Assessment Matrix

Current Comprehensive Inventory				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Containers are appropriately labeled				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Compressed and Cryogenic Gas Safety							
Hazard level of materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Amount of hazardous materials stored in lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Adequate space and proper types of storage for materials				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Condition of containers and contents				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate material segregation				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Appropriate security measures are in place				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Current Comprehensive Inventory				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Containers are appropriately labeled				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Equipment and Physical Hazards Safety							
Sharps Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Trip hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Electrical hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-2: Laboratory Hazard Risk Assessment Matrix

Temperature extreme hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Pressure Extreme Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Moving Parts Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
General Laboratory Safety							
Facilities are adequate for types and quantities of chemicals present				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Facilities are adequate for types and quantities of processes occurring in the lab				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Waste Management							
All waste is stored and segregated appropriately				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
All waste is appropriately labeled				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
All waste is removed on a regular basis				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
All waste containers and contents are in good condition				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-3: Laboratory Process Risk Assessment Matrix

Laboratory Process and Procedure Overview
Laboratory Director / Principal Investigator:
Location:
Process Title:
Description:

Hazard and Exposure Category	How could you be exposed to this hazard?	Given the exposure, what is negative outcome?	Severity of Consequences		Probability of Occurrence		Risk Rating (CV*OV)
			What is the expected harm?	(CV) Value (1,5,10,20)	Existing Control Measure In Place	(OV) Value (0,1,2,3,4)	
Training and Documentation							
Specialized training requirements for material hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Specialized training requirements for equipment / process hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Spill and Emergency Planning							
Means of Egress (Emergency)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Unattended Operations				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Working Alone				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Personal Protective Clothing, Equipment and Engineering Controls							
Skin / Hand Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Eye / Face Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-3: Laboratory Process Risk Assessment Matrix

Respiratory Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Eye Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Cut or Puncture Hazards from Sharp Objects				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Chemical Safety and Exposure Assessment (Global Harmonization Standard (GHS) Hazard Statement Codes in Parenthesis)							
Explosive Self-Reactive Substances Organic Peroxides (A-B) (GHS: H200-H205; H240; H241)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Pyrophoric Self-Heating Substances Organic Peroxides (C-F) (GHS: H242; H250)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Flammable Liquids (GHS: H224-H226)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Flammable Solid or Combustible Dust (GHS: H228)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Oxidizer, Organic Oxidizer (GHS: H271; H272)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Corrosive Acid or Base (GHS: H290; H314; H318)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Acute Toxicity (inhalation) (GHS: H330; H331)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Acute Toxicity (oral, dermal) (GHS: H300; H301; H310; H311)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-3: Laboratory Process Risk Assessment Matrix

Other Irritants Dermal Sensitizers Harmful Materials Narcotic Effects (GHS: H302; H312; H315; H317; H319; H332; H335; H336)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Respiratory Sensitization, Germ Cell Mutagenicity, Carcinogenicity, Reproductive Toxicity, Specific Target Organ Toxicity, Aspiration Hazard (GHS: H304; H334; H340-H373)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Impacts to the Environment (GHS: H400–H420)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Material Handling of Chemicals (Bulk)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Compressed and Cryogenic Gas Safety and Exposure Assessment (GHS Hazard Statement Codes in Parenthesis)							
Flammable Gas/Aerosols (GHS: H220–H223)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Compressed Gas (GHS: H280)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Cryogenic Liquid/Gas (GHS: H281)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Biological Safety and Exposure Assessment							
Human blood, tissue, fluids, or other potentially infectious materials (Bloodborne Pathogens)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Bacteria, viruses, or other research biohazardous agents other than human materials				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-3: Laboratory Process Risk Assessment Matrix

Working with Animals				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Radiation Safety and Exposure Assessment							
Non-ionizing radiation (Laser)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Non-ionizing radiation (Electromagnetic)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Radiation Producing Equipment (Electron Microscope, X-ray diffraction, Diagnostic X-ray, Computed Tomography)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Radioactive Materials: Unsealed Sources				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Radioactive Materials: Sealed Sources				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Radioactive Waste: Solid (paper, plastic glass), Solid Other, Liquid (aqueous, non-aqueous), Mixed Chemical Waste				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
General Laboratory Safety and Exposure Assessment							
Heat/Cold				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Noise				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Walking/Working Surfaces				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Electrical Hazards and Energy Control (Lock-out/Tag-out)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-3: Laboratory Process Risk Assessment Matrix

Fall Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Equipment and Physical Hazards Exposure Assessment							
Pressure Vessels				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Rotating Equipment & Points of Operation				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0
Welding/Cutting Hazards				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	0

Table F-4: Laboratory Process Risk Assessment Checklist for a Process Using a Chemical

Laboratory Process Risk Assessment Checklist Overview
Laboratory Director / Principal Investigator: **Location:** **Process Title:** **Description:**

