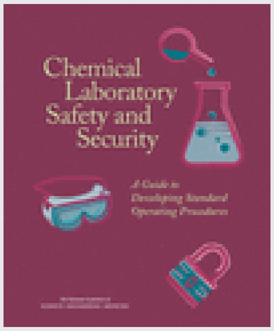

Chemical Laboratory Safety and Security: A Guide to Developing Standard Operating Procedures

DETAILS

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Chemical Laboratory Safety and Security

A Guide to Developing Standard Operating Procedures

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this report:

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Lori Seiler, The Dow Chemical Company

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before the release. The review of this report was overseen by **Stephen Berry** of the University of Chicago. He was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

The *Guide to Developing Standard Operating Procedures* is meant to be used with the *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management* and the accompanying toolkit.

These materials are available on the Internet at www.dels.nas.edu/global/bcst/Chemical-Management.

CONTENTS

1
STANDARD OPERATING PROCEDURES FOR CHEMICAL SAFETY

INTRODUCTION

A daily commitment from all individuals in an institution is required for an effective safety and security program. It is important for individuals at all levels to work together to eliminate the risk of exposure to hazardous materials and conditions in the laboratory. In 2008, the U.S. Department of State contracted with the National Academies of Sciences, Engineering, and Medicine[1] to produce informational materials including a baseline of practices for handling, storage, and use of chemicals on the laboratory scale that are required to promote safety and security in the developing world. To accomplish this task, an expert committee created and published in 2010 the reference guide, *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management,* and its accompanying toolkit. The toolkit includes a quick guide for laboratory managers, an executive summary to share with institutional leaders, an instructor's guide, forms and signs to photocopy and distribute, preplanning reference cards to distribute to laboratory personnel, and helpful reminder signs for posting in the laboratory. All of these products, including the 2010 reference guide, have been translated into Arabic, Bahasa Indonesia, and French and distributed broadly. Together, the 2010 reference guide and its accompanying toolkit provide researchers with best laboratory practices to improve chemical management and increase the level of safety and security in the laboratory. Within the 2010 toolkit, however, a detailed guide on how to develop a standard operating procedure (SOP) is not covered; this *Guide to Developing Standard Operating Procedures*[2] fills this gap and serves as an additional product in the toolkit.

WHAT IS A STANDARD OPERATING PROCEDURE?

For the purposes of chemical safety and management, an SOP is a detailed, written set of procedures that explains how to utilize and manage hazardous chemicals, processes, and procedures to prevent or minimize health and safety concerns. The development and use of SOPs are integral parts of a successful safety program. Poorly written SOPs are of limited value. Therefore, SOPs should be clear, concise, and detailed but not overly complicated. SOPs should provide sufficient detail and be specific to the institution or facility so that someone with limited experience or knowledge of the procedure can successfully and safely follow the procedure. Typically, SOPs focus on

- processes,
- operational ranges and conditions,
- individual hazardous chemicals,
- classes of hazardous chemicals,
- management and use of chemical equipment,
- emergency shutdown,
- authorized users, and
- lab-specific safety and security risks, based on surroundings and environmental factors.

Workers in industry, private research institutions, and academic laboratories use SOPs when their laboratory standards do not sufficiently address the use of hazardous chemicals or conditions. The primary

[1] As of July 2015, the National Research Council is no longer used, and all references are now given as the National Academies of Sciences, Engineering, and Medicine.

[2] Details regarding the statement of task for the *Guide to Developing Standard Operating Procedures* can be found in Appendix A.

objective of a laboratory standard is to communicate basic safety principles governing laboratory activities. Laboratory standards are developed in conjunction with and approved by the institution and conform to best practices as exemplified in *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management*, *Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version*, and, if applicable, the U.S. Occupational Safety and Health Administration's (OSHA) Laboratory Standard (or equivalent), among other resources. Additional details on laboratory standards are provided in Section 2B, pages 14-15 in *Prudent Practices in the Laboratory* (Appendix B).

WHO IS RESPONSIBLE FOR DEVELOPING STANDARD OPERATING PROCEDURES?

Laboratory personnel who supervise or direct hazardous operations are responsible for developing an SOP, in addition to those conducting the hazardous operations. New students and employees are responsible for learning and familiarizing themselves with SOPs. Tailoring the SOP to the specific chemical(s) or process and laboratory setting is required. Existing SOPs from reliable resources can provide background knowledge but should not be directly adopted because of the possible differences in laboratory environment and location, user experience, and equipment. SOPs are needed even when published methods are being followed.

After an SOP has been developed, the principal investigator (PI) or equivalent, who will be responsible for enforcing the SOP, should review the document for accuracy and completeness. If available, then the safety manager should also review the completed SOP.

GUIDE TO DEVELOPING STANDARD OPERATING PROCEDURES

The objective of this *Guide to Developing Standard Operating Procedures* is to provide a framework for laboratory personnel tasked with developing SOPs. The guide builds on the 2010 report *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management* and can be added to the related toolkit. The guide consists of

- Risk Assessment Flowchart
- Chemical Storage Matrix
- Moderate Risk Standard Operating Procedure Form
- High Risk Standard Operating Procedure Form
- Scenarios
  1. Neutralization of Carbonate by Acid
  2. Use and Filtration of a Pyrophoric Catalyst
  3. Toxic and Explosive Gases: Handling Diazomethane and Alternatives
  4. Reagent Storage

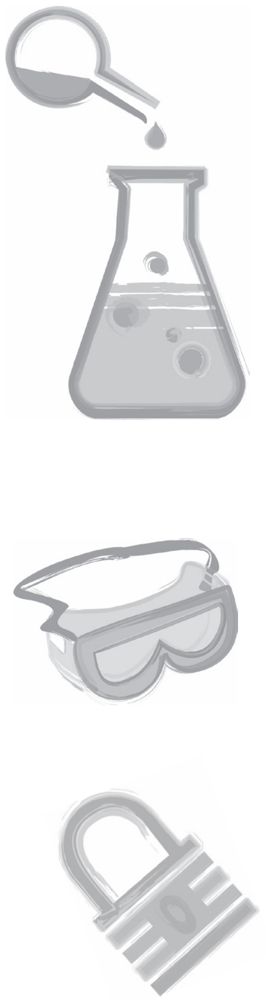
The Risk Assessment Flowchart (**Chapter 2**) can be used to determine whether an SOP is required for the proposed work, and, if so, then which type of SOP. The Chemical Storage Matrix (**Chapter 3**) identifies the safest methods to store and manage hazardous chemicals. If the chemical is (1) used in a specific process that involves some level of risk, (2) a chemical of concern (COC)[3] or a dual-use chemical, or (3) a

[3] See Appendix A in *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management* for a list of COCs.

newly synthesized compound, whose properties may not be fully known, then laboratory personnel should develop an SOP. When the laboratory standards are not sufficient for the scope of work, laboratory personnel will use either a Moderate Risk Standard Operating Procedure Form (**Chapter 4**) or a High Risk Standard Operating Procedure Form (**Chapter 4**). Four hypothetical examples (**Chapter 5**) are presented to demonstrate the application of the *Guide to Developing Standard Operating Procedures*. It is suggested that each institution consider its specific economics, culture, regulations, experience, and scale of operations when applying the best practices presented in this guide. For example, chemical laboratories in areas that are densely populated or have high rates of crime or theft, or where there is conflict or insurgency, could consider adopting a high security level for their facility (see *A Guide to Prudent Chemical Management*, pp. 59–70). Forms for use in training sessions or for development of SOPs are provided in **Chapter 6**.

Users of these materials are expected to have at least a B.S. degree in chemistry, chemical engineering, or an allied field such as biochemistry or materials science or at least 5 years experience as a chemical technician/technologist. Laboratory technicians and undergraduate students, who may not possess a B.S. degree in one of these fields, can contribute to SOP development with guidance from trained staff with a B.S. degree in chemistry, chemical engineering, or an allied field.

The following chapters provide instructions that are pertinent to each product in the guide, and Appendix B provides additional resources.



2
RISK ASSESSMENT FLOWCHART

INTRODUCTION

The Risk Assessment Flowchart is designed to aid in the assessment of the risks associated with specific process and chemicals. The flowchart is divided into two tracks: (1) Process Risk Mitigation and (2) Management and Storage of Chemicals. Development of a Chemical Storage standard operating procedure (SOP; see Chapter 3 for more details), which is the endpoint for the Management and Storage of Chemicals track, would be appropriate for all hazardous chemicals.

MANAGEMENT AND STORAGE

The laboratory worker will use scope criteria to determine whether the risk is inherent in the processing of the chemical or in the management and storage of the chemical to determine whether an SOP is needed for Process Risk Mitigation or Management and Storage of Chemicals (Figure 2-1). If the proper procedures for handling and storing the chemical are unclear, then the worker will select the Management and Storage track as the default. Proper storage is a concern for all hazardous chemicals, even those that will be used in an experiment scheduled for the future. The Chemical Storage Matrix, which will assist in development of the Management and Storage SOP, is presented in Chapter 3.

PROCESS RISK MITIGATION

The worker will select the Process Risk Mitigation track for all processes. Once on this path, the worker will assess the characteristics of each chemical and the processes to be used.

Assessment of Chemicals

The worker will assess the safety-related characteristics of each chemical used in the experiment or operation to determine whether it presents high, moderate, or low risk. Safety-related characteristics include toxicity and health hazards (acute and chronic), flammability, reactivity, and whether the chemical is an oxidizer or peroxide-former. This information can be obtained from Globally Harmonized System (GHS) labeling, Safety Data Sheets, and other literature sources listed in Appendix B.

The worker will also consider the scale of the experiment or operation. For example, the laboratory standard may call for a Moderate Risk SOP if only a small amount (milliliters) of a highly flammable and moderately toxic solvent will be used but a High Risk SOP if the same solvent will be used at a substantially larger scale. Certain chemicals, regardless of quantity, can pose a high risk under harsh weather conditions, such as high level of humidity and/or temperature, which would dictate use of a High Risk SOP.

Assessment of Process Conditions

After assessing the chemical's characteristics, the worker will assess all of the process conditions, which include temperature, pressure, scale, the number of times the process will be repeated, and the training of laboratory personnel. Process conditions also include any hazards inherent in the equipment being used and the location where the process will be performed, for example, in a chemical hood or lab benchtop. Together, the assessment of chemical characterstics and process conditions will indicate a low, moderate, or high level of risk (see Table 2-1).

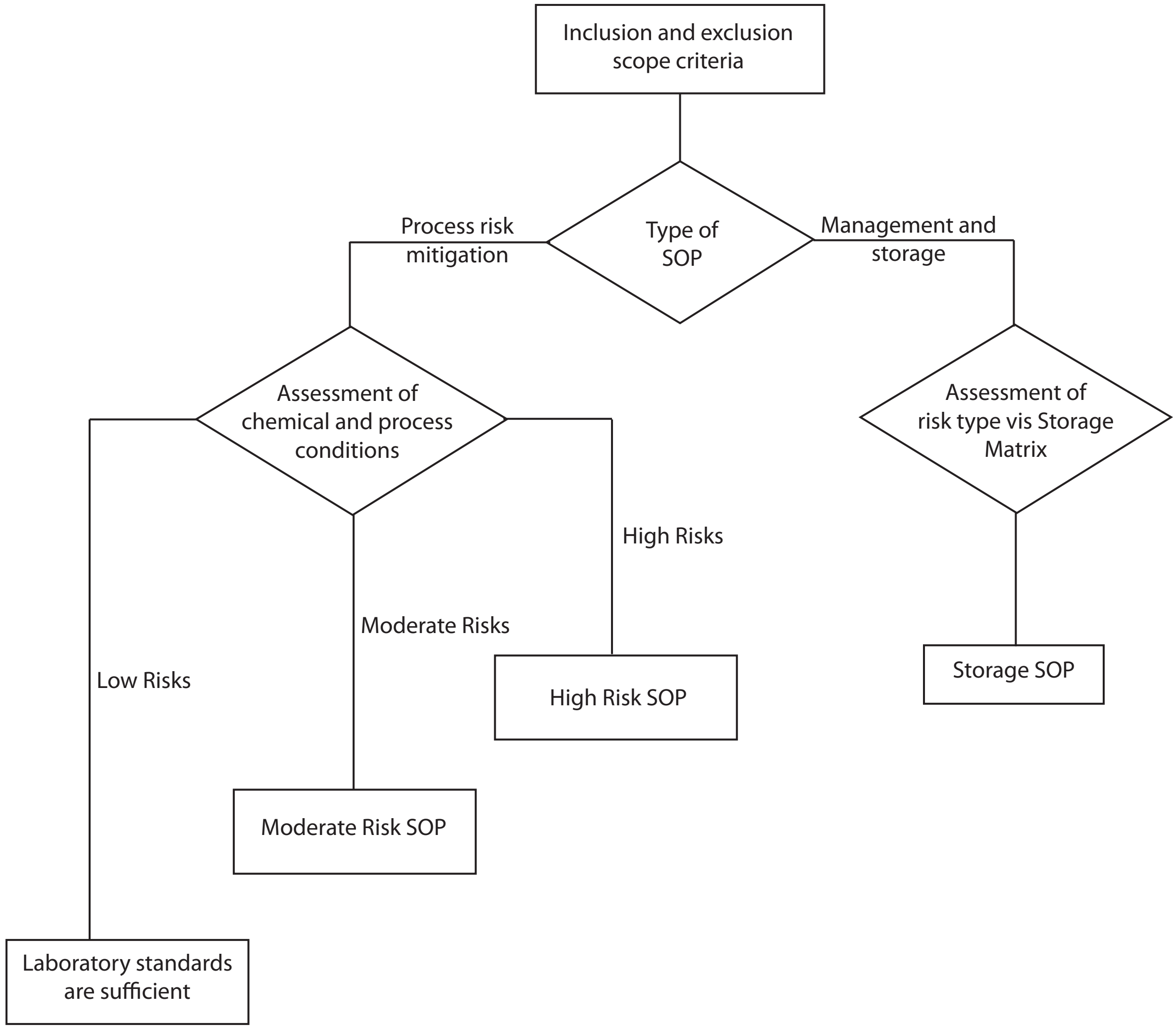


FIGURE 2-1 Risk Assessment Flowchart.

TABLE 2-1 Types of Risk

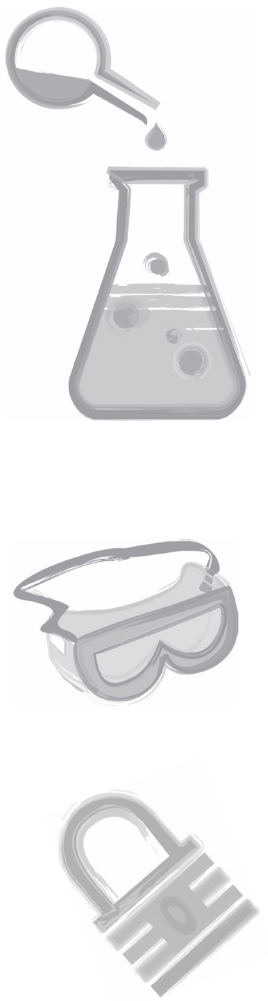
Type of Risk	Description
Low Risk	No additional controls are required.
Moderate Risk	Consider whether the risks can be lowered, where applicable, to a tolerable, preferably acceptable, level, while accounting for the costs of such risk reduction measures. Processes of moderate risk may include neutralization of a carbonate.
High Risk	Substantial efforts should be made to minmize the risk. Risk reduction measures should be implemented urgently. Processes of high risk may involve the use of pyrophorics, explosives, or high volumes of flammable solvents, infrequently performed activities with a high potential for failure, and/or first-time activities with less experience.

