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CAMPUS STANDARD OPERATING PROCEDURES: REQUIREMENTS & RECOMMENDATIONS

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This document summarizes the Standard Operating Procedures (SOPs) that are either required or recommended for the safe use, storage, transport, and disposal of hazardous chemicals or equipment in research activities at UC Davis. These baseline campus requirement and recommendation expectations have been reviewed and endorsed by the campus Chemical and Laboratory Safety Committee (CLSC). SOPs fulfill requirements under the Occupational Safety and Health Administration (OSHA) Laboratory Standard, documenting expectations aimed to minimize exposures to hazardous chemicals. SOPs augment the campus Chemical Hygiene Plan (CHP) describing the laboratory-specific methods for minimizing chemical exposures. They should emphasize the health and safety aspects of the hazardous chemical or equipment in use, and can also serve additional utility such as the following:

1. The foundation of a quality system. Quality systems ensure reproducibility and support accuracy and validity of measurements. This can be important between different individuals, different facilities, different source materials, etc. They are required in good laboratory practice (GLP), good manufacturing practice (GMP) and good documentation practice (GDP) environments. See UC Davis course CHE 145 GQP (Good Quality Practice) for additional information on this topic.
2. Training materials for new research personnel. These training materials serve as support for the research group's quality system.
3. Tools for knowledge transfer between research personnel and collaborators. Effective knowledge transfer can minimize time wasted replicating previously established outcomes. It further lessens the likelihood of lost skills and techniques between personnel.
4. Development of SOPs can aid experiment/research planning and preparation. These documents can be incredibly helpful when writing scientific documentation for peer-reviewed journals or research funding progress and final reports. This can be especially true for materials and methods sections.
5. Preparation of SOPs can increase hazard recognition of proposed research activities. This will be needed to inform a risk assessment and improve mitigation and hazard control efforts.

Where applicable, SOPs should provide sufficiently detailed information such that they may support a positive safety culture and laboratory best practices. SOP categories described in this document are either required or recommended for laboratories using chemical or process/equipment hazards:

I. REQUIRED SOPs: These hazardous chemicals and processes/equipment were determined to REQUIRE a SOP by the CLSC. The SOPs to be developed shall provide detailed description of the use, storage and handling of these materials/processes/equipment. See Table I for a quick reference of required SOPs.

II. RECOMMENDED SOPs: Additional chemical hazards and process/equipment SOPs that are recommended for laboratory hazards is provided. See Table II for a quick reference of SOPs recommended by the CLSC. This list is NOT comprehensive; rather it aims to provide guidance for some commonly encountered laboratory and/or occupational hazards.

Laboratories developing SOPs, which augment the campus Chemical Hygiene Plan (CHP) contained in the Laboratory Safety Manual, may choose to use SOP templates that have been reviewed and approved

by the CLSC or develop their own SOPs. Approved SOP templates, including a blank CLSC-approved template, are available at https://safetyservices.ucdavis.edu/article/standard-operating-procedure-sop-templates. SOPs can be further supported by a Laboratory Safety Plan (LSP). A CLSC-approved LSP template is available on the Safety Services website. A LSP must be implemented if the principal investigator (PI) or lab supervisor delegates any safety responsibilities to members of their lab or if the laboratory has atypical engineering controls (e.g. downdraft tables) or the laboratory has unique personal protective equipment (PPE) requirements (e.g. clean room PPE).

SOPs are separated into three main categories:

A. Hazard control bands address safety considerations pertaining to a chemical hazard class (e.g. corrosives, carcinogens). The efficiency of control bands is that they leverage like behavior or material hazards where exposure control strategies and risk management are similar between the different chemicals;
B. Chemical-specific, which address chemicals or specific, discrete mixtures whose safety considerations largely fall outside chemical hazard control-band SOPs (e.g. hydrofluoric acid, aqua regia); and
C. Process/equipment-specific, which address safety concerns related to specific procedures and equipment.