Laboratory Process Risk Assessment Checklist	How could you be exposed to this hazard?	Given the exposure, what is negative outcome?	Severity of Consequences		Probability of Occurrence		Risk Rating (CV*OV)
			What is the expected harm?	(CV) Value (1,5,10,20)	Existing Control Measure In Place	(OV) Value (0,1,2,3,4)	
Training and Documentation							
Specialized training required for the process or material hazards?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Specialized procedures developed for the safe completion of this operation?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Spill and Emergency Planning							
Does the process present risk of fire?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will any part of the process be unattended while in operation?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Are sufficient means of egress available for the nature and scale of hazards?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Are aisle spaces clear of obstructions and walking surfaces in good condition?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Personal Protective Clothing, Equipment and Engineering Controls							

Table F-4: Laboratory Process Risk Assessment Checklist for a Process Using a Chemical

Is there risk of splashing materials into eyes or on skin?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Is there risk of eye or face impact?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will there be exposure to sharp objects?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Chemical Safety and Exposure Assessment							
Does chemical process present risk of explosion, hazardous polymerization, or other uncontrolled reaction?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will a combustible dust be used or generated?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Is there risk of exposure to corrosive materials?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Is there risk of exposure to acutely toxic materials?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Is there risk of exposure to respiratory sensitizers, mutagens, carcinogens, reproductive toxins, materials that target specific organs, or aspiration hazards?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Are any materials classified as nanomaterials?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Biological Safety and Exposure Assessment							

Table F-4: Laboratory Process Risk Assessment Checklist for a Process Using a Chemical

Will there be exposure to human blood, , tissue, fluids, or other potentially infectious materials (Bloodborne Pathogens)				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will there be exposure to bacteria, viruses, or other research biological hazards?							
Will there be exposure to animals?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Radiation Safety and Exposure Assessment							
Will there be exposure to non-ionizing radiation?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will there be exposure to ionizing radiation?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Compressed and Cryogenic Gas Safety and Exposure Assessment							
Are compressed gases used?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Equipment and Physical Hazards Exposure Assessment							
Will there be exposure to electrical hazards?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Is any part of the process conducted at elevated or low pressure?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Is any part of the process conducted at elevated or low temperature?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	

Table F-4: Laboratory Process Risk Assessment Checklist for a Process Using a Chemical

Will the process involve generation of excessive noise?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will there be exposure to equipment that presents risk of pinching or crushing body parts?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will any part of the operation be conducted on an elevated area?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	
Will personnel be required to lift or otherwise manipulate heavy objects?				No=1 Minor=5 Mod=10 High=20		N/A=0 Rare=1 Poss=2 Likely=3 Certain=4	

Table F-5: Hazard Assessment for a Chemical

Laboratory Chemical Hazard Assessment and Overview
Laboratory Director / Principal Investigator:
Location:
Chemical Name:
Description:

HIGH HAZARD SUBSTANCE (HHS) CHECKLIST			
High Hazard Classification:	☐ High Acute Toxicity ☐ Air Reactive / Pyrophoric	☐ Carcinogen ☐ Water Reactive	☐ Reproductive Toxin ☐ Explosive / Unstable
Physical state/concentration:			
Maximum quantity kept on hand:		Estimated rate of use (e.g., grams/month):	
Toxicity: LD_{50} Oral (Rat)____________ LD_{50} Skin (Rabbit)____________ Other______________ Reactivity and Incompatibility:			

SIGNIFICANT ROUTE(S) OF EXPOSURE (CHECK ALL THAT APPLY)				
☐ Inhalation	☐ Skin contact	☐ Percutaneous injection	☐ Eye contact	☐ Ingestion

ADDITIONAL MATERIALS FOR REVIEW (ATTACHED)
☐ Safety Data Sheet (SDS) ☐ Laboratory/Experimental Protocol ☐ Other:

EXPOSURE CONTROLS
Ventilation/Isolation: Personnel must work under/in the following equipment to minimize personal exposure: ☐ Chemical hood ☐ Glove box/AtmosBag ☐ BioSafety Cabinet ☐ Balance Enclosure ☐ Other (list): If Glove box or AtmosBag, identify gas environment:
Personnel Protective Equipment (PPE)/Clothing: Laboratory coats, close-toed shoes, clothing that covers the legs and gloves (disposable latex or nitrile) are the minimum PPE requirements for all personnel working in the laboratory. Identify additional PPE requirements for work with HHS: Protective clothing: ☐ Disposable laboratory coat ☐ Fire-resistant laboratory coat (e.g., Nomex) ☐ Others (list): ____________________________________ Face / Eyes: ☐ Face shield ☐ Safety goggles ☐ Safety glasses Gloves (type): __________________________ ☐ Respirator (type): ________________

USE AND STORAGE			
Authorized personnel: Identify categories of laboratory personnel who could obtain approval to handle and use this HHS:			
☐ Principal Investigator	☐ Employees/Staff	☐ Students	☐ Volunteers

Table F-5: Hazard Assessment for a Chemical

☐ Postdoctoral Employees ☐ Other (describe):

☐ Personnel must not work alone in the laboratory while handling this material

Procedure: In additional to the institution's chemical hygiene plan, identify what procedures/guidelines are available for the safe handling and use of this HHS. Check all that apply and list below.
☐ Laboratory procedure(s) ☐ Journals ☐ Manufacturer Guidelines ☐ Other
List all procedures:

Vacuum system used? ☐ Yes ☐ No If yes, ☐ Cold trap ☐ Filter ☐ other (list):
Administered to animals? ☐ Yes ☐ No

Use Location:
Bldg(s)/ Room(s):
Identify location(s) where HHS is used (check all that apply):
☐ Entire laboratory ☐ Chemical hood ☐ Designated area
☐ Other (list): ______________________

Storage Location:
Bldg(s)/ Room(s):
Identify location(s) where HHS is stored (check all that apply):
☐ Refrigerator/freezer ☐ Hood ☐ Double containment
☐ Vented cabinet ☐ Flammable liquid storage cabinet
☐ Other (list): ______________________

Hazard Communication and Signage: Confirm that the hazards of the HHS are communicated to laboratory personnel and visitors where HHS is stored and used.
☐ All containers are clearly labeled with the identity of the High Hazard Substance.
☐ Designated storage and use locations within laboratory have signage identifying the HHS hazards present in those locations.

MEDICAL ATTENTION AND FIRST-AID

Laboratory personnel should seek medical attention when:

- signs or symptoms associated with a hazardous chemical exposure are experienced, or
- exposure monitoring reveals an exposure level routinely above acceptable levels, or
- a spill, leak, explosion or other event results in the likelihood of a hazardous exposure.

Emergency Medical Provider:

Location:

Contact Information:

Are specific first-aid supplies/procedures required (e.g., antitoxin) for work with this material? ☐ Yes ☐ No
If yes, attach the specific procedures to be followed post exposure to this form.

DECONTAMINATION

Are special decontamination procedures required for this HHS? ☐ Yes ☐ No If Yes, provide information below:
Identify items that require decontamination:
☐ Work areas ☐ Nondisposable equipment ☐ Glassware ☐ Disposable laboratory equipment and supplies
☐ Other (list):

Decontamination Method (describe):

EMERGENCY PROCEDURES AND SPILL RESPONSE

Emergency Safety Equipment: In addition to an eyewash station, emergency shower and ABC fire extinguisher, are any other

Table F-5: Hazard Assessment for a Chemical

specialized emergency spill control or clean-up supplies required when working with this HHS? ☐Yes ☐ No If yes, list all required supplies/equipment with locations:
WASTE MANAGEMENT AND DISPOSAL
Identify waste management methods for all research and waste byproducts associated with this HHS: ☐ Chemicals wastes are collected and disposed as EPA hazardous waste including chemically contaminated sharps. ☐ Neutralization or deactivation in laboratory prior to disposal (describe method; this method requires EHS preapproval). ☐ HHS is EPA Acutely Toxic Chemical. Collect Sharps and used containers as Hazardous Waste. ☐ Other disposal method (describe method; this method requires EHS preapproval). Chemical Waste Storage Location: ______________________________
TRAINING
All laboratory personnel must at a minimum completed safety training on an annual basis. Additionally, laboratory personnel who handle or use the High Hazard Substance must demonstrate specific competency and familiarity regarding the safe handling and use of this HHS prior to purchase or use. The Principal Investigator is responsible for ensuring all laboratory personnel handling and using this HHS are trained in the following: ☐ Review of HHS Checklist and associated documentation including Exposure Controls and PPE. ☐ Review Safety Data Sheet including Signs and Symptoms of Exposure. ☐ Hands-on training with the Principal Investigator or other knowledgeable and experienced senior laboratory staff member on the safe handling and use of the High Hazard Substance. ☐ New personnel must work under close supervision of Principal Investigator or other knowledgeable and experienced senior laboratory staff member. ☐ Other (list): ______________________________

Table F-6: Chemical Hazard Assessment Example: Sodium Cyanide

Laboratory Chemical Hazard Assessment and Overview

Laboratory Director / Principal Investigator:

Location:

Chemical Name: Sodium Cyanide (NaCN) **Trade name/Synonyms:** Hydrocyanic acid, sodium salt; Cyanogram:

Description:

HIGH HAZARD SUBSTANCE (HHS) CHECKLIST

High Hazard Classification:	☒ High Acute Toxicity	☐ Carcinogen	☐ Reproductive Toxin
	☐ Air Reactive / Pyrophoric	☐ Water Reactive	☐ Explosive / Unstable

Physical state/concentration: Solid (powder) / ≥97.0 %

Maximum quantity kept on hand:	**Estimated rate of use (e.g., grams/month):**

Toxicity: **LD50 Oral (Rat):** 4.8 mg/kg **LD50 Skin (Rabbit):** 10.4 mg/kg Other_______________

OSHA HAZARD CLASSIFICATION:
Target Organ Effect, Highly toxic by inhalation, Highly toxic by ingestion, Highly toxic by skin absorption

GHS CLASSIFICATION: (http://www.osha.gov/dsg/hazcom/ghs.html)

H300: Acute toxicity, Oral (Category 1)
H310: Acute toxicity, Dermal (Category 1)
H330: Acute toxicity, Inhalation (Category 2)
H400: Acute aquatic toxicity (Category 1)

GHS PICTOGRAM:

DANGER: Acute Toxicity

Reactivity and Incompatibility: Incompatible with strong acids and strong oxidizers. Sodium cyanide easily dissociates to the free cyanide ion in the presence of acids, water or water vapor. Reacts with acids to liberate toxic and flammable hydrogen cyanide gas. Water or weak alkaline solutions can produce dangerous amounts of hydrogen cyanide in confined areas. Can react with carbon dioxide in ordinary air to form hydrogen cyanide gas. Hydrogen cyanide is a chemical asphyxiant and interferes with cellular uptake of oxygen.