If the process conditions pose a low level of risk, then the existing laboratory standards[1] will be sufficient to minimize concerns about the health and safety of the laboratory personnel and others in the surrounding area. At a minimum, sufficient laboratory standards will address personal apparel and personal protective equipment, laboratory housekeeping, emergency action plan, safety equipment such as eye washes, showers, and fire extinguishers, and handling of chemical waste.

If the process conditions pose a moderate level of risk, then the worker will develop a Moderate Risk SOP. An example of a moderate-risk process is neutralization of carbonate with acid in a workup step in a chemical synthesis (see Chapter 5, Scenario 1).

Finally, if the process conditions pose a high level of risk, then the personnel will develop a High Risk SOP. Examples of high-risk processes are the use and filtration of a pyrophoric palladium on carbon catalyst from a hydrogenation reaction in methanol solvent (see Chapter 5, Scenario 2) or the handling of diazomethane (see Chapter 5, Scenario 3). When deciding between a Moderate Risk and a High Risk SOP, the worker must consider the level of experience of the laboratory personnel performing the process.

[1] Each laboratory develops and implements a written program that sets forth procedures, equipment, personal protective equipment, and work practices that are capable of protecting employees from the health hazards presented by hazardous chemicals used in that particular workplace.



3
CHEMICAL STORAGE MATRIX

INTRODUCTION

The safe and secure storage of chemicals is a core component of the standard operating procedures (SOPs) necessary for a chemical safety and security program. If the relevant data safety sheets are available, then the Chemical Storage Matrix can be applied to development of an SOP before the receipt of all hazardous chemicals. A Chemical Storage SOP includes four basic components:

1. Storage procedure and conditions based on intrinsic characteristics of the chemicals;
2. Segregation and security strategy;
3. Process for labeling of the chemicals to ensure proper storage; and
4. Inventory process

This four-part approach to chemical management will provide laboratory personnel with a safe environment, laboratory managers with a maximally utilized inventory, and emergency responders with the critical information needed to respond appropriately if there is an incident. An example of a Chemical Storage Matrix and how it can be used is presented in Chapter 5.

PRIMARY STORAGE REQUIREMENT

Most institutions that use chemicals have a selection of storage areas for chemicals or substances that pose risks. Locations include ventilated and nonventilated storage as well as ambient, refrigerated, and freezer storage. Explosion-proof equipment for any volatile organic compounds stored in refrigerators or freezers is also important. An important component of the Chemical Storage SOP is the specification of the type of storage that provides maximum safety and security for each chemical (see Table 3-1 for options and considerations). Chemical laboratories that are located in conflict regions or in areas that are densely populated or have high crime rates or that handle large quantities of chemicals of concern or dual-use chemicals may choose to adopt elevated or high security measures (see *A Guide to Prudent Chemical Management*, pp. 59-70 and Appendix E). Such measures may include high-security locks, access control systems, biometric verification, intrusion alarm systems, closed-circuit television cameras, an inventory system, intervention zones, and an overall security plan. Facilities in highly urbanized areas should also strictly comply with government regulations (e.g., building codes).

Before developing an SOP, the laboratory worker should have an accurate inventory of the available storage spaces at the institution and a thorough understanding of the internal and external guidelines and regulations that apply to the facility.

In the event of a power outage, vulnerable items should be transferred from cold rooms and refrigerators that have lost power to equipment that may be powered by emergency generators. Refrigerators and freezers may maintain their temperature for several hours if they are not opened.

TABLE 3-1 Primary Storage Requirements

Storage Options and Considerations	Chemical Characteristics
Ventilated storage cabinets (Typically the default storage location and of a size that allows enough space to segregate potentially cross-reactive compounds. See Secondary Storage Requirements.)	Toxicity, volatility, odor
Flammable storage cabinets (Generally non-ventilated. Fire codes may govern quantities or require fire suppression.)	Flammable liquids
Desiccant storage and inert atmosphere storage	Air and/or water-sensitive chemicals
Below ambient temperature storage: refrigerator or freezer	Stability with temperature
Designated areas and protocols for cylinder storage	Compressed gases

SECONDARY STORAGE REQUIREMENT

After establishing the types of available storage locations, the worker will determine the secondary storage requirement. To this end, the worker must determine whether chemical segregation, such as oxidants and reductants or acids and bases, and chemical security with limited access and monitoring is needed. Certain chemicals may be incompatible in the same space (e.g., acids and bases), require tight security and monitoring (e.g., chemicals that could be used to synthesize illegal drugs or chemical weapons or their precursors), or are thermally unstable and therefore require interlocks and alarms, so secondary storage needs should be determined. The storage of chemicals and chemical equipment is discussed in detail in Chapter 8, Section 5 of the 2010 toolkit reference guide. Together, the primary and secondary storage requirements determine the number and types of storage areas needed at the facility.

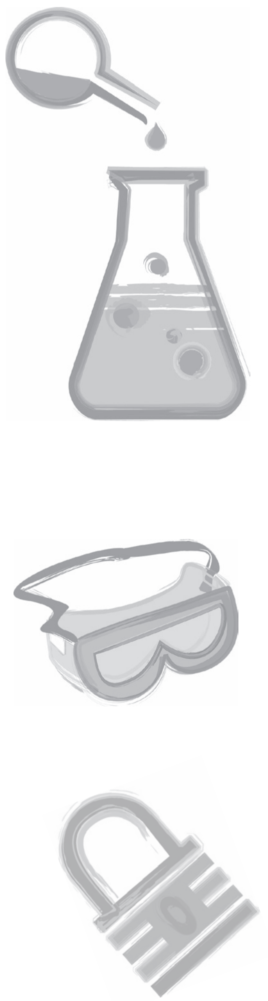
LABELING

After the Chemical Storage Matrix is established, the worker will develop the procedure for labeling chemicals to ensure that they are used as intended and returned to their proper storage locations, which assists in protecting laboratory personnel. Proper labeling clarifies the appropriate storage location for a chemical with multiple hazards (e.g., acetic acid is both an acid and a flammable substance; many highly toxic chemicals are also flammable) as well as the maximum allowable quantities of materials per regulatory requirements (e.g., building codes, fire protection codes). In addition, labels should provide the chemical owner name and date of receipt.

When there is clear labeling from the manufacturer, additional labeling can be as simple as a color code that denotes the appropriate storage location, which will also be labeled to match the color codes for the appropriate chemicals. Many laboratories define a standard or default location for chemicals (often ventilated, room temperature). In this case, the worker will develop a color-coding system for chemicals that are not stored in this default location: flammable, highly toxic compounds, chemicals of concern (COCs) or dual-use chemicals, acids and bases, and compounds requiring refrigeration with safe explosion-proof equipment or other cold storage.

INVENTORY OF CHEMICALS

A chemical storage program should maintain an accurate inventory of chemicals, which will apprise users of the hazards in the space and is necessary for emergency responders (e.g., for fire, chemical release, potential explosions) to take the appropriate action(s). An accurate inventory also avoids the issues associated with re-ordering chemicals already in possession by the laboratory, that is, strains on storage capacity, waste, and unnecessary expenditures. Inventories can be recorded in different formats, for example, paper, electronic spreadsheet, or commercial software. Regardless of the format, the SOP should include a process to ensure that the inventory is up-to-date and backed up. For example, if new chemicals are brought to the laboratory each week, then inventories should be reconciled every six months. In contrast, for laboratories whose inventory is more static, annual review is sufficient. The inventory process could also be used to identify expired, degraded, or unneeded chemicals for proper disposal.



4
STANDARD OPERATING PROCEDURE FORMS

INTRODUCTION

Safe and secure execution of experiments will minimize health and safety risks to laboratory personnel and those in the surrounding area. When institutional laboratory standards are not sufficient to mitigate the risks, laboratory personnel may use the Moderate Risk Standard Operating Procedure (SOP) or the High Risk SOP for the specific process.

MODERATE RISK STANDARD OPERATING PROCEDURE

A Moderate Risk SOP is suggested for processes, experiments, or manipulations that pose moderate risks and that call for protective steps beyond those dictated by accepted laboratory standards. The Moderate Risk SOP form is a condensed version of the High Risk SOP.

Moderate Risk Standard Operating Procedure Form

Implementation of the Moderate Risk SOP is suggested for processes, experiments, or manipulations that pose moderate risks and that call for protective steps beyond those dictated by accepted laboratory standards. They are intended to limit the potential for injury, equipment damage, or environmental impact.

1. TITLE AND DESCRIPTION OF EXPERIMENT OR PROCESS:

2. PREPARER(S):

3. LOCATION:

4. AUTHORIZED PERSONNEL (WITH CONTACT INFORMATION)
   a. PRINCIPAL INVESTIGATOR (PI)/SUPERVISOR:
   b. STUDENT(S)/TECHNICIAN(S)/OPERATOR(S):
   c. OTHERS TO BE NOTIFIED (*e.g., other workers in the same laboratory, or other members of the research group*):

5. POTENTIAL HAZARDS:

6. DESCRIBE ALL SPECIAL REQUIREMENTS FOR SPECIFIC ITEMS THAT REQUIRE A GREATER LEVEL OF SAFETY

Planned chemicals involved	
Personal protective equipment	
Engineering and environmental controls	
Operational ranges and conditions	
Special handling and storage requirements	
Spill and accident procedure as needed	
Waste handling and disposal	

7. IDENTIFY ANY TRAINING NEEDS

Specific training required	
Users requiring training	
Date completed	

8. VERIFICATION AND REVIEW
By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print)	
PI signature	
Safety staff name (please print)	
Safety staff signature	
Current date	
Date of SOP expiration (e.g., 1 year)	

9. LIST OF REFERENCES (include Safety Data Sheets, Globally Harmonized System, any outside personnel consulted in preparation of document, peer reviewers, etc.)

Moderate Risk Standard Operating Procedure Review and Modifications Log

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

The worker will first record basic information on the Moderate Risk SOP form, including the title of the experiment or operation, the name of the person(s) preparing the SOP, where the experiment or procedure will take place, and the names of authorized personnel.

Identifiable potential hazards (Step 5) are those that laboratory personnel are aware of before carrying out the experiment or procedure. Hazards may be posed by any chemical of concern, particularly if handled by inexperienced workers, as well as any reaction products that may be generated either in situ or as intended products or byproducts.

The most crucial item in the Moderate Risk SOP is Step 6: "Describe all special requirements for specific items that require a greater level of safety." Laboratory personnel are encouraged to review all available resources (see Appendix B), such as the literature, existing SOPs, and Safety Data Sheets (SDSs), and consult with other members at the institution to complete Step 6 with as much detail as possible.

A. Personal protective equipment (PPE) includes gloves, goggles, safety glasses, face shield, laboratory coat, special shoes (i.e., toe protection), respirator, and other items required for the experiment or procedure.

B. Engineering and environmental controls refer to the space and environment in which the experiment or procedure will take place, such as a fume hood or an inert atmosphere.
C. Special handling and storage requirements are described in detail to prevent spills or accidents. Handling and storage procedures include, for example, use of specific glassware (e.g., open container, Schlenk flask) or techniques that can minimize spills and accidents.
D. Spill and accident procedures should be listed in the event of an accident.
E. Procedures for handling and disposing of waste will assist the laboratory worker in the proper and safe disposal of the chemical reagents, solvents, and byproducts and any disposable equipment, such as paper towels and pipettes.

After the form has been completed, senior staff will review the SOP for completeness and accuracy. A modifications log appears at the end of the form for laboratory personnel who carried out the same process but modified or updated some of the information on the form. Each facility is responsible for establishing what necessitates a modification to the SOP. Supervisors, professors, and chemical hygiene officers are all acceptable positions for review and approval of modifications and updates.

HIGH RISK STANDARD OPERATING PROCEDURE

If after completing the Risk Assessment Flowchart, the laboratory worker has determined that the chemical(s) or conditions pose a high risk for hazard, then he or she should develop a High Risk SOP. The High Risk SOP can be applied to processes, experiments, or manipulations that are not addressed by the institution's acceptable laboratory standards and are considered to present high risks for both inexperienced and experienced laboratory workers.

As with the Moderate Risk SOP, the High Risk SOP form begins with basic information (i.e., experiment title, name of the person preparing the SOP, experiment location, and names of authorized personnel). The second item calls for a description of the techniques and manipulations to be employed and any specific training that is required to complete the experiment or procedure safely, such as for proper use of a pressurized gas or for manipulations on a Schlenk line.

High Risk Standard Operating Procedure Form

Implementation of the High Risk SOP is suggested for processes, experiments, or manipulations that pose high risks and that call for protective steps beyond those dictated by accepted laboratory standards. They are intended to limit the potential for injury, equipment damage, or environmental impact.

1. TITLE AND DESCRIPTION OF EXPERIMENT OR PROCESS:

2. PREPARER(S):

3. LOCATION:

4. AUTHORIZED PERSONNEL (WITH CONTACT INFORMATION)
   a. PRINCIPAL INVESTIGATOR (PI)/SUPERVISOR:
   b. STUDENT(S)/TECHNICIAN(S)/OPERATOR(S):
   c. OTHERS TO BE NOTIFIED (*e.g., other workers in the same laboratory, or other members of the research group*):

5. IDENTIFY ANY TRAINING NEEDS

Experimental techniques	
Specific training required	
Users requiring training	
Date completed	

6. DETAILED PROCESS DESCRIPTION

List ranges for variables	Temperature:
	Pressure:
	Viscosity:
	Flammability:
	Other:
List operational ranges and conditions	
Materials to be used	Chemicals:
	Equipment:

DETAILED PROCEDURE:
Column A: Process Steps provide step-by-step normal operating procedures, including the transfer of chemicals between or across laboratories, production of gases, workup of products, and preparation of wastes.

Column B: Safety Notes describe how the risk can be mitigated (i.e., minimize clutter, control flammables, secure gas cylinders, ensure good condition of pump belts).