Note that laboratories are not required to use the hazard control band approach and may choose to develop their own process or chemical-specific SOPs. All chemical, equipment, or process hazards that require a SOP must have all their corresponding hazards described in one SOP or a combination of SOPs that collectively describe the hazards. For example, ethanol may be covered in a chemical-specific SOP, by a combination of the Flammable Liquids and the Reproductive Toxins hazard control-band SOPs, or by a process-specific SOP that notes the flammability and reproductive toxicity hazards of ethanol (and any hazards for other chemicals being used in the process).

I. Campus Requirements

The following control-band, chemical-specific, and process/equipment-specific SOPs are required if the hazard class, specific chemical, or process/equipment is used or stored in the laboratory. It is expected that SOPs reflecting these hazards and their control will be developed for each campus research group no later than October 1, 2019*. Where appropriate, applicable Globally Harmonized System (GHS) hazard codes are provided that aid identification of chemicals to be listed in the SOP:

A. Hazard Control Bands:

1. Acutely Toxic Gases

- Acutely Toxic Gases (ATGs) have an LC_{50} in air ≤ 2000 ppm by volume for gas or vapor, or ≤ 20 mg/L for mist, fume or dust, when administered continuously for one hour to albino rats.
- GHS hazard codes: H330 (fatal if inhaled) or H331 (toxic if inhaled). See Appendix A for a decision tree to determine whether an ATG SOP is appropriate for the chemicals in question.

2. Acutely Toxic Solids/Liquids
   - Acutely Toxic Solids/Liquids (ATS/L) have an $LD_{50} \leq 50$ mg/kg when administered orally to albino rats -OR- an $LD_{50} \leq 200$ mg/kg when administered by continuous skin contact for 24 hours to albino rabbits -OR- an LC_{50} in air ≤ 200 ppm by volume for gas and vapor, 2 mg/L for mist, fume, or dust, when administered by continuous inhalation for 1 hour to albino rats.
   - GHS hazard codes: H300 (fatal if swallowed), H310 (fatal in contact with skin), and/or H330 (fatal if inhaled). In this case, the H330 code refers to the vapor over the ATS/L used in the solid/liquid state. If these materials are being intentionally aerosolized, boiled, or otherwise used without adequate engineering controls (e.g. chemical fume hood), an ATG or chemical-specific SOP must be developed and implemented. See Appendix A for a decision tree to determine whether an ATG SOP is also necessary for the solid and/or liquid chemicals in question.

3. Carcinogens
   - Carcinogens regulated by Cal/OSHA can be found in Title 8 of California Code of Regulations (8 CCR), Article 110, §5200-5220. Additionally, Cal/OSHA defines guidelines for identification of carcinogens in 8 CCR §5191.
   - A SOP must be developed for the following carcinogen groups:
     a. Carcinogens
        - GHS hazard codes: H350 (may cause cancer) and H351 (suspected of causing cancer).
        - Note: This control band DOES NOT include 8 CCR 5209 Listed Carcinogens, these are covered in the Listed Carcinogens SOP as well as listed in Appendix B.

     b. Listed Carcinogens
        - Listed carcinogens are identified in Title 8 of California Code of Regulations (8 CCR 5209), in the Listed Carcinogen SOP template, and in Appendix B.
        - Please contact chem-safety@ucdavis.edu for consultation if you are considering the purchase, use and/or storage of a Listed Carcinogen. Please restrict future purchase and use if possible due to regulatory compliance challenges. Stringent use requirements and decontamination procedures present increased complexity and oversight for proper handling and use.

4. Corrosives
   - Corrosives are chemicals that cause visible destruction or irreversible alterations in living tissue and other materials by chemical action at the site of contact. Corrosives represent a broad range of chemicals and can be corrosive to metal and skin alike.
   - GHS hazard codes: H314 (causes severe skin burns and eye damage), H318 (causes serious eye damage) and H290 (may be corrosive to metals).

5. Engineered Nanomaterials
   - According to OSHA, engineered nanoscale materials or nanomaterials are materials that have been purposefully manufactured, synthesized, or manipulated to have a size with at least one dimension in the range of approximately 1 to 100 nanometers and that exhibit unique properties determined by their size.