SIGNIFICANT ROUTE(S) OF EXPOSURE (CHECK ALL THAT APPLY)

☒ Inhalation ☒ Skin contact ☐ Percutaneous injection ☐ Eye contact ☒ Ingestion

ADDITIONAL MATERIALS FOR REVIEW (ATTACHED)

☒ Safety Data Sheet (SDS) ☐ Laboratory/Experimental Protocol

☒ Other: Safe Weighing of Toxic Powders

Table F-6: Chemical Hazard Assessment Example: Sodium Cyanide

EXPOSURE CONTROLS
Ventilation/Isolation: Personnel must work under/in the following equipment to minimize personal exposure**:** ☒ Chemical hood ☐ Glove box/AtmosBag ☐ BioSafety Cabinet ☐ Balance Enclosure ☐ Other (list): If Glove box or AtmosBag, identify gas environment:
Personnel Protective Equipment (PPE)/Clothing: Lab coats, close-toed shoes, clothing that covers the legs and gloves (disposable latex or nitrile) are the minimum PPE requirements for all personnel working in the lab. Identify additional PPE requirements for work with HHS: Protective clothing: ☒ Disposable lab coat ☐ Fire-resistant lab coat (e.g., Nomex) ☐ Others (list): Face / Eyes: ☐ Face shield ☒ Safety goggles ☐ Safety glasses Gloves (type): Nitrile (minimum layer thickness: 0.11 mm) ☐ Respirator (type): *Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. After removal of gloves, wash hands thoroughly with soap and copious amounts of water.*
USE AND STORAGE
Authorized personnel: Identify categories of laboratory personnel who could obtain approval to handle and use this HHS: ☒ Principal Investigator ☒ Employees/Staff ☐ Students ☐ Volunteers ☒ Postdoctoral Employees ☐ Other (describe):
☒ Personnel must not work alone in the laboratory while handling this material
Procedure: In additional to the institution's chemical hygiene plan, identify what procedures/guidelines are available for the safe handling and use of this HHS. Check all that apply and list below. ☒ Lab procedure(s) ☐ Journals: ☐ Manufacturers Guidelines ☒ Other: List all procedures: • Follow "*Safe Weighing of Toxic Powders*" procedures when weighing sodium cyanide powder. • All work MUST be done in a chemical fume hood that is operating properly. • Do not work alone when working with cyanides. • Keep container dry and avoid formation of dust and aerosols. When preparing solutions, add small volumes of dry sodium cyanide to large volumes of water (do not add small volumes of water to dry sodium cyanide. • Secure storage of solid sodium cyanide; in a dry well ventilated place. Vacuum system used? ☐ Yes ☐ No If yes, ☐ Cold trap ☐ Filter ☐ other (list): Administered to animals? ☐ Yes ☐ No If yes, is a RARC Protection and Control from completed? ☐ Yes ☐ No

Use Location: Bldg(s)/ Room(s): Identify location(s) where HHS is used (check all that apply): ☐ Entire lab ☐ Chemical hood ☐ Designated area ☐ Other (list):	**Storage Location:** Bldg(s)/ Room(s): Identify location(s) where HHS is stored (check all that apply): ☐ Refrigerator/freezer ☐ Hood ☐ Double containment ☐ Vented cabinet ☐ Flammable liquid storage cabinet ☐ Other (list):

Hazard Communication and Signage: Confirm hazards of HHS are communicated to laboratory personnel and visitors where HHS is stored and used. ☒ All containers are clearly labeled with the identity of the High Hazard Substance. ☒ Designated storage and use locations within laboratory have signage identifying the HHS hazards present in those locations.
MEDICAL ATTENTION AND FIRST-AID
All laboratory personnel who work with hazardous chemicals have access to medical attention and first-aid, including follow-up examinations which the examining physician determines to be necessary. Laboratory personnel should seek medical attention when: • signs or symptoms associated with a hazardous chemical exposure are experienced, or • exposure monitoring reveals an exposure level routinely above acceptable levels, or • a spill, leak, explosion or other event results in the likelihood of a hazardous exposure.