	Column A: Process Steps	Column B: Safety Notes
1.0		*e.g., specific personal protective equipment requirements*
1.1		
1.2		

2.0		
2.1		
2.2		

3.0		
3.1		
3.2		

4.0		
4.1		
4.2		

7. ENGINEERING CONTROLS (check all that apply and provide a detailed description)

Engineering Controls	Check box if applicable	Description
Ex. Glove box	☑	*Use inert air (N_2 or Ar)*
Fume hood or glove box	☐	
Special ventilation	☐	
HEPA-filtered vacuum lines	☐	
Non-reactive containers	☐	
Pressure relief devices	☐	
Temperature control	☐	
Bench paper, pads, plastic-backed paper	☐	
Special signage	☐	
Safe sharp devices	☐	
Other safety devices used:	☐	

8. PERSONAL PROTECTIVE EQUIPMENT (check all that apply)

Personal Protective Equipment	Check box if applicable	Description
Gloves	☐	
Lab coats	☐	
Suits	☐	
Aprons	☐	
Long pants	☐	
Close-toed shoes	☐	
Long sleeves	☐	
Safety glasses	☐	
Goggles	☐	
Face shields	☐	
Respirators (include cartridge type and cartridge change-out schedule)	☐	
Hearing protection (include level of protection needed)	☐	
Special equipment (i.e., blast shields, special enclosures)	☐	
Other PPE	☐	

9. WORK PRACTICE CONTROLS

Controls	Description
Designated areas	
Procedures for requesting emergency assistance	
Emergency phone numbers	
Locations of fire alarms, fire extinguishers, fire blankets, eye washes, showers, etc.	
Emergency responders	
Workers on shifts	
Training on all experimental techniques and experiments	
Restricting access; locks	
Housekeeping	
Lockout/tagout[a] procedure plan	
After-hour procedures	
Preventive maintenance	

[a] Lockout/tagout refers to specific procedures to safeguard researchers from an unexpected startup of machinery and equipment, or a release of hazardous energy during service or maintenance activities.

10. MONITORING

Monitoring	Description
Personnel exposure monitoring	*e.g., wearable sensors for toxics, radiation badges*
Leak checking	
Gas and spill release monitoring	
Temperature and pressure	
Alarms	

11. SPILL AND ACCIDENT PROCEDURES

	Description and Location
Secondary containment	
Spill kits	
Emergency shutdown procedures	
Process shutdown	
Persons to inform	

12. WASTE DISPOSAL PROCEDURES (include segregation of acids, bases, halogenated compounds, PPE, collection and transport procedures, proper documentation, regulations, etc.)

13. STORAGE (check all that apply)

Ventilated enclosures ☐
Refrigeration ☐
Gas cabinet ☐
Compliance with regulations ☐
Expiration date:
Inventory:
Other:

14. TRANSPORTATION PROCEDURES:
(e.g., secondary container for transporting between and across laboratories; secondary containment for experimental apparatus)

15. PEER REVIEW

Name (please print)	
Signature	
Date	
Notes	

Name (please print)	
Signature	
Date	
Notes	

16. VERIFICATION AND REVIEW

By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print)	
PI signature	
Safety staff name (please print)	
Safety staff signature	
Current Date	
Date of SOP expiration (e.g., 1 year)	

17. LIST OF REFERENCES (include Safety Data Sheets, Globally Harmonized System, any outside personnel consulted in preparation of document, peer reviewers, etc.)

High Risk Standard Operating Procedure Review and Modifications Log

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Laboratory personnel are strongly encouraged to review other resources as thoroughly as possible to inform completion of Step 6 of the High Risk SOP. Physical properties of the chemicals that can change during the experiment (e.g., temperature, pressure, viscosity) should be listed clearly, as well as the ranges of acceptable values. The chemicals and equipment that will be used during the experiment, as well as the scale of the experiment (i.e., size of equipment and quantities of chemicals), should also be described.

Normal operating procedures (Step 6 of the High Risk SOP) must be detailed step by step in column A, "Process Steps." For many processes, the steps must be followed in precise order. The process steps may include the following:

- transfer of a chemical between laboratories
- valve closing and opening
- product workup
- preparation of wastes
- predicted hazard of expected product(s) of a chemical procedure

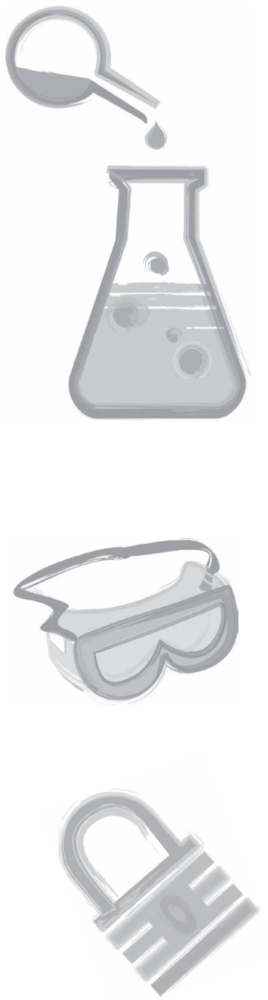
Column B, "Safety Notes," describes how the risk can be mitigated, for example by

- controlling flammables
- securing gas cylinders
- ensuring that vacuum pump belts are in good condition
- minimizing clutter

Steps 7 and 8 list the engineering controls and PPE to use during the experiment or procedure. A descriptions of an item that requires more detailed information should be added next to the checkbox. For example, the glove type can be specified (e.g., nitrile, vinyl, butyl) or, if multiple gloves are to be used, the order of wear can be specified.

Steps 9-13 relate to the laboratory setting. This section will include information to assist the worker(s) conducting the experiment and people in the surrounding vicinity in the event of an accident. Although not recommended, if a worker is conducting an experiment alone, then security staff and other on-site laboratory personnel must check on that worker periodically. In case of an emergency, the worker must notify emergency staff. Finally, in Step 14, even though transportation procedures may have been described in Step 6, include them here, with details on items such as secondary containers for transport of chemicals between laboratories as needed.

Senior staff will review the SOP for completeness and accuracy. Each institution will establish what constitutes the need for modifications, which will be recorded in the modifications log. Supervisors, professors, and chemical hygiene officers are all acceptable positions for review and approval of modifications and updates.



5
APPLICATION OF THE *GUIDE TO DEVELOPING STANDARD OPERATING PROCEDURES*

The following four hypothetical scenarios demonstrate how to use the tools described in this *Guide to Developing Standard Operating Procedures*. The entries in the four forms were completed by the expert committee and are solely for illustrative purposes; real situations will call for procedures that are suited to the specific laboratory surroundings and personnel.

SCENARIO 1: NEUTRALIZATION OF CARBONATE BY ACID

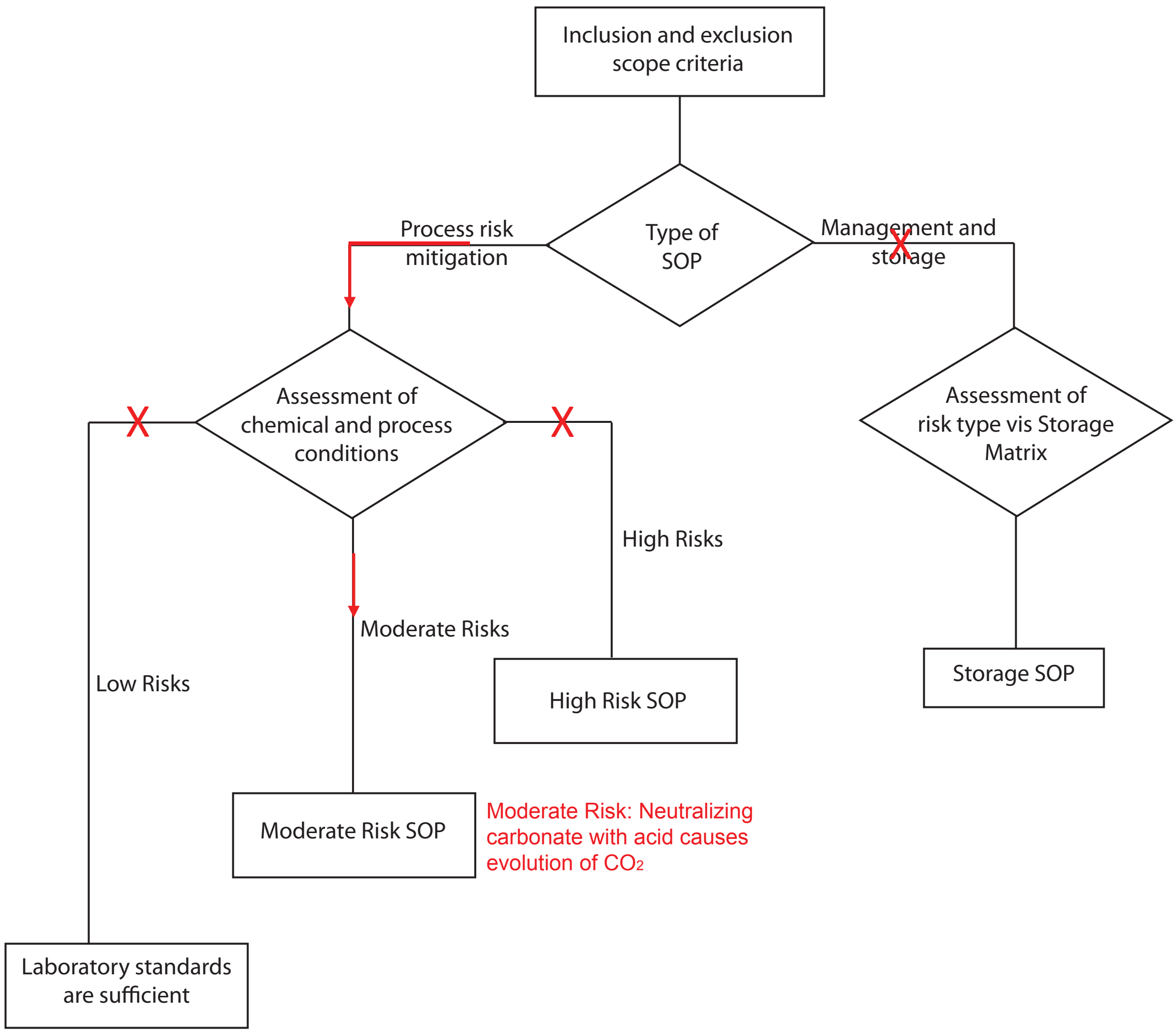
Overview: This scenario describes a situation in which a student with moderate experience is conducting a routine procedure of neutralizing a carbonate species with acid in a chemical laboratory at a university.

SCENARIO:

The student wants to hydrolyze an ester. The chemical reaction is carried out in an aqueous-organic medium with sodium carbonate or bicarbonate as the base. The desired product is soluble in the excess aqueous base. To obtain the product, the medium is neutralized with concentrated hydrochloric acid. The use of concentrated acid helps keep the total reaction fluid volume low, thereby optimizing precipitation or extraction of the product. The vigorous effervescent release of carbon dioxide, however, is a potential concern to the student. How should the student proceed?

Suggested solution:

To conduct the reaction safely, the student uses the Risk Assessment Flowchart to determine whether the laboratory standards are sufficient or whether a standard operating procedure is needed.


Inclusion and exclusion scope criteria
Type of SOP
Process risk mitigation
Management and storage
Assessment of chemical and process conditions
Assessment of risk type vis Storage Matrix
High Risks
Moderate Risks
Low Risks
High Risk SOP
Storage SOP
Moderate Risk SOP
Moderate Risk: Neutralizing carbonate with acid causes evolution of CO_2
Laboratory standards are sufficient

Moderate Risk Standard Operating Procedure Form

1. TITLE AND DESCRIPTION OF EXPERIMENT OR PROCESS: *Hypothetical workup of a reaction medium requiring neutralization of carbonates using concentrated hydrochloric acid*

2. PREPARER(S): *[name]*

3. LOCATION: *Laboratory*

4. AUTHORIZED PERSONNEL (WITH CONTACT INFORMATION)
   a. PRINCIPAL INVESTIGATOR (PI)/SUPERVISOR: *[name] (555) 343-1515*
   b. STUDENT(S)/TECHNICIAN(S)/OPERATOR(S): *[name] (555) 321-5762*
   c. OTHERS TO BE NOTIFIED (*e.g., other workers in the same laboratory, or other members of the research group*): *[name] (555) 724-8921*

5. POTENTIAL HAZARDS: *Concentrated hydrochloric acid (HCl, 37%). Hydrochloric acid is corrosive and causes burns on eyes, skin, and digestive and respiratory tracts. It may be fatal if inhaled or swallowed. Repeated exposure may cause erosion of exposed teeth.*

6. DESCRIBE ALL SPECIAL REQUIREMENTS FOR SPECIFIC ITEMS THAT REQUIRE A GREATER LEVEL OF SAFETY

Planned chemicals involved	*Concentrated hydrochloric acid (HCl, 37%)*
Personal protective equipment	*Lab coat, long pants, closed-toed shoes, double gloves (vinyl gloves over nitrile gloves), safety goggles*
Engineering and environmental controls	*Any handling of concentrated hydrochloric acid outside of the fume hood is limited and done within closed containers only.*
Operational ranges and conditions	*See special handling section.*
Special handling and storage requirements	*Neutralization should take place in a large-mouth open vessel (a beaker, not an Erlenmeyer flask) in a hood. It is often prudent to chill the carbonate mixture in an ice-salt bath and to stir the mixture vigorously while the acid is added. If a product precipitates at neutrality, then remove it by filtration. If extraction is necessary to obtain the product, then take great care that gas evolution has ceased before the contents are transferred to a separatory funnel. Shaking a separatory funnel with a gas-evolving solution will often blow the stopper and jettison the contents.* *Unused chemicals are stored in 2.5 L glass containers in a specially designed and designated acid storage cabinet. In addition, small amounts (40 mL) of hydrochloric acid can be stored in beakers with a glass lid in the fume hood. The aqueous waste is stored in a 4 L High-Density Polyethylene (HDPE) storage bottle in the fume hood or in the designated acid cabinet. No acid is stored outside this cabinet or the fume hood, even temporarily.*

Spill and accident procedure as needed	*An acid-base spill cleanup kit should be used only for very small spills up to 50 mL, following the instructions provided for the kit. Otherwise, secondary containment should be used that contains the entire spill. In the event of a small spill, clean up the spill immediately. If the spill is large, then isolate the area, deny entry, leave the room, and call appropriate emergency responders. If exposed, then remove clothing and use the emergency shower located directly outside of room. If someone is incapacitated, then call 911 and initiate first aid if possible.*
Waste handling and disposal	*For spills: place the used absorbent in 4 L HDPE storage bottle for pick-up. For the aqueous waste left after removal of the product, attach Hazardous Waste Label, accumulate said waste according to laboratory requirements, and contact the waste pick-up operator.*

7. IDENTIFY ANY TRAINING NEEDS *No specific training required*

Specific training required	
Users requiring training	
Date completed	

9. VERIFICATION AND REVIEW

By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print)	*Professor [name]*
PI signature	*Professor*
Safety staff name (please print)	*[name]*
Safety staff signature	*signature*
Current date	*01/29/2016*
Date of SOP expiration (e.g., 1 year)	*01/29/2017*

9. LIST OF REFERENCES (include Safety Data Sheets, Globally Harmonized System, any outside personnel consulted in the preparation of the document, peer reviewers, etc.)