- Materials of particular emphasis in this category are those with greater risk for inhalation or ingestion exposures. These are typically dry and loose powders or fibers, as opposed to powders/fibers in solution or bound to a larger matrix.
- Depending on their physical form (e.g. solids, aerosols, solutions, bound to a substrate, etc.), these materials can present unique challenges for controlling inhalation, ingestion, and contact exposures. Please contact chem-safety@ucdavis.edu for assistance in risk assessment and control strategies.
- Any ENM that lacks a waste determination involving toxicity testing must at a minimum have documentation describing how the ENM will be disposed of as hazardous waste. See SafetyNet #132 for more information and further resources.

6. Flammable Liquids
   - Flammable liquids, as defined by OSHA, are materials that have a flash point (f.p.) less than 37.8 °C (100 °F). Many laboratory solvents are flammable liquids, such as Acetone (f.p. = 1 °F), Acetonitrile (f.p. = 42 °F), Benzene (f.p. = 12 °F), Diethyl Ether (f.p. = -49 °F), Ethanol, (f.p. = 55 °F), Methanol (f.p. = 52 °F), Isopropanol (f.p. = 74 °F), and Toluene (f.p. = 40 °F).
   - GHS hazard codes: H224 (extremely flammable liquid and vapor), H225 (highly flammable liquid and vapor), and H226 (flammable liquid and vapor).
7. Flammable Solids
   - Flammable solids are materials which burn rapidly or intensely when ignited.
   - GHS hazard code: H228 (flammable solid).
8. Potentially Explosive Compounds
   - Any compound or mixture that, upon suitable ignition (e.g. heat, friction, etc.), undergoes rapid a chemical change producing large volumes of heated gases or vapors that exert pressure on the surrounding medium.
   - Potentially Explosive Compounds (PECs) are a broad class of materials that are rarely labeled with a GHS code indicating their potentially explosive properties.
   - Bretherick's Handbook of Reactive Chemical Hazards (available via the UC Davis library) is an excellent resource for identifying PECs and the conditions under which they become explosive. Section 10 of the Safety Data Sheet (SDS) is another potential resource for this information.
9. Pyrophorics
   - Pyrophorics, as defined by the California Fire Code, are materials that auto-ignite below 54.4 °C (130 °F).
   - GHS hazard code: H250 (catches fire spontaneously if exposed to air).
10. Reproductive Toxins
    - Reproductive toxins are substances that may have adverse effects on various aspects of reproduction in both men and women.
    - GHS hazard codes: H340 (may cause genetic defects), H341 (suspected of causing genetic defects), H360 (may damage fertility or the unborn child), H361 (suspected of damaging fertility or the unborn child), and/or H362 (may cause harm to breast-fed children).

11. Water Reactives
    - Water Reactives are materials that can react violently with water or atmospheric moisture to produce flammable or toxic gas and heat.
    - GHS hazard codes: H260 (in contact with water releases flammable gases which may ignite spontaneously) and H261 (in contact with water releases flammable gas). GHS codes identify materials of flammable gases, however materials that generate toxic gases are not always identifiable. Please contact chem-safety@ucdavis.edu for assistance in risk assessment and control strategies.

B. Chemical-Specific

1. Aqua Regia: The fuming liquid mixture of concentrated nitric and hydrochloric acids.
2. Hydrofluoric Acid: Hydrofluoric acid (HF, liquid or gas) greater than 0.05% HF.
3. Piranha: The liquid mixture of concentrated sulfuric acid and 30% hydrogen peroxide.

C. Process/Equipment-Specific

1. Lasers (Class 3B & 4)
    - Lasers that pose significant exposure hazards to the eyes (Class 3B) or to both eyes and skin (Class 4).
2. Unattended Operations*
    - Control measures involving unattended operations (e.g. hazard management with loss of power or cooling water) must be documented in the lab-specific LSP or clearly defined in the SOPs involving the Unattended Operations.
    - The hazard control band SOP templates were drafted for the hazard in question and not the process of utilization. As such, many of the controls for Unattended Operations are not presently in the approved template language.
3. Working Alone
    - Any work where an individual is beyond visible or audible range of another individual for more than a few minutes at a time.