Table F-6: Chemical Hazard Assessment Example: Sodium Cyanide

Emergency Medical Provider: Location: Contact Information:
Are specific First-Aid supplies/procedures required (e.g., antitoxin) for work with this material? (Yes (No If Yes, attach the specific procedures to be followed post exposure to this form. Acute Effects: In most cases, cyanide poisoning causes a deceptively healthy pink to red skin color. However, if a physical injury or lack of oxygen is involved, the skin color may be bluish. Reddening of the eyes and pupil dilation are symptoms of cyanide poisoning. Cyanosis (blue discoloration of the skin) tends to be associated with severe cyanide poisonings. Trained emergency response personnel should administer a standard cyanide antidote kit (small inhaled doses of amyl nitrite, followed by intravenous sodium nitrite, followed by intravenous sodium thiosulfate). Working with a significant quantity of sodium cyanide requires the presence of an antidote kit containing amyl nitrite ampoules. Actions to be taken in case of cyanide poisoning should be planned and practiced before beginning work with cyanides. Inhalation: Corrosive to the respiratory tract. Sodium cyanide inhibits cellular respiration and may cause blood, central nervous system, and thyroid changes. May cause headache, weakness, dizziness, labored breathing nausea and vomiting, which can be followed by weak and irregular heartbeat, unconsciousness, convulsions, coma and death. Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic. Get medical attention immediately. Ingestion: Corrosive to the gastrointestinal tract with burning in the mouth and esophagus, and abdominal pain. Larger doses may produce sudden loss of consciousness and prompt death from respiratory arrest. Smaller but still lethal doses may prolong the illness for one or more hours. Bitter almonds odor may be noted on the breath or vomitus. Other symptoms may be similar to those noted for inhalation exposure. If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately. Skin Contact: Corrosive. May cause severe pain and skin burns. Solutions are corrosive to the skin and eyes, and may cause deep ulcers which heal slowly. May be absorbed through the skin, with symptoms similar to those noted for inhalation. In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical attention immediately. Eye Contact: Corrosive. Symptoms may include redness, pain, blurred vision, and eye damage. Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately. Chronic Effects: Prolonged or repeated skin exposure may cause a "cyanide" rash and nasal sores. Cancer Hazard: Unknown. It is a mutagen and should be treated as a possible carcinogen. FIRST AID PROCEDURES 1. Personal Protection By First Aid Personnel First aid personnel providing first aid treatment to a patient exposed to sodium cyanide solid should observe the following precautions for their own personal protection: · Avoid contact with contaminated skin, clothing and equipment by wearing protective gloves; · Wear chemical goggles as a minimum level of eye protection to prevent sodium cyanide dust entering eyes; · Avoid inhalation of sodium cyanide dust during rescue in contaminate areas by wearing suitable respiratory protection; · Respiratory protection suggested is: an air supplied breathing apparatus, or positive pressure self contained breathing apparatus. 2. Swallowed Immediately: · Remove the patient from the source of contamination to fresh air, if hydrogen cyanide gas (HCN) is present;

Table F-6: Chemical Hazard Assessment Example: Sodium Cyanide

· If the patient is not breathing, do not use mouth to mouth, or mouth to nose ventilation, because of the danger to the rescuer, instead use a resuscitation bag and mask (Oxy-Viva);
· If pulse is absent, start external cardiac massage and follow standard Advanced Cardiovascular Life Support (ACLS) guidelines;
· Give 100% oxygen by mask (Oxy-Viva) if available;
· Remove all contaminated clothing and footwear into a sealable collection bag, launder contaminated clothing thoroughly and wash the affected areas with soap and copious amounts of water.

3. Eyes

Persons with potential eye exposure should not wear contact lenses.
Immediately irrigate eye with copious amounts of water, while holding eyelids open, for at least 15 minutes.
Seek medical assistance immediately.

4. Skin

Wash affected area with copious amounts of water for at least 15 minutes.
Remove contaminated clothing and launder before reuse.
Seek medical assistance following skin contact.

5. Inhalation

Proceed as for 2. Swallowed above.

DECONTAMINATION

Are special decontamination procedures required for this HHS? ☒ Yes ☐ No If Yes, provide information below:

Identify items that require decontamination:
☒ Work areas ☒ Non-disposable equipment ☒ Glassware ☒ Disposable lab equipment and supplies
☐ Other (list):

Decontamination Method (describe): Decontaminate work space and equipment with 10% bleach solution. Avoid creating dust. Contaminated pipette tips, tubes, weighing trays, gloves, paper towel, napkins and any other clean up debris must be disposed of as hazardous waste. After removal of gloves, wash hands thoroughly with soap and copious amounts of water.

EMERGENCY PROCEDURES AND SPILL RESPONSE

Emergency Safety Equipment: In addition to an eyewash station, emergency shower and ABC fire extinguisher, are any other specialized emergency spill control or cleanup supplies required when working with this HHS? ☐Yes ☒ No

If yes, list all required supplies/equipment with locations:

Spill Response Procedures:
Remove everyone from the area. Close all doors leading to the lab and restrict access to the area. Call safety office immediately after at __________.