Moderate Risk Standard Operating Procedure Review and Modifications Log

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

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If no, then list date of approval	
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Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

SCENARIO 2: USE AND FILTRATION OF A PYROPHORIC CATALYST

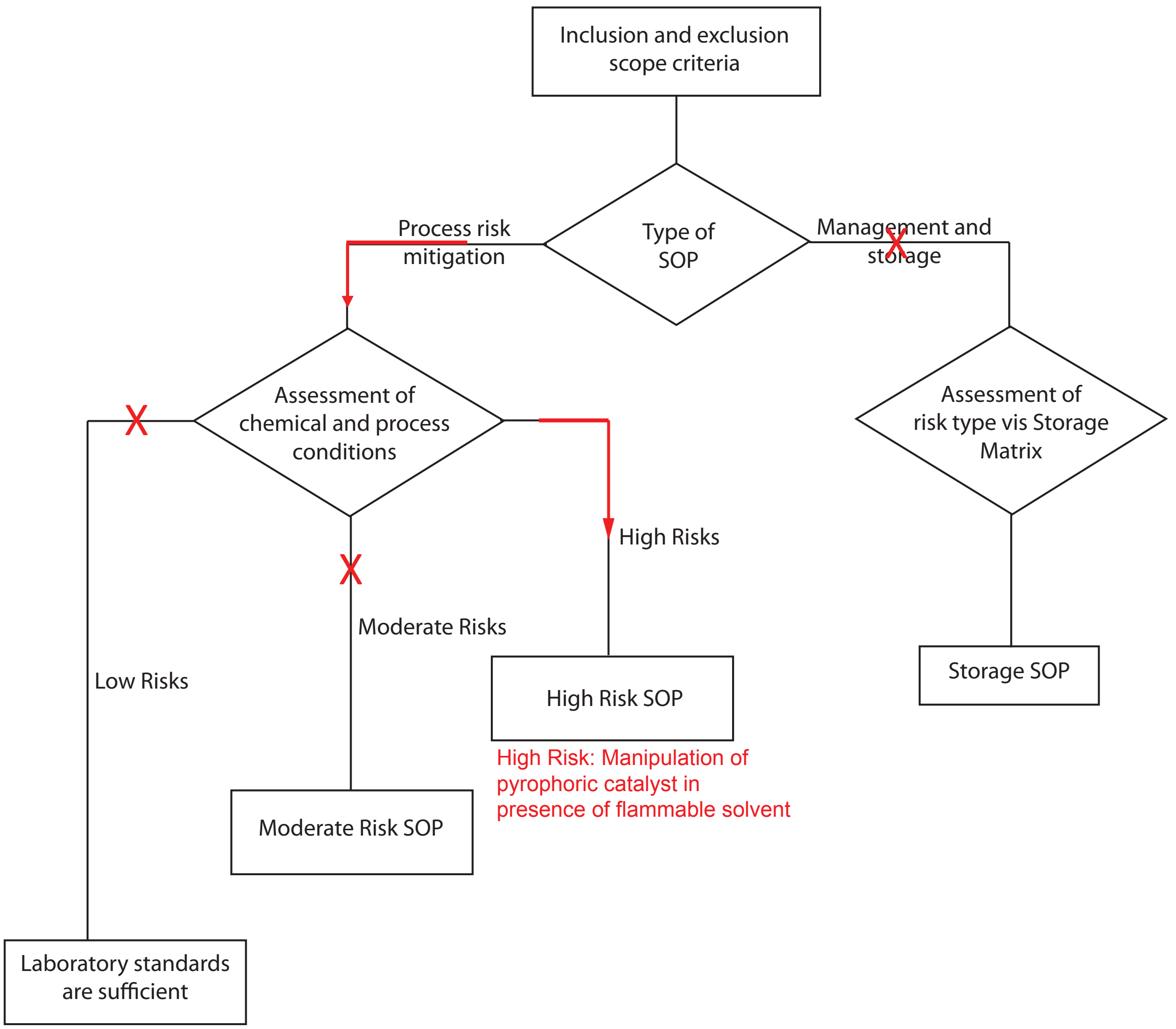
Overview: This scenario describes a situation where an inexperienced researcher wants to complete a reaction using a pyrophoric heterogeneous catalyst, followed by a filtration workup step.

SCENARIO:

A newly hired researcher in an industrial laboratory is using a pyrophoric heterogeneous catalyst in a hydrogenation reaction. After reviewing section 9.7.4 of the National Academies of Sciences, Engineering, and Medicine report, *A Guide to Prudent Chemical Management*, the researcher discovers special hazards that may be encountered when filtering the hydrogen-saturated catalyst from the flammable organic reactants.

Suggested solution:

To minimize fires and explosions during the filtration step, the researcher goes through a hazard assessment checklist. After completing the assessment checklist, the researcher concludes that he/she will need a High Risk SOP.


Inclusion and exclusion scope criteria
Type of SOP
Process risk mitigation
Management and storage
Assessment of chemical and process conditions
Assessment of risk type vis Storage Matrix
High Risks
Moderate Risks
Low Risks
High Risk SOP
Storage SOP
High Risk: Manipulation of pyrophoric catalyst in presence of flammable solvent
Moderate Risk SOP
Laboratory standards are sufficient

High Risk Standard Operating Procedure Form

1. TITLE AND DESCRIPTION OF EXPERIMENT OR PROCESS: *Pyrophoric/ignitable catalyst: Procedure for addition to reaction vessel and separation from reaction mixture by filtration*

2. PREPARER(S): *[name]*

3. LOCATION: *industrial laboratory*

4. AUTHORIZED PERSONNEL (WITH CONTACT INFORMATION)
   a. PRINCIPAL INVESTIGATOR (PI)/SUPERVISOR: *[name] (555) 123-4567*
   b. STUDENT(S)/TECHNICIAN(S)/OPERATOR(S): *[name] (555) 401-6333*
   c. OTHERS TO BE NOTIFIED (*e.g., other workers in the same laboratory, or other members of the research group*): *[name] (555) 202-3333*

5. IDENTIFY ANY TRAINING NEEDS

Experimental techniques	*Filtration techniques, vacuum trap for solvents*
Specific training required	*See #12 Waste disposal*
Users requiring training	
Date completed	*12/15/2015*

6. DETAILED PROCESS DESCRIPTION

This SOP covers the use of a wide variety of pyrophoric catalysts. The catalysts may become pyrophoric after exposure to reducing agents (e.g., organic solvents, hydrogen) or are pyrophoric as obtained from vendors.

It is essential that the activated catalyst does not become dry or exposed to air, especially in the presence of solvent vapors, or a fire will result. Raney metal catalysts are pyrophoric as obtained from vendors and are typically provided as water slurries to prevent ignition. These catalysts must be wetted during all manipulations.

The fire potential is mitigated by (1) keeping the pyrophoric catalyst wetted with solvent and/or water during all stages of handling, including final transfer to a waste container, (2) maintaining an inert gas purge or blanket above the pyrophoric catalyst, and (3) eliminating clutter and any additional fuel sources from the immediate work area.

List ranges for variables	Temperature: *ambient*	
	Pressure: *n/a*	
	Viscosity: *n/a*	
	Flammability: *reaction solvents are flammable; catalyst may be pyrophoric*	
	Other:	
List of operational ranges and conditions		
Materials to be used	Chemicals: *pyrophoric catalyst, reaction solvent, Celite*	
	Equipment: *reaction vessel, filter flask, filter, inert gas source*	

DETAILED PROCEDURE:

Column A: Process Steps provide detailed step-by-step normal operating procedures, including the transfer of chemicals between or across laboratories, production of gases, workup of products, and preparation of wastes.

Column B: Safety Notes describe how the risk can be mitigated (i.e., minimize clutter, control flammables, secure gas cylinders, ensure good condition of pump belts).

	Column A: Process Steps	Column B: Safety Notes
1.0	*Charging pyrophoric catalyst to a vessel.*	*Engineering controls: The following operations are conducted in a functioning fume hood with sash.* *PPE requirements: Flame-resistant lab coat, face shield, gloves appropriate for the solvent being used (consult a glove selection guide).*
1.1	*Clear the hood where the procedure will take place; move flammables, squirt bottles (acetone, methanol, etc.), and clutter out of the immediate vicinity.*	*Have Metal-X extinguishing agent and a squirt bottle of water within reach of the work area. Although Metal-X extinguishing is an ideal product for this purpose, alternatives would be a bucket of sand and/or finely divided NaCl. Ensure local fire extinguishers are in their proper locations and are fully charged.*
1.2	*Purge the vessel with inert gas for at least 5 minutes.*	

1.3	*Weigh out the catalyst and add it to the vessel, continuing to purge the vessel with an inert gas.*	*Most unactivated metal catalysts (e.g., Pd/C, Ru/C, PtO2, Ni/Kieselguhr) are not pyrophoric as obtained from vendors, but they become pyrophoric upon exposure to certain solvents (especially alcohols) and hydrogen.* *Raney metal catalysts (e.g., Raney Nickel) are typically provided and weighed/manipulated as water slurries. These catalysts will ignite upon air exposure and will dry if allowed.* *Do not purge the vessel too vigorously; otherwise, the purge may blow the finely divided catalyst into the hood.*
1.4	*Slowly add the desired solvent to the vessel while maintaining the inert gas purge.*	
1.5	*Add any other reagents to the vessel while maintaining the inert gas purge.*	*For Steps 1.3, 1.4, and 1.5 ensure that the catalyst and solvent are in contact only when under inert atmosphere, thus preventing the possibility of ignition and fire.*

2.0	*Filtering a pyrophoric heterogeneous catalyst from a reaction solution.*	*Engineering controls: The following operations are conducted in a fume hood with sash.* *PPE requirements: Flame-resistant lab coat, face shield, gloves appropriate for the solvent being used (consult a glove selection guide).*
2.1	*Clear the hood of clutter and flammables.*	*Eliminate any additional fuel sources in the event of a fire.*
2.2	*Ensure fire extinguishers are in their proper location and ready for use.*	*Have Metal-X extinguishing agent and a squirt bottle of water within reach of the work area. Although Metal-X-extinguishing is an ideal product for this purpose, alternatives would be a bucket of sand and/or finely divided NaCl.*
2.3	*Choose an appropriate filter and filter flask and secure them in place to the flex frame. Have a means with which to blanket the headspace above the filter with inert gas.*	*A tall filter is preferable because it allows enough solvent volume above the solid catalyst to blanket the catalyst and protect it from air exposure during filtration. Use a receiving flask large enough to hold the filtrate plus washings. Clamp the apparatus to the flex frame to prevent spills during filtration.*
2.4	*Slurry pack the filter with Celite in wash solvent using sufficient Celite to give a uniform 1-2 cm thick bed.*	*The vacuum system is protected from solvent contamination by means of appropriate traps.*
2.5	*Open the vessel containing the reaction mixture and purge with inert gas.*	

2.6	*With inert gas purging of both the vessel and the filter, carefully pour the reaction mixture onto the Celite bed. Apply slight vacuum to the receiving flask to begin the filtration. Do not filter all of the solvent; leave a small amount of solvent above the catalyst solids.*	*DO NOT PERMIT THE CATALYST ON TOP OF THE CELITE BED TO BE EXPOSED TO AIR. FIRE WILL OCCUR IF THE CATALYST IS EXPOSED TO AIR.* *Adjust the vacuum as needed to give an adequate filtration rate. Maintain a nitrogen blanket above the Celite/catalyst bed.*
2.7	*Rinse the vessel with solvent and add to the filter as in Step 2.6. When the vessel has been adequately rinsed, add water using a squirt bottle and set aside.*	
2.8	*Wash the catalyst solids with solvent as needed. When filtering the final wash, allow the solvent level to drop to just above the solid level and then stop the filtration. Remove the filter from the receiving flask and then add water to the filter to wet the catalyst. Move the receiving flask to another area of the hood.*	*DO NOT PERMIT THE CATALYST ON TOP OF THE CELITE BED TO BE EXPOSED TO AIR—A FIRE WILL OCCUR.* *Relocate the receiving flask to another area in the hood so that it will not contribute to a fire during catalyst disposal.*
2.9	*Add water to a jar or waste container. Purge this container with inert gas. Quickly transfer the filter contents to the waste jar using a spatula and water. Keep the catalyst solids under inert gas as much as possible during this transfer. Rinse the filter with water until all catalyst is transferred to the container.*	*Do not mix other types of waste in this container.*
2.10	*After purging the waste container with inert gas, properly cap and label the container.*	*Label the waste jar properly, and use appropriate warning signs.*

7. ENGINEERING CONTROLS (check all that apply and provide a detailed description)

Engineering Controls	Check box if applicable	Description
Ex. Glove box	☑	*Use inert air (N_2 or Ar)*
Fume hood or glove box	☑	
Special ventilation	☐	
HEPA-filtered vacuum lines	☐	
Non-reactive containers	☐	
Pressure relief devices	☐	
Temperature control	☐	
Bench paper, pads, plastic-backed paper	☐	
Special signage	☐	
Safe sharp devices	☐	
Other safety devices used:	☐	

8. PERSONAL PROTECTIVE EQUIPMENT (check all that apply)

Personal Protective Equipment	Check box if applicable	Description
Gloves	☑	*Appropriate for solvent being used. (consult a glove selection guide)*
Lab coats	☑	*Flame resistant*
Suits	☐	
Aprons	☐	
Long pants	☑	
Close-toed shoes	☑	
Long sleeves	☐	
Safety glasses	☐	
Goggles	☑	
Face shields	☑	
Respirators (include cartridge type and cartridge change out schedule)	☐	
Hearing protection (include level of protection needed)	☐	
Special equipment (i.e., blast shields, special enclosures	☐	
Other PPE	☐	

9. WORK PRACTICE CONTROLS

Controls	Description
Designated areas	*Do not work alone—have others present*
Procedures for requesting emergency assistance	*Follow lab emergency procedures*
Emergency phone numbers	*911* *EHS number*
Locations of fire alarms, fire extinguishers, fire blankets, eye washes, showers, etc.	*Eye washes and shower are located in Room 101. Fire blanket is located on west wall to entrance door to lab.*
Emergency responders	
Workers on shifts	*yes*
Training on all experimental techniques and experiments	*yes*
Restricting access; locks	*yes*
Housekeeping	*Eliminate clutter and any additional fuel sources from the immediate work area.*
Lockout/tagout[a] procedure plan	*n/a*
After-hour procedures	*No work after office hours.*
Preventive maintenance	*n/a*

[a] Lockout/tagout refers to specific procedures to safeguard researchers from an unexpected startup of machinery and equipment, or a release of hazardous energy during service or maintenance activities.

10. MONITORING

None required for this procedure

Monitoring	Description
Personnel exposure monitoring	*n/a*
Leak checking	*n/a*
Gas and spill release monitoring	*n/a*
Temperature and pressure	*n/a*
Alarms	*n/a*

11. SPILL AND ACCIDENT PROCEDURES

Wearing a flame-resistant lab coat, eye protection, and gloves, immediately cover spilled pyrophoric catalyst with water (squirt bottle) or Metal-X. Then thoroughly soak some paper towels with water. Use the wetted paper towels to mop up the spilled catalyst. Immediately place the used paper towels in the waste container designated for pyrophoric catalysts—do not allow the contaminated towels to dry in the air. Purge the waste container with inert gas and then cap tightly.