*Unattended Operations SOP required starting October 1st, 2020. All other SOPs listed in Section I are required starting October 1st, 2019.

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II. Campus Recommendations

The following chemical control bands, chemical-specific, and process/equipment-specific SOPs are recommended if the hazard class, specific chemical, or process/equipment is used in the laboratory:

A. Controls Bands

1. Cryogens
   - Cryogens are liquefied or solid gases at extremely low temperatures. Cryogenic liquids have a normal boiling point below -150 ºC (-240 ºF). Cryogenic solids are defined as solids with a sublimation range of -78.5 ºC to -109.3 ºC (-109.3 °F to -164.7 °F).
   - GHS hazard code: H281 (contains refrigerated gas; may cause cryogenic burns or injury).
2. Lachrymators:
   - Lachrymators are substances that irritate the eyes and causes tears to flow.
   - Note that not all substances with these GHS hazard codes are lachrymators: H318 (causes serious eye damage) and H319 (causes serious eye irritation).
3. Oxidizing Materials
   - Oxidizing Materials are substances that react chemically to oxidize other materials in a way that increases the chance of fire or explosion.
   - Most health and safety concerns related to oxidizers involve chemical segregation to prevent contact with incompatible materials. This lab-specific information may be contained in a SOP or within a LSP.
   - GHS hazard codes: H271 (may cause fire or explosion; strong oxidizer), H272 (may intensify fire; oxidizer), and H273 (may intensify fire; oxidizer).
4. Sensitizers
   - Sensitizers are chemicals that cause a substantial portion of exposed individuals to develop an allergic reaction after repeated exposure to the chemical. A common example is formaldehyde.
   - GHS hazard code: H317 (may cause an allergic skin reaction) and H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled).

B. Chemical-Specific

1. Phenol: due to the unique first aid procedures for a phenol exposure.
2. Sodium Azide: poses unique hazards, though these may be covered using a combination of control-banded SOPs (Acutely Toxic Solids/Liquids and Potentially Explosive Compounds, depending on the preparation).

C. Process/Equipment-Specific

1. Compressed Gases
   - The laboratory-specific protocols related to compressed gases can be described in a SOP, or the information can be integrated into a LSP. In certain instances a SOP may have greater utility than embedding the information into the LSP.
   - A SOP should be developed for the following Compressed Gases:
     a. Acetylene: The unstable, reactive nature of Acetylene necessitates unique safety controls.

b. Flammable Compressed Gases: All Flammable Gases present the risk of fire, especially when confined or improperly ventilated.

- GHS hazard code: H280 (contains gas under pressure; may explode if heated). Flammable gases are also identified by H220 (extremely flammable gas) and H221 (flammable gas). Oxidizing gases are identified by H270 (may cause or intensify fire; oxidizer).

2. Field Research
   - A Field Research SOP should capture the elements of remote communication (e.g. hierarchy and contact information, mechanism for contact without phone or cellular service, frequency of contact expectations), necessary emergency provider information for the respective field location (e.g. closest emergency room, police/fire service, U.S. Consulate), and transportation for personnel, equipment and any hazardous materials. Alternatively, this information can be contained within a LSP, with a site summary sheet attached as an appendix for each unique field location (e.g. field safety plan template).
   - The recommendation for a SOP or inclusion in a LSP is not meant to replace existing, established field research safety programs (e.g., Boating Safety, Diving Safety, etc.), but to serve as a complimentary resource in these instances.
3. Furnaces
   - For use of laboratory furnaces capable of generating temperatures above 500 C during operation.
4. High/Low Pressure Activities
   - The utility of such a SOP is strongly dependent on a lab-specific definition of high and/or low pressure. This information can either be contained in a SOP or a LSP, and must include lab-specific definition(s) of high/low pressure.
5. Strong Magnetic Fields
   - This SOP provides a summary of basic magnetic field safety and hazards specific to the operation and maintenance of instrumentation that produces magnetic fields in excess of 600 gauss (60 mT) or the field maintains strength greater than 5 gauss over a distance of 6 inches.
6. Vivarium Hazardous Chemical Use
   - This SOP describes the lab-specific expectations for hazardous chemical use in the animal research vivarium environment. Informational elements such as hazardous chemical transport to/from the vivarium, procedures to handle chemical spill/exposure in the vivarium, and chemical storage (after receiving pre-approval from the vivarium manager) should be contained in such a SOP. Alternatively, this information could also be contained in a LSP.