WASTE MANAGEMENT AND DISPOSAL

Identify waste management methods for all research and waste byproducts associated with this HSS:
☒ Chemicals wastes are collected and disposed as EPA hazardous waste including chemically contaminated sharps.
☐ Neutralization or deactivation in laboratory prior to disposal (describe method and requires EHS preapproval).
☒ HHS is EPA Acutely Toxic Chemical. Collect Sharps and used containers as Hazardous Waste.
☐ Other disposal method (describe method and requires EHS preapproval).
Chemical Waste Storage Location: ____

TRAINING

All laboratory personnel must at a minimum completed safety training on an annual basis. Additionally, laboratory personnel who handle or use the High Hazard Substance must demonstrate specific competency and familiarity regarding the safe handling and use of this HHS prior to purchase or use. The Principal Investigator is responsible for ensuring all laboratory personnel handling and using this HHS are trained in the following:

(Review of HHOP and associated documentation including Exposure Controls and PPE.
(Review Safety Data Sheet including Signs and Symptoms of Exposure

Table F-6: Chemical Hazard Assessment Example: Sodium Cyanide

(Hands-on training with the Principal Investigator or other knowledgeable and experienced senior laboratory staff on the safe handling and use of the High Hazard Substances.
(New personnel must work under close supervision of Principal Investigator or other knowledgeable and experienced senior laboratory staff.
(Other (list):

APPENDIX G: SUPPORTING INFORMATION FOR STRUCTURED DEVELOPMENT OF SOPs

Table G-1: Example of Completed Matrix for the Structured Development of SOPS
Figure G-2: Example Standard Operating Procedure

Table G-1 (columns 1–4): Example of Completed Matrix for the Structured Development of SOPs

Evaluate Each Step or Task	Hazard Identification - Known and Potential Hazards - Safety constraints & restrictions	Specific issues identified	Risk Assessment - What is most likely to go wrong - what are the most severe consequences even if unlikely?	Literature search and consultation with experienced supervisors for lessons learned
Regulatory Concerns	Understanding applicability, cost constraints, lack of options, delays, require assistance, permits	Fire codes for flammable compressed gases limits storage amounts and conditions, regulators, tubing, connections and may require special storage, alarms, etc. Fire code requires conditions for safe egress. Compressed gases are regulated by NFPA and OSHA. NFPA and IFC also regulate toxic gases (see below).	Improper storage can lead to a leak or high vol. gas release. Improper connections can lead to a leak or static buildup. Emergency response may be impeded by lack of shut off valves or kill switches. Lack of fire alarms/suppression could result in catastrophic fire damage. For flammable gas CO, regulatory concerns relate to flammability, toxicity, and gas under pressure (see below).	NFPA codes have been written to address deficiencies in construction, operations, storage, etc. that had led to loss of life. Literature reviews should uncover laboratory accidents involving most flammable gases, compressed gases, many pieces of equipment and many processes. Additionally, the release of toxic gases is well documented
Human Factors	Inexperienced worker, new experiment, work hours, follows directions, medical conditions, effect of errors, effect of cold or fatigue, language barrier	Relatively new graduate student from overseas with limited command of English. New experiment for this student.	Student may misunderstand parts of scientific procedure/safety procedures. Student may not have been adequately prepared or trained. Student may not be able to acquire emergency help.	Student should be required to review literature extensively to understand the hazards, potential for accidents, measures for mitigation or prevention of an accident.
Facility	Lighting, hand wash sink, egress, electrical circuits, ventilation, emergency equip., code adherence, confined space, storage arrangements, sturdy shelves		Is gas segregated from oxidizers? Is cylinder secured? Does the cylinder impede egress? Are there sprinklers in the laboratory and/or the hood?	
Materials	Biological, Radiological, Chemicals; for chemicals--flammability, toxicity, PEL, Physical data, reactivity, corrosivity, thermal & chemical stability, inadvertent mixing, routes of exposure	The flammable gas is carbon monoxide, a toxic gas with a GHS acute toxicity rating of 3 and no physiological warning properties. Must be used at 100%, passed through a synthesis unit, and released. May run continuously for 24 hours.	Potential for fire, but if leak develops, exposure risk is high. Realize that a gas leak can only be detected w/monitoring system; note potential for slow buildup of toxic gas, and potential for chronic sub-acute poisoning; effects of illness may be delayed	At the time of publication OSHA guidance is found at: http://www.osha.gov/SLTC/healthguidelines/carbonmonoxide/recognition.html Lessons Learned: http://thepost.ohiou.edu/content/plans-initiated-prevent-carbon-monoxide-leaks ; recommend internet search for other information
Equipment and Labware	Materials integrity, maintenance, piping, electrical, relief systems, ventilation systems, safety mechanism		Ensure use of appropriate piping with adequate safety mechanisms	
Process	Unsafe quantity or concentration, unsafe temp, pressure, flow or composition, deviations, potential for runaway reaction		Identify potential ignition sources. Is there a possibility of an explosive quantity?	
Effect of change in design or conditions	More energetic or toxic, increase potential for release, hazards of scale up			

Table G-1 (columns 1–4): Example of Completed Matrix for the Structured Development of SOPs