	Description and Location
Secondary containment	
Spill kits	
Emergency shutdown procedures	
Process shutdown	
Persons to inform	

12. WASTE DISPOSAL PROCEDURES (include segregation of acids, bases, halogenated compounds, PPE, collection and transport procedures, proper documentation, regulations, etc.)
It is suggested that waste containers containing pyrophoric catalysts contain ample water to ensure the solids remain wetted. The container will be flushed with inert gas and then tightly capped. The container is designated for pyrophoric catalysts only, and no other types of waste can be added to it. Spent pyrophoric catalysts are generally designated as reactive waste and are handled accordingly.

13. STORAGE (check all that apply)

Ventilated enclosures ☐
Refrigeration ☐
Gas cabinet ☐
Compliance with regulations ☑
Expiration date:
Inventory:
Other:
Most vendor-supplied metal catalysts are not supplied in an activated state and are not pyrophoric until activated. Normal storage procedures can be applied. Raney metal catalysts are provided as water slurries to prevent ignition. These samples are stored in tightly capped containers to prevent them from drying out. Inspect routinely and segregate from flammable materials.

14. TRANSPORTATION PROCEDURES:
(e.g., secondary container for transport between and across laboratories; secondary containment for experimental apparatus)
Secondary container for transport between and across laboratories
Secondary containment for experimental apparatus

15. PEER REVIEW

Name (please print)	*[name]*
Signature	*signature*
Date	*01/31/2016*
Notes	

Name (please print)	*[name]*
Signature	*signature*
Date	*02/03/2016*
Notes	

16. VERIFICATION AND REVIEW

By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print)	*[name]*
PI signature	*signature*
Safety staff name (please print)	*[name]*
Safety staff signature	*signature*
Current date	*02/10/2016*
Date of SOP expiration (e.g., 1 year)	*02/10/2017*

17. LIST OF REFERENCES (include Safety Data Sheets, Globally Harmonized System, any outside personnel consulted in preparation of document, peer reviewers, etc.)

High Risk Standard Operating Procedure Review and Modifications Log

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

SCENARIO 3: TOXIC AND EXPLOSIVE GASES: HANDLING DIAZOMETHANE AND ALTERNATIVES

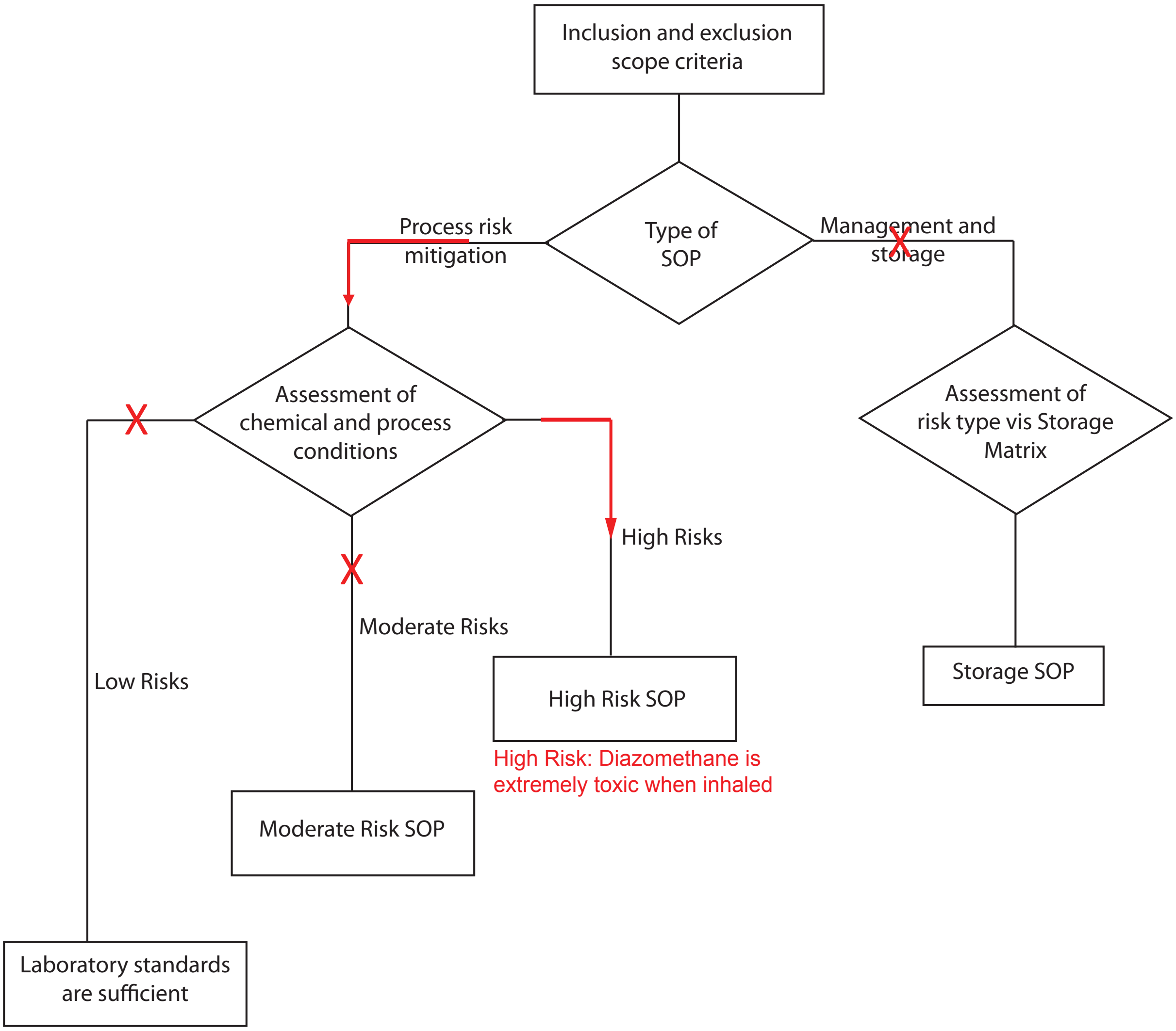
Overview: This scenario describes a situation where a graduate student wants to run a reaction that calls for diazomethane. After completing the hazard assessment checklist, she develops a High Risk SOP. Her advisor, who reviews the SOP, does not approve of the use of diazomethane and suggests an alternative compound (trimethylsilyl)diazomethane (TMSD).

SCENARIO:

An experienced student wants to use diazomethane as an alkylating agent in her reaction. Diazomethane has been flagged as highly hazardous because of its flammability, explosive potential, and toxicity as noted in sections 7 and 9 of the National Academies of Sciences, Engineering, and Medicine report, *Chemical Laboratory Safety and Security*. The student immediately recognizes that she will need to develop a High Risk SOP. She asks her advisor to review her SOP. He does not approve the SOP, even though the student followed and completed the correct steps.

Suggested solution:

The advisor recognized that diazomethane can be substituted with (trimethylsilyl)diazomethane (TMSD) because it is less likely to explode as it generates diazomethane in situ and may be used for the reaction. TMSD is commercially available in anhydrous hexanes or diethyl ether, and the respective Safety Data Sheets are available online. Although explosive accidents have not occurred with TMSD, TMSD is far from being a perfect surrogate. The toxicity of TMSD is still high, with at least two recorded deaths from inhalation.


Inclusion and exclusion scope criteria
Type of SOP
Process risk mitigation
Management and storage
Assessment of chemical and process conditions
Assessment of risk type vis Storage Matrix
High Risks
Moderate Risks
Low Risks
High Risk SOP
High Risk: Diazomethane is extremely toxic when inhaled
Storage SOP
Moderate Risk SOP
Laboratory standards are sufficient

High Risk Standard Operating Procedure Form

1. TITLE AND DESCRIPTION OF EXPERIMENT OR PROCESS: *Toxic and Explosive Gases: Safe Handling of Diazomethane and Alternatives*

2. PREPARER(S): *[name]*

3. LOCATION: *Room 101 Chemistry Hall*

4. AUTHORIZED PERSONNEL (WITH CONTACT INFORMATION)
   a. PRINICIPAL INVESTIGATOR (PI)/SUPERVISOR: *[name] (555) 854-9654*
   b. STUDENT(S)/TECHNICIAN(S)/OPERATOR(S): *[name] (555) 202-2020*
   c. OTHERS TO BE NOTIFIED (*e.g., other workers in the same laboratory, or other members of the research group*): *[name] (555) 333-4444*

5. IDENTIFY ANY TRAINING NEEDS: *No specific training required*

Experimental techniques	
Specific training required	
Users requiring training	
Date completed	

6. DETAILED PROCESS DESCRIPTION *See SDS for CAS Registry Number 18107-18-1*

List ranges for variables	Temperature:
	Pressure:
	Viscosity:
	Flammability:
	Other:
List of operational ranges and conditions	
Materials to be used	Chemicals: *(trimethylsilyl)diazomethane*
	Equipment: *Diazomethane will be generated in situ from TMSD. Diazomethane is known to detonate on sharp glass or metal surfaces. Use a special diazomethane flask with fire-polished Clear-Seal™ joints.*

DETAILED PROCEDURE:

Column A: Process Steps provide detailed step-by-step normal operating procedures, including the transfer of chemicals between or across laboratories, production of gases, workup of products, and preparation of wastes.

Column B: Safety Notes describe how the risk can be mitigated (i.e., minimize clutter, control flammables, secure gas cylinders, ensure good condition of pump belts).

	Column A: Process Steps	Column B: Safety Notes
1.0	*In situ synthesis of diazomethane from TMSD and substrate methylation.*	*Engineering controls: The following operations are conducted in a functioning fume hood with sash. Diazomethane explosions can be highly energetic, and blast shields are recommended.* *PPE Requirements: Wear respiratory protection and full face protection. Avoid breathing vapors, mist, or gas. If contact is likely, then double glove using a second exam-grade nitrile glove under the utility-grade nitrile glove. Wear a flame-resistant lab coat.* *Remove all sources of ignition.*
1.1	*Assemble a three-neck reaction flask containing a pressure-equalizing addition funnel, gas inlet/outlet, thermometer, and magnetic stir bar.*	*Use cut-resistant gloves when assembling glassware.*
1.2	*Charge the reaction flask with solvent and reagents, and then chill to 0°C using an ice bath.*	*Place the ice bath on top of a magnetic stirrer.*
1.3	*Charge the addition funnel with TMSD solution.*	
1.4	*Add TMSD in commercially supplied solvent in dropwise fashion to an excess of the substrate for methylation. TMSD is used because it is less likely to explode as it generates diazomethane in situ and is commercially available in anhydrous hexanes or diethyl ether.*	*Stir the mixture at a moderate rate to ensure methylation. If the yellow color of diazomethane is present, then slow the rate of addition of TMSD and increase the stirring speed.* *If large quantities of diazomethane are to be generated, even in a high-flow hood, then some safety authorities recommend wearing a respirator.*

2.0	*Isolation and clean-up.*	*The deactivation of both diazomethane and TMSD is accomplished in the acetic acid quench. Explosive hazard and toxic vapor hazards are mitigated. PPE: exam-grade nitrile gloves are sufficient.*
2.1	*Add excess acetic acid until any yellow color dissipates and gas evolution ceases.*	*Diazomethane is yellow, and reaction completion is usually signaled by the loss of yellow color. Both diazomethane and TMSD are destroyed by acetic acid.*
2.2	*Subsequent workup is by published methods.*	*Ensure any additional hazards are evaluated in published methods.*

7. ENGINEERING CONTROLS (check all that apply and provide a detailed description)

Engineering Controls	Check box if applicable	Description
Ex. Glove box	☑	*Use inert air (N_2 or Ar)*
Fume hood or glove box	☑	
Special ventilation	☑	
HEPA filtered vacuum lines	☐	
Non-reactive containers	☐	
Pressure relief devices	☐	
Temperature control	☐	
Bench paper, pads, plastic-backed paper	☐	
Special signage	☐	
Safe sharp devices	☐	
Other safety devices used:	☐	

8. PERSONAL PROTECTIVE EQUIPMENT (check all that apply)

Personal Protective Equipment	Check box if applicable	Description
Gloves	☑	*Nitrile 8-mil gloves recommended. If contact is likely, then double glove using a second exam-grade nitrile glove first and the utility-grade nitrile glove second.*
Lab coats	☑	*Flame resistant*
Suits	☐	
Aprons	☐	
Long pants	☑	
Close-toed shoes	☑	
Long sleeves	☐	
Safety glasses	☐	
Goggles	☑	
Face shields	☑	
Respirators (include cartridge type and cartridge change out schedule)	☑	
Hearing protection (include level of protection needed)	☐	
Special equipment (i.e. blast shields, special enclosures	☐	
Other PPE	☐	

9. WORK PRACTICE CONTROLS

Controls	Description
Designated areas	*Fume hood with sash*
Procedures for requesting emergency assistance	*Follow lab standards*
Emergency phone numbers	*911* *Fire Department Number*
Locations of fire alarms, fire extinguishers, fire blankets, eye washes, showers, etc.	*One fire alarm in Room 101 Chemistry Hall. Three fire blankets located on the walls of Room 101. Shower located near back wall of Room 101.*
Emergency responders	*911*
Workers on shifts	*yes*
Training on all experimental techniques and experiments	*yes*
Restricting access; locks	*yes*
Housekeeping	*yes*
Lockout/tagout[a] procedure plan	*yes*
After-hour procedures	*no*
Preventive maintenance	*yes*

[a] Lockout/tagout refers to specific procedures to safeguard researchers from an unexpected startup of machinery and equipment, or a release of hazardous energy during service or maintenance activities.

10. MONITORING

Monitoring	Description
Personnel exposure monitoring	*Air samples should be taken in the user's breathing zone. The collection of vapors by an adsorption tube containing a resin coated with octanoic acid, followed by desorption with carbon disulfide can be measured by gas chromatographic analysis.*
Leak checking	
Gas and spill release monitoring	
Temperature and pressure	
Alarms	

11. SPILL AND ACCIDENT PROCEDURES

	Description and Location
Secondary containment	*n/a*
Spill kits	
Emergency shut down procedures	*If the researcher has inhaled diazomethane or TMSD, then seek immediate exposure to fresh air followed by prompt care at an emergency room.*
Process shutdown	*If spill happens inside fume hood, then immediately close sash and let evaporate. Activate emergency exhaust.*
Persons to inform	

12. WASTE DISPOSAL PROCEDURES (include segregation of acids, bases, halogenated compounds, PPE, collection and transport procedures, proper documentation, regulations, etc.)

After the diazomethane solution is quenched, dispose of it through normal waste streams.

13. STORAGE (check all that apply) *Storage of diazomethane solutions is highly discouraged*

Ventilated enclosures ☐
Refrigeration ☐
Gas cabinet ☐
Compliance with regulations ☐
Expiration date:
Inventory:
Other:

14. TRANSPORTATION PROCEDURES:

(e.g., secondary container for transport between and across laboratories; secondary containment for experimental apparatus)

n/a

15. PEER REVIEW

Name (please print)	*[name]*
Signature	*signature*
Date	*08/13/2016*
Notes	

Name (please print)	
Signature	
Date	
Notes	

16. VERIFICATION AND REVIEW
By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print)	*[name]*
PI signature	*signature*
Safety staff name (please print)	*[name]*
Safety staff signature	*signature*
Current date	*08/15/2016*
Date of SOP expiration (e.g., 1 year)	*01/15/2017*

17. LIST OF REFERENCES (include Safety Data Sheets, Globally Harmonized System, any outside personnel consulted in preparation of document, peer reviewers, etc.)