NOTE: Guidance on SOP reviews, revisions, and training is contained in Administrative Controls section of the Laboratory Safety Manual.

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Table I: REQUIRED SOPs		
SOP type:	GHS Hazard Code(s):	Description:
Hazard Control Bands:		
Acutely Toxic Gases	H330, H331	LC_{50} in air ≤2000 ppm by volume for gas or vapor, or ≤20 mg/L for mist, fume or dust (as measured in albino rat).
Acutely Toxic Solids/Liquids	H300, H310, H330	Oral LD_{50} ≤50 mg/kg (albino rat) -OR- 24-hour skin contact LD_{50} ≤200 mg/kg (albino rabbit) -OR- a 1-hour continuous inhalation LC_{50} in air ≤200 ppm by volume for gas and vapor or 2 mg/L for mist, fume, or dust (albino rat).
Carcinogens	H350, H351	Carcinogens regulated by Cal/OSHA can be found in Title 8 of California Code of Regulations (8 CCR), Article 110, §5200-5220. Additionally, Cal/OSHA defines guidelines for identification of select carcinogens in 8 CCR §5191.
Listed Carcinogens	See Appendix B for list. Restrict purchase.	Listed Carcinogens are identified in 8 CCR §5209. Contact EH&S, as stringent use requirements and decontamination procedures present increased complexity and oversight for proper handling and use.
Corrosives	H314, H318, H290	A chemical that causes destruction or irreversible alterations in living tissue by chemical action at the site of contact.
Engineered Nanomaterials		Nanomaterials are materials that have been purposefully manufactured, synthesized, or manipulated to have a size with at least one dimension in the range of approximately 1 to 100 nanometers and that exhibit unique properties determined by their size. Emphasis is placed on materials having greater risk of inhalation or ingestion exposures.
Flammable Liquids	H224, H225, H226	Liquid chemicals that have a flash point less than 37.8 °C (100 F).
Flammable Solids	H228	Flammable solids are materials which burn rapidly or intensely when ignited.
Potentially Explosive Compounds	Not always noted with explosive GHS hazard codes. See Section 10 of SDS.	Any compound or mixture that, upon suitable ignition (e.g. heat, friction, etc.), undergoes rapid chemical change producing large volumes of heated gases or vapors that exert pressure on the surrounding medium.
Pyrophorics	H250	Materials that auto-ignite below 54.4 °C (130 °F).
Reproductive Toxins	H340, H341, H360, H361, H362	Substances that may have adverse effects on various aspects of reproduction in both men and women.
Water Reactives	H260, H261, no GHS hazard code for toxic gas evolution	Water Reactives are materials that can react violently with water or atmospheric moisture to produce gas and heat. GHS codes identify materials of flammable gases, and materials that generate toxic gases are not always identifiable.
Chemical-Specific:		
Aqua Regia		The fuming liquid mixture of concentrated nitric and hydrochloric acids.
Hydrofluoric Acid (HF)		Hydrofluoric acid (HF, liquid or gas) greater than 0.05% HF.
Piranha Solution		The liquid mixture of concentrated sulfuric acid and 30% hydrogen peroxide.
Process/Equipment-Specific:		
Lasers (Class 3B, 4)		Lasers that pose a significant exposure hazard to the eyes (Class 3B) or both the eyes and skin (Class 4).
Unattended Operations*		Control measures for unattended operations must be detailed in the LSP, a SOP, etc.
Working Alone		Any work where a researcher is beyond visible or audible range of another individual for more than a few minutes.