Evaluate Each Step or Task	Hazard Identification - Known and Potential Hazards - Safety constraints & restrictions	Specific issues identified	Risk Assessment - What is most likely to go wrong - what are the most severe consequences even if unlikely?	Literature search and consultation with experienced supervisors for lessons learned
Possibility for additive or synergistic effect or unknown effects	Lack of expertise or knowledge, newly synthesized materials, untested or unfamiliar equipment, materials or processes			
Effluents and waste management	Challenges to proper disposal, potential for exposure or contamination, hazardous releases to air or water		Is gas used up in experiment or will some be released?	
Availability of PPE	Inadequate PPE or shielding for hazard, cost factors, worker compliance, lack of alternatives		Eye protection, shielding, flame resistant lab coat, gloves. Wear nonsynthetic clothing.	
Emergency Response resources	Inadequate or unavailable, lack of knowledge about emergency procedures		Identify location of fire extinguishers. Review how to request emergency assistance.	
Potential failure points or routine activities with high risk of harm	Weighing toxic materials on lab bench, opening an autoclave, hard to close caps, lack of "kill" switch		Automatic shut off in the event of a fire?	

Table G-1 (columns 5–9): Example of Completed Matrix for the Structured Development of SOPs

Evaluate Each Step or Task	Strategies to Eliminate, Control or Mitigate Hazard	Suggested strategies to address identified hazards (Plan A)	Ask Again - What Could Go Wrong? Consider atypical or less likely events - Identify possible Failure points or known failures of prior strategies	Plan B to Eliminate, Control or Mitigate	Will Standard Precautions be Adequate? (Develop written criteria)
Regulatory Concerns	CHP, OSHA carcinogen regulations, controlled substances DEA regulations, permits for select agents and/or radioactive materials, etc. Review compliance plan with EHS or other local and national experts. Consult technical experts from gas vendor for guidance. Make a checklist using applicable regulations and insert into lab safety manual or CHP	Verify within code limits using checklist and other identified compliance strategies. For CO, a gas cabinet or other exhaust cabinet is required for storage. Determine if small volume cylinders can be used and store them in the fume hood.	Think about why these codes exist. What purpose are the regulations requiring certain connections, tubing materials, shut off valves and switches, safe egress, fire monitoring and suppression, toxic gas alarms?	Identify compliance weakness (e.g., old building without sprinklers). Identify secondary measures that could address these deficiencies: install sprinklers, install extra alarm systems; have emergency backup support ready; isolate experiment to safest part of lab, move experiment to sprinklered lab	Standard precautions are probably not adequate without considering the regulations addressed in the review and checklist. Once the checklist is completed and plans are determined to be adequate, this part of the SOP could be standard.
Human Factors	Reiterative training, enforce lab rules, supervision, ascertaining worker knowledge, ensure worker is well-informed, practice small, SOPs, buddy system. Ensure student has taken all relevant training including emergency response. Student should be directly supervised until he/she has shown proficiency in all aspects of hazard control and emergency response. Student should write SOP and review with senior lab staff.	Student should be adequately trained and supervised. A dry run or scaled down experiment should be performed first.	Most likely human failure would involve communication difficulties. These must be addressed in advance as well as monitored during a hazardous experiment.	Supervisor and student should discuss scenarios for potential gas leak, fire, explosion, and supervisor should be satisfied that student can address these. Alternatively, student may assist more experienced lab worker.	SOP may be developed if experiment becomes routine, as long as clear indications are present regarding when to consult supervisors or review safety plan.
Facility	Ensure proper environment and conditions - **can use checklist**	Checklist to verify proper configuration prior to start work each day.			

Table G-1 (columns 5–9): Example of Completed Matrix for the Structured Development of SOPs

Evaluate Each Step or Task	Strategies to Eliminate, Control or Mitigate Hazard	Suggested strategies to address identified hazards (Plan A)	Ask Again - What Could Go Wrong? Consider atypical or less likely events - Identify possible Failure points or known failures of prior strategies	Plan B to Eliminate, Control or Mitigate	Will Standard Precautions be Adequate? (Develop written criteria)
Materials	Eliminate, substitute or reduce amt.? Detection & warning methods? Use of administrative, engineering or PPE controls (expand). Completely enclose process in fume hood, if possible; use gas monitoring/alarm systems, normally - closed valves which shut off with power failure, create lab SOP requiring checking of all systems before an experiment. May only be used during work hours or if monitored. If leak is detected, turn off gas sources and evacuate lab.	Use mixture with inert gas if possible. Keep quantity to a practical minimum.			
Equipment and Labware	Integrity check, right tool for job, maintenance, correct use, troubleshoot, normal and emergency operations delineated	Conduct integrity check each day prior to work.			
Process	Change process, small tests, test runs without hazard present, acquire expert assistance, secondary controls, emergency response actions	May wish to conduct dry run with nitrogen or compressed air. Identify potential ignition sources and check for these each day.			
Effect of change in design or conditions	Assume and prepare for increased risks, identify these in order of potential, require review by experts, require continuous monitoring, install safeguards, warning systems, shutdown mechanisms and remote monitoring	Conduct thorough review when changing out cylinders.			
Possibility for additive or synergistic effect or unknown effects					
Effluents and waste management	Must be resolved before experiment, proper disposal containment and methods for				