SDS for (trimethylsilyl)diazomethane—CAS Registry Number 18107-18-1

High Risk Standard Operating Procedure Review and Modifications Log

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

SCENARIO 4: REAGENT STORAGE

Overview: This scenario describes a situation in which a laboratory manager in a large academic laboratory receives three requests from chemistry graduate students for chemical reagents:

- Sodium Azide, 5 g
- Piperonal, 500 g
- Diazald, 25 g

SCENARIO:

The University has a different level of experience and safety awareness with each of these reagents. Exemplary execution of the pre- and post-ordering activities and storage process for these three reagents is shown below:

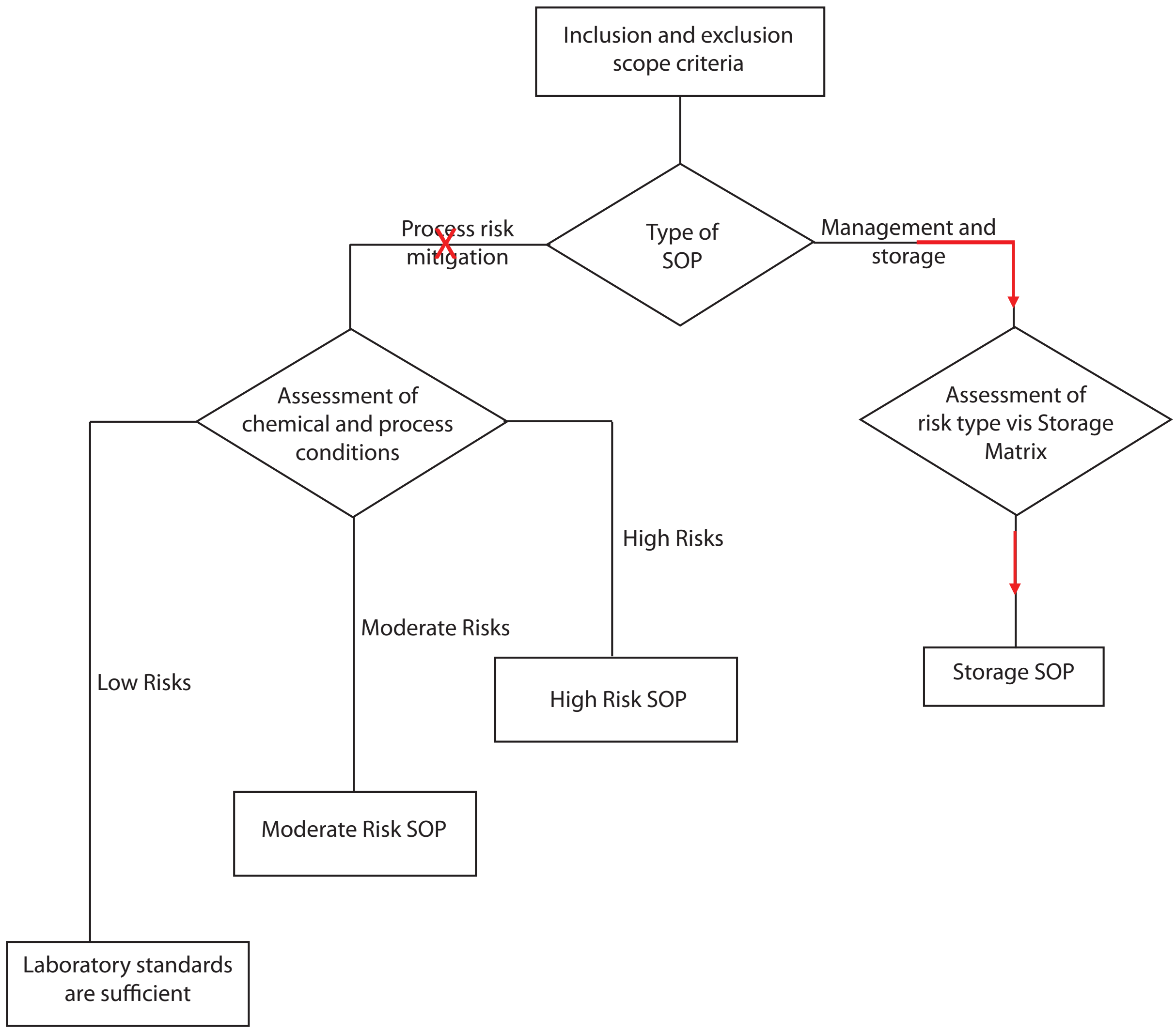
Suggested Solution:

Sodium Azide: *When the laboratory manager receives the request for sodium azide, he searches the chemical reagent inventory list and realizes that this reagent has not previously been ordered for use in the department. He accesses the vendor's website to review the Safety Data Sheet (SDS) and notes warnings of acute toxicity (oral, dermal, inhalation), "Health Hazard" for respiratory sensitization, and "Environment" for hazard to the aquatic environment, both acute and chronic. Azides in combination with acid or acid vapors can form deadly hydrazoic acid, a toxic gas. Azides also present a severe explosion risk when shocked or heated. It is suggested that sodium azide be stored tightly in closed containers in a well-ventilated and dry area away from acid. Because of the explosive potential and safety and security concerns, sodium azide should be avoided in a synthesis if a reasonable alternative exists whenever possible. The student consults the literature and does not find an alternative that will work in the synthetic reaction. After reviewing the SDS and confirming that the reagent is not on the University's Dual-Use Chemicals List, the laboratory manager places the order for this chemical reagent.*

While waiting for the bottle of sodium azide to arrive from the vendor, the laboratory manager uses the Chemical Storage Matrix to identify the chemical's storage requirements: Are there special temperature requirements? Does the reagent need to be segregated from other chemicals? Are there special security considerations? There are no special requirements for temperature to store sodium azide. Storage in standard ventilated room temperature reagent cabinets will segregate the chemical from acids (because acids are segregated). Therefore, the laboratory manager arrives at the conclusion that "Aggregated—Ventilated Room Temperature" in an area that is temperature and humidity controlled is the proper location for this reagent. Out of an abundance of caution, the laboratory manager stores sodium azide in a secondary container with Drierite (anhydrous sodium sulfate). For future reference, this reagent is added to the University's list of chemical reagents with the storage designation "Aggregated—Ventilated Room Temperature" with secondary containment. When the student picks up the chemical reagent, the laboratory manager provides a copy of the Safety Data Sheet, notes the hazardous nature of the chemical, and recommends that the student speak with his or her professor before running the first reaction to discuss safe handling for the reaction. In that discussion, the student and professor agree that a Moderate Risk SOP should be drafted for the use of this reagent. While that SOP is being drafted, the student performs the initial probe reactions using sodium azide on a very small scale (< 10 mmol), mitigating the danger of this reaction.

Piperonal: *Following the University's SOP for chemical reagent management, the laboratory manager scans the University's Dual-Use Chemicals List prior to ordering the chemical and notes that this reagent is on the list* *because of its potential to be used for the synthesis of illicit drugs. Although the reagent has been used before at the University, there is presently no material available. The laboratory manager finds that piperonal is a volatile aldehyde that releases a vapor that can induce central nervous system depression. The laboratory manager also reviews the catalog of the chemical supplier and learns that this reagent is available in much smaller quantities than the 500 g bottle requested by the student. As a result, the laboratory manager alerts the student to the fact that this reagent is on the Dual-Use Chemical List and inquires whether 25 g will meet the student's needs. The student explains that he recommended the 500 g bottle because the unit price at 500 g is one-quarter the unit price at 25 g. After the laboratory manager explains that the best practice guideline is to order the minimum quantity of dual-use chemicals, the student agrees that 25 g is sufficient for his research needs. The laboratory manager then emails the student's professor as required by the SOP for reagent management to request authorization to order this dual-use reagent. The professor and the student discussed the use of this reagent at the previous day's group meeting, so the professor immediately approves the request, and the laboratory manager places the order. Upon its arrival, the reagent is placed in a locked storage cabinet, which is ventilated at room temperature. The student is notified of the reagent's arrival and is reminded that the reagent must be checked out and returned the same day so that it can be secured.*

Diazald: *Diazald is a common precursor for the generation of diazomethane. The laboratory manager is aware of the danger of diazomethane and of an alternative reagent to diazald. The laboratory manager emails the professor (and copies the student) asking for verification of the need for this chemical reagent. In this case, the professor was unaware that the student was approaching the chemical reaction using the diazald procedure for generation of diazomethane. The professor suggests that the student first try the reaction with (trimethylsilyl) diazomethane, a safer alternative. The laboratory manager searches the existing chemical inventory and finds a recently ordered bottle (2 M dissolved in diethyl ether) in one of the laboratory refrigerators. The student borrows the existing diazald and discusses prudent safeguards with another student in the laboratory with experience with the reagent before performing the reaction.*


Inclusion and exclusion scope criteria
Type of SOP
Process risk mitigation
Management and storage
Assessment of chemical and process conditions
Assessment of risk type vis Storage Matrix
High Risks
Moderate Risks
Low Risks
High Risk SOP
Storage SOP
Moderate Risk SOP
Laboratory standards are sufficient

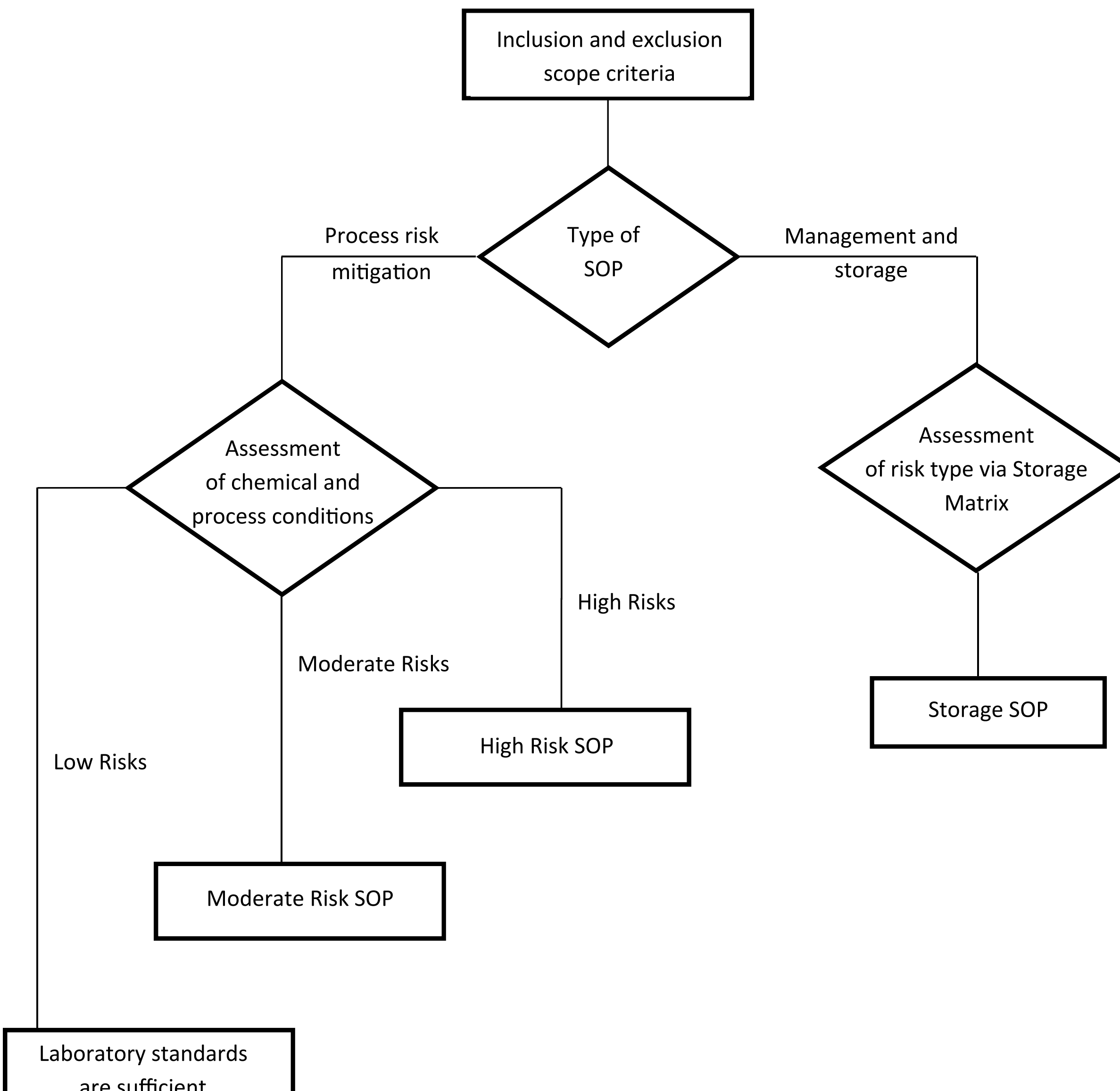
CHEMICAL STORAGE MATRIX

STORAGE OPTIONS	CONSIDERATIONS: Aggregated	Segregated	Secured
Ventilated Storage at Room Temperature	Sodium Azide		Piperonal
Flammable Storage/ Non-Ventilated at Room Temperature			
Open Laboratory Shelving			
Low Temperature	(Trimethylsilyl) Diazomethane		
Compressed Gas Storage			

6
FORMS

RISK ASSESSMENT FLOWCHART

The *Risk Assessment Flowchart* is intended for use by laboratory personnel with a B.S. degree in chemistry or equivalent. The flowchart is divided into Process Risk Mitigation and Management and Storage of Chemicals. Users will answer a series of questions that lead to one of four potential outcomes: (1) Laboratory Standards Are Sufficient, (2) Moderate Risk Standard Operating Procedure Is Required, (3) High Risk Standard Operating Procedure Is Required, and (4) Storage Matrix Standard Operating Procedure Is Required.



CHEMICAL STORAGE MATRIX

		CONSIDERATIONS		
		Aggregated	Segregated	Secured
STORAGE OPTIONS	Ventilated Storage at Room Temperature	Use normal storage location	See Appendix C	See Appendix E
	Flammable Storage/ Non-Ventilated at Room Temperature	See Appendix D	See Appendix C and D	See Appendix D and E
	Open Laboratory Shelving	Weak acid and base aqueous solutions, sodium chloride, etc.		
	Low Temperature	Refer to manufacturer's guidance on low temperature storage	Refer to manufacturer's guidance on low temperature storage	See Appendix E
	Compressed Gas Storage		See Appendix C	See Appendix C and E

MODERATE RISK STANDARD OPERATING PROCEDURE FORM

Implementation of the Moderate Risk Standard Operating Procedure is suggested for processes, experiments, or manipulations that pose moderate risks and that call for protective steps beyond those dictated by accepted laboratory standards. They are intended to limit the potential for injury, equipment damage, or environmental impact.