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Table II: RECOMMENDED SOPs		
SOP type:	GHS Hazard Code(s):	Description:
Hazard Control Bands:		
Cryogens	H281	Liquefied or solid gases at extremely low temperatures.
Lachrymators	Some H318, H319	Substances that irritate the eyes and causes tears to flow. Not all chemicals with GHS hazard code H318 or H319 are lachrymators; see chemical-specific SDS. These chemicals may also be covered in other chemical control band SOPs.
Oxidizing Materials	H271, H272, H273	Substances that react chemically to oxidize other materials in a way that increases the chance of fire or explosion. Segregation and handling procedures may be contained in a SOP or in the LSP.
Sensitizers	H317, H334	Chemicals that cause a substantial portion of exposed individuals to develop an allergic reaction after repeated exposure.
Chemical-Specific:		
Phenol		Recommended based on the unique first aid procedures for a phenol exposure.
Sodium Azide		Can also be covered by implementing an Acutely Toxic Solids/Liquids SOPs and/or Potentially Explosive Compounds (depending on physical state and concentration).
Process/Equipment-Specific:		
Compressed Gases	H280	The laboratory-specific protocols related to compressed gases can be described in a SOP, or the information can be integrated into a LSP.
Acetylene Gas		The unstable, reactive nature of Acetylene necessitates unique safety controls.
Flammable Gases	H220, H221	All Flammable Gases present the risk of fire, especially when confined or improperly ventilated.
Field Research		Captures elements of remote communication, emergency provider information for the field location, transportation of personnel and hazardous materials.
Furnaces		For use of laboratory furnaces capable of generating temperatures above 500□C during operation.
High/Low Pressure Activities		Strongly dependent on a lab-specific definition of high and/or low pressure. Guidance may be captured in a SOP or integrated into the LSP.
Strong Magnetic Fields		Hazards specific to instrumentation that produce magnetic fields in excess of 600 gauss (60 mT) or the field maintains strength greater than 5 gauss over a distance of 6 inches.
Vivarium Hazardous Chemical Use		Includes elements such as hazardous chemical transport to/from the vivarium, chemical spill/exposure procedure in the vivarium, and chemical storage should be contained in such a SOP.

*SOP required starting October 1st, 2020. All other SOPs listed in the "required" section of Table 1 are required starting October 1st, 2019.