Table G-1 (columns 5–9): Example of Completed Matrix for the Structured Development of SOPs

Evaluate Each Step or Task	Strategies to Eliminate, Control or Mitigate Hazard	Suggested strategies to address identified hazards (Plan A)	Ask Again - What Could Go Wrong? Consider atypical or less likely events - Identify possible Failure points or known failures of prior strategies	Plan B to Eliminate, Control or Mitigate	Will Standard Precautions be Adequate? (Develop written criteria)
	experiment waste				
Availability of PPE	Design experiment to reduce reliance on PPE, combine control methods, prohibit use of inadequate PPE				
Emergency Response resources	Buddy system, alarms, ensure availability of equipment & personnel, emergency drills & training, spill kits, AED. All lab staff must have fire extinguisher training.	Conduct a drill involving one or more emergency scenarios prior to conducting experiment.			
Potential failure points or routine activities with high risk of harm	Review and change work practices, extensive training, instructions to address unexpected - failures, breakage				

Figure G-2: Sample Standard Operating Procedure

Standard Operating Procedure
Use of Carbon Monoxide to Create Metal Complexes under Pressure

NOTE: You must read this entire document and both you and the Principal Investigator must sign it before commencing any work.

Principal Investigator/Supervisor: ______________________________

Room and Building where SOP is used: ___________________________

Summary of how material will be used

Carbon monoxide will be used to create metal complexes by conducting reactions up to 24 hours in a chamber under pressure with a palladium catalyst, all in a fume hood.

Potential hazards

CO is classified as an extremely flammable gas, with an acute toxicity rating of 3 under GHS. The gas is colorless and odorless (no warning properties). There is also the possibility of explosion.

Regulatory Issues

The National Fire Protection Association requires CO greater than lecture bottle-size to be stored "in approved continuously mechanically ventilated gas cabinets."

Engineering Controls

Use in fume hood. Keep shield and/or hood sash between reaction vessel and laboratory worker. Work should be conducted in a laboratory where there are sprinklers in the hood and/or the general laboratory. Install flow restrictors, normally closed pneumatic valves that will close on loss of exhaust, loss of power, or activation of the CO detector.

Work Practice Controls

New workers must review the "Structured Development of SOPs spreadsheet" and this SOP with the PI, supervisor, or experienced lab worker prior to conducting work. At the beginning of the experiment, review at least two references on carbon monoxide properties and/or incidents. Review emergency procedures—both how to request assistance and how to notify other nearby workers. Do not work alone. Use in fume hood. Make sure the cylinder is secured. Verify that appropriate piping with adequate safety mechanisms is being used. Check connections to cylinder for leaks before each use. Verify that CO monitor is working. Make sure there are no oxidizers or open flames that could react with or ignite the gas. Make sure that laboratory equipment is structurally sound and capable of maintaining integrity under pressure. If reaction is allowed to proceed unattended, label fume hood with appropriate signage. After initial experiment and when encountering changes or unexpected reactions, review this SOP with other experienced researchers. When done with the experimental work, close all valves, clear lines, and put all experimental materials in their proper places.

Specific experimental procedures

(Use this space for the specific procedures to be used in your laboratory)

Personal Protective Equipment

Wear protective eyewear and lab coat made of flame resistant material at all times. Appropriate gloves (specify type: ______________) should also be worn.

Storage

CO must be stored in a gas cabinet or fume hood. Purchase the smallest amount necessary for the work. A small cylinder that could be stored in the fume hood is preferred, if the scale of the experiment is small. All cylinders must be secured to prevent damage to the valve.

Waste disposal

(Use this space to indicate how any wastes from the experiment are to be handled.)

Spills and Releases

If exposure symptoms are present, seek medical help immediately. If a release occurs, immediately stop all work. If safe to do so, close the main valve on the cylinder to prevent any additional gas escape. Alert other nearby workers and supervisor to the situation. Evacuate area and allow any residual CO to escape through the fume hood or gas cabinet. Make sure no one has received a hazardous exposure. Thoroughly check lines and equipment for leaks before restarting the experimental work.

Emergency Procedures

The nearest fire extinguisher is located ____________________. In the event of a fire, do not attempt to fight it unless you have had fire extinguisher training and you are confident you can safely extinguish the fire. Emergency assistance can be obtained by calling 911 or activating a pull station (specify location). If emergency responders are requested, meet them when they arrive on scene and be available to provide information about the incident. Contact (your institution's) Occupational Medicine Department for medical advice on exposure to CO. Have a copy of the CO Safety Data Sheet available when meeting with medical personnel. Complete your institution's work injury or illness report form.

Training Records

"By my signature, I verify that I have read and understand this SOP, and have discussed any questions I have had with the indicated trainer. I agree to fully adhere to its requirements."

Last	First	Signature	Trainer/PI	Date

Prepared by: ACS Hazard Assessment Task Force Date:

Updated by: ______________________________ Date: ________________