1. TITLE AND DESCRIPTION OF EXPERIMENT OR PROCESS:

2. PREPARER(S):

3. LOCATION:

4. AUTHORIZED PERSONNEL (WITH CONTACT INFORMATION)
   a. PRINCIPAL INVESTIGATOR (PI)/SUPERVISOR:
   b. STUDENT(S)/TECHNICIAN(S)/OPERATOR(S):
   c. OTHERS TO BE NOTIFIED (*e.g., other workers in the same laboratory, or other members of the research group*):

5. POTENTIAL HAZARDS:

6. DESCRIBE ALL SPECIAL REQUIREMENTS FOR SPECIFIC ITEMS THAT REQUIRE A GREATER LEVEL OF SAFETY

Planned chemicals involved	
Personal protective equipment	
Engineering and environmental controls	
Operational ranges and conditions	
Special handling and storage requirements	
Spill and accident procedure as needed	
Waste handling and disposal	

7. IDENTIFY ANY TRAINING NEEDS

Specific training required	
Users requiring training	
Date completed	

8. VERIFICATION AND REVIEW
By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print)	
PI signature	
Safety staff name (please print)	
Safety staff signature	
Current date	
Date of SOP expiration (e.g., 1 year)	

9. LIST OF REFERENCES (include Safety Data Sheets, Globally Harmonized System, any outside personnel consulted in preparation of document, peer reviewers, etc.)

MODERATE RISK STANDARD OPERATING PROCEDURE REVIEW AND MODIFICATIONS LOG

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and described modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

HIGH RISK STANDARD OPERATING PROCEDURE FORM

Implementation of the High Risk Standard Operating Procedure Form is suggested for processes, experiments, or manipulations that pose high risks and that call for protective steps beyond those dictated by accepted laboratory standards. They are intended to limit the potential for injury, equipment damage, or environmental impact.

1. TITLE AND DESCRIPTION OF EXPERIMENT OR PROCESS:

2. PREPARER(S):

3. LOCATION:

4. AUTHORIZED PERSONNEL (WITH CONTACT INFORMATION)
    a. PRINCIPAL INVESTIGATOR (PI)/SUPERVISOR:
    b. STUDENT(S)/TECHNICIAN(S)/OPERATOR(S):
    c. OTHERS TO BE NOTIFIED (*e.g., other workers in the same laboratory, or other members of the research group*):

5. IDENTIFY ANY TRAINING NEEDS

Experimental techniques	
Specific training required	
Users requiring training	
Date completed	

6. DETAILED PROCESS DESCRIPTION

List ranges for variables	Temperature:
	Pressure:
	Viscosity:
	Flammability:
	Other:
List of operational ranges and conditions	
Materials to be used	Chemicals:
	Equipment:

DETAILED PROCEDURE:

Column A: Process Steps provide step-by-step normal operating procedures, including the transfer of chemicals between or across laboratories, production of gases, workup of products, and preparation of wastes.

Column B: Safety Notes describe how the risk can be mitigated (i.e., minimize clutter, control flammables, secure gas cylinders, ensure good condition of pump belts).

	Column A: Process Steps	Column B: Safety Notes
1.0		*e.g., specific personal protective equipment requirements*
1.1		
1.2		

2.0		
2.1		
2.2		

3.0		
3.1		
3.2		

4.0		
4.1		
4.2		

7. ENGINEERING CONTROLS (check all that apply and provide a detailed description)

Engineering Controls	Check box if applicable	Description
Ex. Glove box	☑	*Use inert air (N_2 or Ar)*
Fume hood or glove box	☐	
Special ventilation	☐	
HEPA-filtered vacuum lines	☐	
Non-reactive containers	☐	
Pressure relief devices	☐	
Temperature control	☐	
Bench paper, pads, plastic-backed paper	☐	
Special signage	☐	
Safe sharp devices	☐	
Other safety devices used:	☐	

8. PERSONAL PROTECTIVE EQUIPMENT (check all that apply)

Personal Protective Equipment	Check box if applicable	Description
Gloves	☐	
Lab coats	☐	
Suits	☐	
Aprons	☐	
Long pants	☐	
Close-toed shoes	☐	
Long sleeves	☐	
Safety glasses	☐	
Goggles	☐	
Face shields	☐	
Respirators (include cartridge type and cartridge change-out schedule)	☐	
Hearing protection (include level of protection needed)	☐	
Special equipment (i.e., blast shields, special enclosures)	☐	
Other PPE	☐	

9. WORK PRACTICE CONTROLS

Controls	Description
Designated areas	
Procedures for requesting emergency assistance	
Emergency phone numbers	
Locations of fire alarms, fire extinguishers, fire blankets, eye washes, showers, etc.	
Emergency responders	
Workers on shifts	
Training on all experimental techniques and experiments	
Restricting access; locks	
Housekeeping	
Lockout/tagout[a] procedure plan	
After-hour procedures	
Preventive maintenance	

[a] Lockout/tagout refers to specific procedures to safeguard researchers from an unexpected startup of machinery and equipment, or a release of hazardous energy during service or maintenance activities.

10. MONITORING

Monitoring	Description
Personnel exposure monitoring	*e.g., wearable sensors for toxics, radiation badges*
Leak checking	
Gas and spill release monitoring	
Temperature and pressure	
Alarms	

11. SPILL AND ACCIDENT PROCEDURES

	Description and Location
Secondary containment	
Spill kits	
Emergency shutdown procedures	
Process shutdown	
Persons to inform	

12. WASTE DISPOSAL PROCEDURES (include segregation of acids, bases, halogenated compounds, PPE, collection and transport procedures, proper documentation, regulations, etc.)

13. STORAGE (check all that apply)

Ventilated enclosures ☐
Refrigeration ☐
Gas cabinet ☐
Compliance with regulations ☐
Expiration date:
Inventory:
Other:

14. TRANSPORTATION PROCEDURES:
(*e.g., secondary container for transporting between and across laboratories; secondary containment for experimental apparatus*)

15. PEER REVIEW

Name (please print)	
Signature	
Date	
Notes	

Name (please print)	
Signature	
Date	
Notes	

16. VERIFICATION AND REVIEW
By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print)	
PI signature	
Safety staff name (please print)	
Safety staff signature	
Current Date	
Date of SOP expiration (e.g., 1 year)	

17. LIST OF REFERENCES (include Safety Data Sheets, Globally Harmonized System, any outside personnel consulted in preparation of document, peer reviewers, etc.)

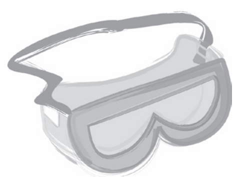
HIGH RISK STANDARD OPERATING PROCEDURE REVIEW AND MODIFICATIONS LOG

Were modifications made to current SOP?	Yes ☐ No ☐
If no, then list date of approval	
Last reviewed by (please print)	
If yes, then list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, list date of approval	
Last reviewed by (please print)	
If yes, list and describe modifications	

Were modifications made to current SOP?	Yes ☐ No ☐
If no, list date of approval	
Last reviewed by (please print)	
If yes, list and describe modifications	

APPENDIXES



A

CHARGE TO THE COMMITTEE

The U.S. Department of State charged the Academies with the task of producing a protocol for development of standard operating procedures (SOPs) that would serve as a complement to *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management* and would be added to the 2010 toolkit (see Box 1-1). To accomplish this task, the Academies formed a committee of experts with experience and knowledge in good chemical safety and security practices in academic and industrial laboratories and awareness of international standards and regulations.

To assemble this *Guide to Developing a Standard Operating Procedure*, the committee gathered information from a variety of sources including discussions with chemical safety experts from trade organizations and industry during a public data-gathering meeting; published literature, including the 2010 reference guide and toolkit; and existing SOP templates that are publicly available on the Web sites of many universities in the United States. This new product will enhance the use of the previous reference book and the accompanying toolkit, especially in developing countries where safety resources are scarce and the experience of operators and end users may be limited.

BOX 1-1
STATEMENT OF TASK

Building on the Chemical Laboratory Safety and Security Toolkit materials developed in 2010 for the State Department's Chemical Security Engagement Program (CSP), an ad-hoc committee under the auspices of the National Academy of Science's Board on Chemical Sciences and Technology will develop a template and guide for developing standard operating procedures for safe and secure handling, management, and storage of chemicals in chemical laboratories.

These deliverables will be designed for use in academic and small- to mid-sized industrial settings in countries where CSP is active. These materials may be translated into multiple languages, including Bahasa Indonesian, Arabic, and French, to serve as a complement to the Chemical Laboratory Safety and Security Toolkit.

B

AVAILABLE RESOURCES

American Chemistry Council
www.responsiblecare-us.com

American Chemical Society—Division of Chemical Health and Safety
www.dchas.org

American Chemical Society. *Identifying and Evaluating Hazards in Research Laboratories*. 2013.

Arab Union of Chemists
www.arabchem.org (Arabic language)

Bretherick, L., P. G. Urben, and M. J. Pitt. *Bretherick's Handbook of Reactive Chemical Hazards: An Indexed Guide to Published Data* (7th ed.) Oxford: Butterworth-Heinemann, 2006.

The Dow Chemical Company Lab Safety Academy
http://safety.dow.com/en

Federation of Asian Chemical Societies
www.facs-as.org

Federation of African Societies of Chemistry
www.faschem.org

Harvard University
http://ehs.harvard.edu/programs/safe-chemical-work-practices

The International Program on Chemical Safety INCHEM program
www.inchem.org

International Union of Pure and Applied Chemistry. Risk assessment for occupational exposure to chemicals. A review of current methodology. *Pure and Applied Chemistry* 73(6): 993-1031, 2001.

International Union of Pure and Applied Chemistry and World Health Organization. *Chemical Safety Matters*. Cambridge: Cambridge University Press, 1992. ISBN 0-521-41375-3 paperback.

National Research Council. *Promoting Chemical Laboratory Safety and Security in Developing Countries*. Washington, DC: The National Academies Press, 2010.

National Research Council. *Chemical Laboratory Safety and Security: A Guide to Prudent Chemical Management*. Washington, DC: The National Academies Press, 2010.

National Research Council. *Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version*. Washington, DC: The National Academies Press, 2011.

National Research Council. *Safe Science: Promoting a Culture of Safety in Academic Chemical Research*. Washington, DC: The National Academies Press, 2014.

Occupational Safety and Health Administration

a. https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760
b. https://www.osha.gov/SLTC/controlhazardousenergy/

Organization for the Prohibition of Chemical Weapons
www.opcw.org

Princeton University
https://ehs.princeton.edu/laboratory-and-research-safety/chemical-safety/chemical-specific-protocols-0

PubChem
https://pubchem.ncbi.nlm.nih.gov/docs/subcmpd_summary_page_help.html

PubMed (cytotoxic effects of chemicals can often be found here by entering the chemical's name; many of the primary journals cited will be open access)
http://www.ncbi.nlm.nih.gov/pubmed/

Sax, N. I., R. J. Lewis, Sr. *Rapid Guide to Hazardous Chemicals in the Workplace*. New York: Van Nostrand Reinhold Company, 1986. ISBN 0-442-28220-6.

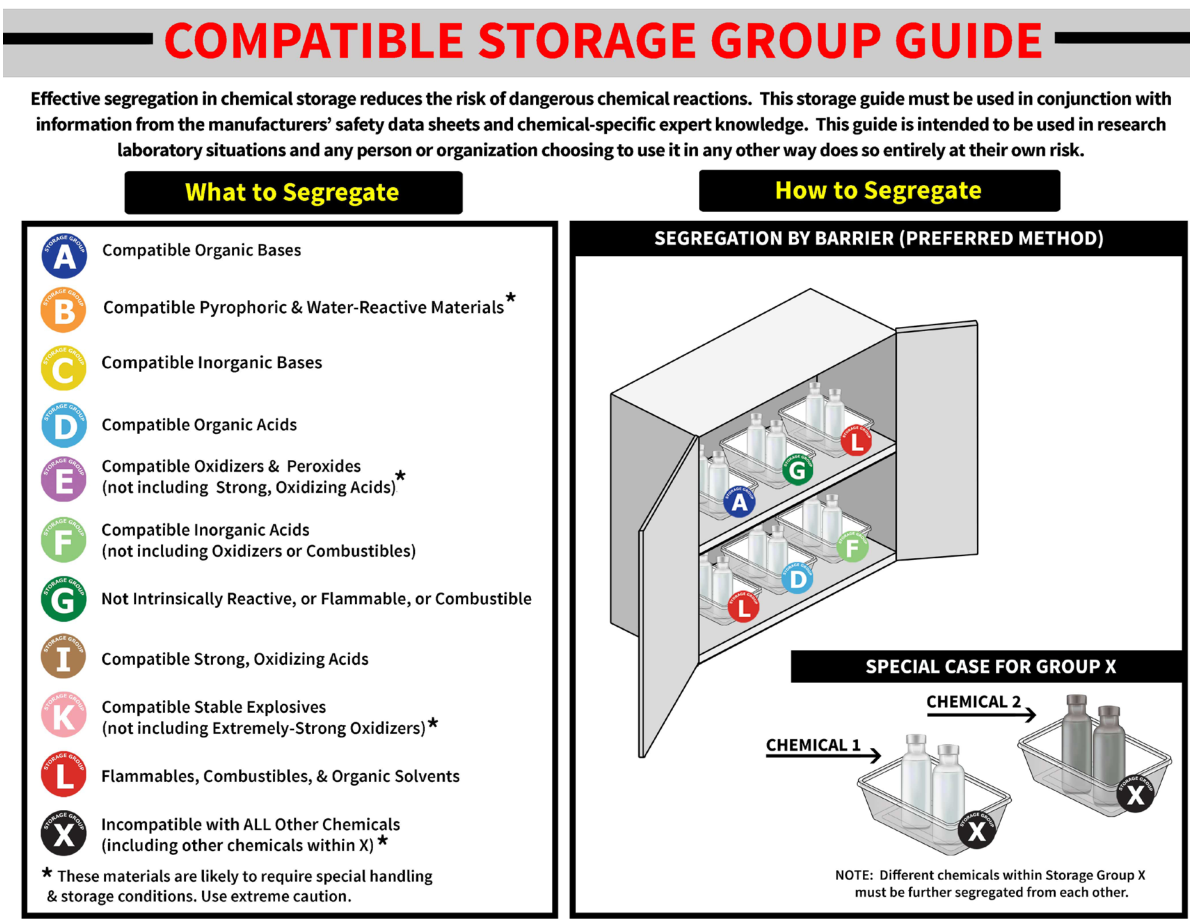
Stockholm Convention on Persistent Organic Pollutants
http://chm.pops.int

Strategic Approach to International Chemicals Management
www.saicm.org
University of Illinois
https://www.drs.illinois.edu/

The U.S. Chemical Security Engagement Program
www.csp-state.net

C

SEGREGATION LIST



SOURCE: Used with permission from Lawrence M. Gibbs, Stanford University.
NOTE: The storage guide is only an example of a best management practice which is used at Stanford. Any chemical segregation system, including the example from Stanford, should not be used as the sole means of making a determination of safe segregation and storage for a chemical.

D

FLAMMABLE LIST

Properties of Some Common Organic Solvents							
Solvent	Formula	Molecular Weight	Boiling Point (°C)	Melting Point (°C)	Density (g/mL)	Solubility in Water (g/100g)	Flash Point (ºC)
acetic acid	$C_2H_4O_2$	60.052	118	16.6	1.049	Miscible	39
acetone	C_3H_6O	58.079	56.2	–94.3	0.786	Miscible	–20
acetonitrile	C_2H_3N	41.052	81.6	–46	0.786	Miscible	6
benzene	C_6H_6	78.11	80.1	5.5	0.879	0.18	–11
1-butanol	$C_4H_{10}O$	74.12	117.6	–89.5	0.81	7.7	37
2-butanol	$C_4H_{10}O$	74.12	99.5	–114.7	0.808	18.1	24
2-butanone	C_4H_8O	72.11	79.6	–86.3	0.805	25.6	–9
t-butyl alcohol	$C_4H_{10}O$	74.12	82.2	25.5	0.786	Miscible	11
carbon tetrachloride	CCl_4	153.82	76.7	–22.4	1.594	0.08	—
chlorobenzene	C_6H_5Cl	112.56	132	–45.6	1.106	0.05	28
chloroform	$CHCl_3$	119.38	61.2	–63.5	1.498	0.8	—
cyclohexane	C_6H_{12}	84.16	80.7	6.6	0.779	<0.1	–20
1,2-dichloroethane	$C_2H_4Cl_2$	98.96	83.5	–35.4	1.235	0.87	13
diethyl ether	$C_4H_{10}O$	74.12	34.5	–116.2	0.713	7.5	–45
diethylene glycol	$C_4H_{10}O_3$	106.12	245	–10	1.118	Miscible	124
diglyme (diethylene glycol dimethyl ether)	$C_6H_{14}O_3$	134.17	162	–64	0.945	Miscible	67
1,2-dimethoxy- ethane (glyme, DME)	$C_4H_{10}O_2$	90.12	85	–58	0.868	Miscible	–2
dimethyl-formamide (DMF)	C_3H_7NO	73.09	153	–61	0.9445	Miscible	58
dimethyl sulfoxide (DMSO)	C_2H_6OS	78.13	189	18.4	1.092	Miscible	95
1,4-dioxane	$C_4H_8O_2$	88.11	101.1	11.8	1.033	Miscible	12
ethanol	C_2H_6O	46.07	78.5	–114.1	0.789	Miscible	13

Solvent	Formula	Molecular Weight	Boiling Point (°C)	Melting Point (°C)	Density (g/mL)	Solubility in Water (g/100g)	Flash Point (°C)
ethyl acetate	$C_4H_8O_2$	88.11	77	–83.6	0.894	8.7	–4
ethylene glycol	$C_2H_6O_2$	62.07	197	–13	1.115	Miscible	111
glycerin	$C_3H_8O_3$	92.09	290	17.8	1.261	Miscible	160
heptane	C_7H_{16}	100.2	98	–90.6	0.684	0.0003	–4
hexamethylphosphoramide (HMPA)	$C_6H_{18}N_3OP$	179.2	232.5	7.2	1.03	Miscible	105
hexamethylphosphorous triamide (HMPT)	$C_6H_{18}N_3P$	163.2	150	–44	0.898	Miscible	26
hexane	C_6H_{14}	86.18	69	–95	0.655	0.0014	–22
methanol	CH_4O	32.04	64.6	–98	0.791	Miscible	12
methyl *t*-butyl ether (MTBE)	$C_5H_{12}O$	88.15	55.2	–109	0.741	4.8	–28
methylene chloride	CH_2Cl_2	84.93	39.8	–96.7	1.326	1.32	1.6
N-methyl-2-pyrrolidinone (NMP)	CH_5H_9NO	99.13	202	–24	1.033	10	91
nitromethane	CH_3NO_2	61.04	101.2	–29	1.382	9.5	35
pentane	C_5H_{12}	72.15	36.1	–129.7	0.626	0.004	–49
petroleum ether (ligroine)	—	—	30-60	–40	0.656	—	–30
1-propanol	C_3H_8O	88.15	97	–126	0.803	Miscible	15
2-propanol	C_3H_8O	88.15	82.4	–88.5	0.785	Miscible	12
pyridine	C_5H_5N	79.1	115.2	–42	0.982	Miscible	17
tetrahydrofuran (THF)	C_4H_8O	72.106	66	–108.4	0.886	30	–14
toluene	C_7H_8	92.14	110.6	–93	0.867	0.05	4
triethyl amine	$C_6H_{15}N$	101.19	88.9	–114.7	0.728	0.02	–11
o-xylene	C_8H_{10}	106.17	144	–25.2	0.897	Insoluble	32
m-xylene	C_8H_{10}	106.17	139.1	–47.8	0.868	Insoluble	27
p-xylene	C_8H_{10}	106.17	138.3	13.3	0.861	0.02	27

SOURCE: Dr. Steven Murov, Professor Emeritus of Chemistry, Modesto Junior College.

E

SECURITY LIST

Toxic Chemicals		
		(CAS Registry Number)
1.	Phosgene: Carbonyl dichloride	(75-44-5)
2.	Cyanogen chloride	(506-77-4)
3.	Hydrogen cyanide	(74-90-8)
4.	Chloropicrin: Trichloronitromethane	(76-06-2)
Precursors		
		(CAS Registry Number)
5.	Phosphorous oxychloride	(10025-87-3)
6.	Phosphorus trichloride	(7719-12-2)
7.	Phosphorus pentachloride	(10026-13-8)
8.	Trimethyl phosphite	(121-45-9)
9.	Triethyl phosphite	(122-52-1)
10.	Dimethyl phosphite	(868-85-9)
11.	Diethyl phosphite	(762-04-9)
12.	Sulfur monochloride	(10025-67-9)
13.	Sulfur dichloride	(10545-99-0)
14.	Thionyl chloride	(7719-09-7)
15.	Ethyldiethanolamine	(139-87-7)
16.	Methyldiethanolamine	(105-59-9)
17.	Triethanolamine	(102-71-6)

SOURCE: Adapted by the Organisation for the Prohibition of Chemical Weapons.
https://www.opcw.org/chemical-weapons-convention/annexes/annex-on-chemicals/schedule-3/.

F

COMMITTEE AND STAFF BIOGRAPHIES

Ned D. Heindel (*Chair*) is the H. S. Bunn Chair Professor of Chemistry at Lehigh University and a consultant on drug development for Azevan Pharmaceuticals. Dr. Heindel has graduated 40 doctoral students, most of whom have entered academia or the health care industry. He has engaged in contract research and development (R&D) for Astra-Zeneca, Air Products, BMS, Merck, J&J, and DuPont, as well as for eight venture capital start-up firms. At Lehigh University, he teaches general, organic, and medical chemistry and organic mechanisms along with three web-mounted graduate courses in a Distance Education program. Dr. Heindel is a graduate of Lebanon Valley College (BS, 1959), the University of Delaware (PhD, 1963), and Princeton University (postdoc, 1964). He taught at the University of Delaware, Marshall University, and Ohio University before joining the faculty of Lehigh University. Dr. Heindel also served as President of the American Chemical Society (ACS) in 1994.

Montgomery Alger received BS and MS degrees in chemical engineering from the Massachusetts Institute of Technology and a PhD in chemical engineering from the University of Illinois at Urbana-Champaign. Dr. Alger serves on the Chemical Engineering Advisory Councils at Lehigh University, Georgia Institute of Technology, and the University of California-Santa Barbara. He served as a board member for the American Institute of Chemical Engineers and is a member of the National Academy of Engineering. Dr. Alger is a certified Six Sigma Master Black Belt.

William Bullock is Senior Director, Research Business Operations, Bristol-Myers Squibb (BMS). Dr. Bullock received his PhD from Emory University in organic chemistry. After completing a chemistry postdoctoral fellowship with National Academy of Sciences member Prof. Larry Overman (University of California, Irvine), he accepted a position as laboratory supervisor with Bayer Pharmaceutical. During his 15-year career with Bayer, he contributed to and led a variety of successful research programs in Connecticut and Germany. By 2002, Dr. Bullock was appointed to the position of Director, contributing chemistry leadership to the diabetes drug discovery portfolio. In addition, he reexamined and redefined several global R&D processes. These efforts included a fundamental transformation of the early drug candidate selection process, resulting in increased Phase 1 success; global harmonization of research practices and roles, allowing for the creation of a web-based portfolio management tool; and deployment of electronic notebooks in the United States.

In 2007, Dr. Bullock joined BMS as Director in Research Business Operations. Today, he has business operations responsibilities for five departments within research and is chair of the Research Technology Evaluation and Sustainability Committee and of the Chemistry Safety Committee. He has either contributed to or led several notable projects, including centralization of all final drug candidate purification, incorporation of safety warning systems into the BMS electronic notebook system, and transformation of lab and office design from high customization to high flexibility, and the Global R&D Footprint Committee.

Mark Cesa is a physical organic/organometallic chemist with research interests in homogeneous and heterogeneous catalysis and organic reaction kinetics and mechanisms. He studied chemistry at Princeton University, where he earned an AB in 1974. He earned his MS (1977) and PhD (1979) in organic chemistry at the University of Wisconsin-Madison, under the supervision of Prof. Charles P. Casey. Dr. Cesa has recently retired from his position as Process Chemistry Consultant with INEOS Nitriles, Naperville, Illinois, where he was responsible for process chemistry research and support for INEOS Nitriles manufacturing plants. Dr. Cesa was the 2014-2015 President of the International Union of Pure and Applied Chemistry. He also served as chair of the IUPAC Committee on Chemistry and Industry, where he coordinated the IUPAC Safety Training Program. Dr. Cesa is currently chair of the American Chemical Society Committee on Science and has served on the ACS Committee on Chemical Safety.

Thomas Edgar is the George T. and Gladys H. Abell Chair in Chemical Engineering at the University of Texas (UT) at Austin. He received his BS in chemical engineering from the University of Kansas and PhD from Princeton University. Dr. Edgar worked as a process engineer with the Continental Oil Company before joining UT's faculty in 1971. He served as Department Chair of Chemical Engineering (1985-1993), Associate Dean of Engineering (1993-1996), and Associate Vice President for Academic Computing (1996-2001) at UT-Austin. He recently became Director of the UT Energy Institute (2012).

For the past 40 years Dr. Edgar has concentrated his academic work in process modeling, control, and optimization. He has published more than 450 articles and book chapters in the above fields applied to separations, chemical reactors, energy systems, and semiconductor manufacturing. He has supervised the thesis research of more than 45 MS and 80 PhD students. He also co-directs the Texas-Wisconsin-California Control Consortium, which involves 12 companies.

Patrick J. Y. Lim is Professor and former Chair (2004-2011) of the Department of Chemistry at the University of San Carlos (USC) in Cebu City, Philippines. He earned his PhD in chemistry (2000) at the University of Melbourne under the supervision of Assoc. Prof. Charles G. Young, investigating novel reactions of metal–sulfur compounds with activated alkynes. He served as an accreditor of the Philippines Accrediting Association of Schools, Colleges and Universities and was also a member of the Philippine Commission on Higher Education Technical Committee for Chemistry (2007-2009). He has served as editor of *The Philippine Scientist*, a multidisciplinary ISI-listed journal published by USC Press, since 2008. Dr. Lim has been engaged in chemical safety and security in various capacities from professional meetings in Spiez, Switzerland, and at the OPCW Headquarters in The Hague, the Netherlands, to conducting trainings in Karachi, Pakistan, and Taiz, Yemen, as well as in the central and southern Philippines.

Kenneth Moloy is currently a Program Director at the National Science Foundation. He received a PhD in inorganic chemistry from Northwestern University in 1984 and a BS in chemistry from Indiana University in 1980. Following graduate school he joined Union Carbide's Technical Center in South Charleston, West Virginia, working in long-range R&D. In 1995 he moved to the DuPont Central Research and Development in Wilmington, Delaware. Dr. Moloy left DuPont in 2016 as a Research Fellow. Dr. Moloy's expertise lies in the areas of organometallic chemistry, catalysis, organic chemistry, and process chemistry. He has chaired the Gordon Research Conference on Organometallic Chemistry and also the Organometallic Subdivision of the ACS Division of Inorganic Chemistry. Dr. Moloy recently participated on a National Academy of Sciences (NAS) committee to revise *Prudent Practices in the Laboratory*. Dr. Moloy is also a current member of the National Academies of Sciences, Engineering, and Medicine's Chemical Sciences Roundtable.

Supawan Tantayanon is a Professor of Chemistry of the Faculty of Science, Chulalongkorn University, Thailand. She received her BSc Honor (chemistry) from Chulalongkorn University, MSc (organic chemistry) from Mahidol University, Thailand, and PhD (organic chemistry) from Worcester Polytechnic Institute, Massachusetts. She initiated and became the first Director of three new academic programs of Chulalongkorn University, namely the Applied Chemistry (BSc program), the Petrochemistry and Polymer Science (MSc and PhD program), and the Technopreneurship and Innovation Management Program (MSc and PhD program). Her research interest involves organic and polymer syntheses but has recently focused more on green chemistry and its commercialization.

Dr. Tantayanon served as President of the Polymer Society of Thailand (1997-2003), Pacific Polymer Federation (2002-2003), Chemical Society of Thailand (2007-2012), and Federation of Asian Chemical Societies (2011-2013). Currently she is a member of the National Hazardous Materials Committee, and the Council of Science and Technology Professionals of Thailand.

Staff

Camly Tran joined the Board on Chemical Sciences and Technology at the National Academy of Sciences, Engineering, and Medicine in 2014 as a postdoctoral fellow after receiving her PhD in chemistry from the Department of Chemistry at Brown University and is currently an Associate Program Officer. During her time at Brown, she received various honors including the Elaine Chase Award for Leadership and Service, American Chemical Society Global Research Exchanges Education Training Program, and the Rhode Island NASA grant. Dr. Tran completed the workshop summary *Mesoscale Chemistry* and consensus studies *Spills of Diluted Bitumen from Pipelines* and *Effective Chemistry Communication in Informal Environments*. Dr. Tran is currently supporting activities on the changing landscape of hydrocarbon feedstocks for chemical production, chemistries of the microbiome, and standard operating procedures for safe and secure handling, management, and storage of chemicals in chemical laboratories.

Claire Ballweg joined the National Academy of Sciences, Engineering, and Medicine in April of 2015 as a Senior Program Assistant on the Board on Environmental Studies and Toxicology after receiving her MS in ecological applications from Imperial College London. In January 2016, she assumed the role of Program Coordinator for the Board on Chemical Sciences and Technology. During her time at Imperial College, she completed a thesis analyzing complex global datasets using Geographic Information Systems to develop a model for identifying appropriate and ideal tropical forest conservation areas. She is currently supporting activities on the role of chemistry in human, marine, and geological microbial communities, and standard operating procedures for safe and secure handling, management, and storage of chemicals in chemical laboratories.