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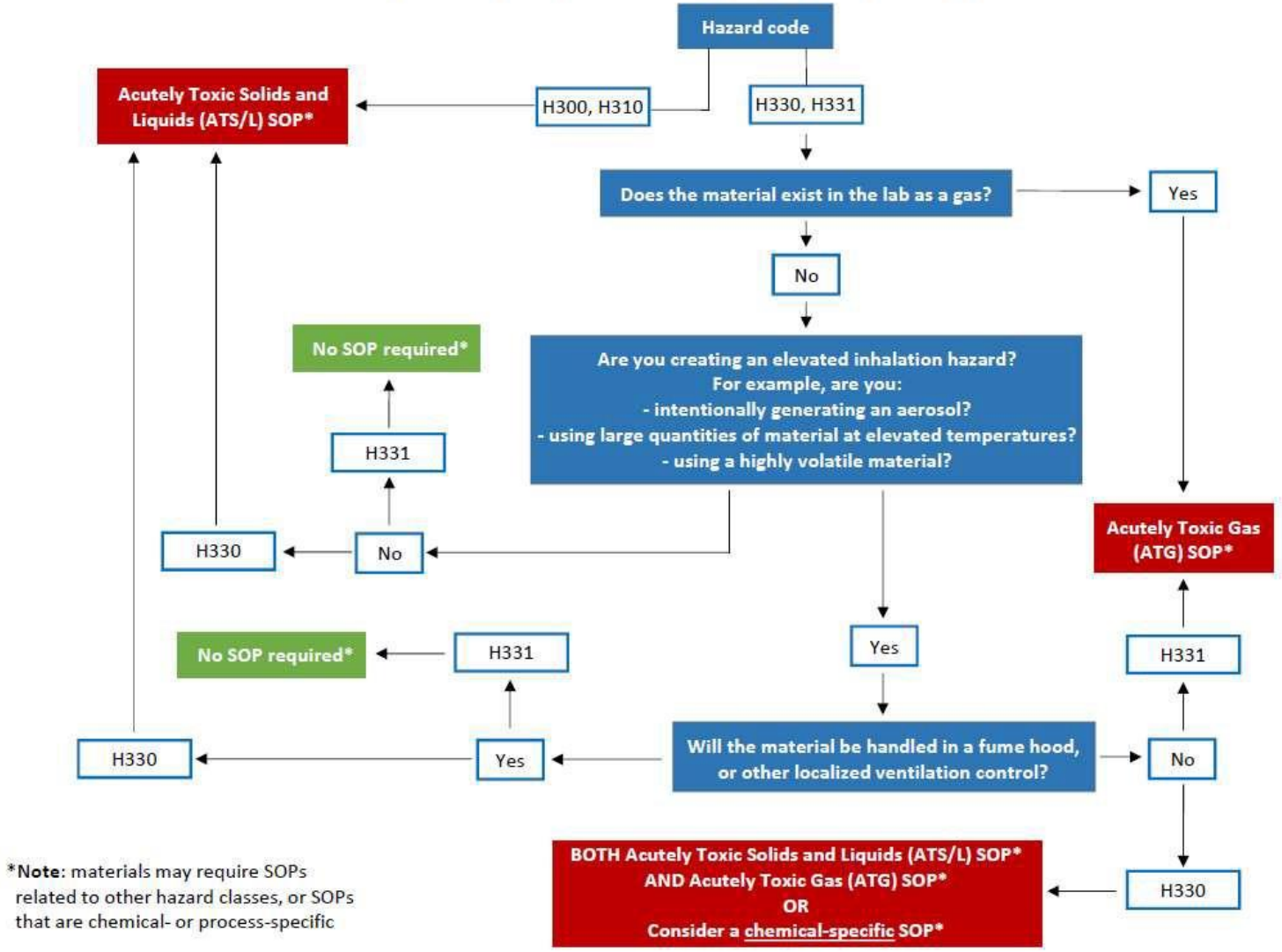
Appendix A

Acutely Toxic Solids, Liquids and Gases SOP Decision Tree



*Note: materials may require SOPs related to other hazard classes, or SOPs that are chemical- or process-specific

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Appendix B
Listed Carcinogens

Compound	CAS#	Weight/Volume Percent
2-Acetylaminofluorene	53-96-3	1.0
4-Aminodiphenyl	92-67-1	0.1
Benzidine	92-87-5	0.1
Benzidine Acetate	36341-27-2	0.1
Benzidine Dihydrochloride	531-85-1	0.1
Benzidine Hydrochloride	14414-68-7	0.1
Benzidine Sulfate	21136-70-9	0.1
Benzidine Sulfate	531-86-2	0.1
3,3'-Dichlorobenzidine	91-94-1	1.0
3,3'-Dichlorobenzidine Dihydrochloride	612-83-9	1.0
3,3'-Dichlorobenzidine Dihydrogen Bis(sulphate)	64969-34-2	1.0
3,3'-Dichlorobenzidine Hydrochloride	56532-21-9	1.0
3,3'-Dichlorobenzidine Sulfate	74332-73-3	1.0
4-Dimethylaminoazobenzene	60-11-7	1.0
α-Naphthylamine	134-32-7	1.0
β-Naphthylamine	91-59-8	0.1
4-Nitrobiphenyl	92-93-3	0.1
N-Nitrosodimethylamine	62-75-9	1.0
β-Propiolactone	57-57-8	1.0
bis-Chloromethyl Ether	542-88-1	0.1
Methyl Chloromethyl Ether	107-30-2	0.1
Ethyleneimine	151-56-4	1.0

Document Revision History

Version	Date Approved	Author	Revision Notes:
1.0	7/3/2018	Chris Jakober and Alexi Ball-Jones	CLSC approval and publication
1.1	7/10/2019	Karen Gagnon	Updated GHS codes for Acutely Toxic Solids/Liquids and Appendix A: Acutely Toxic Solids, Liquids, and Gases SOP Decision Tree. Updated expected completion date for Unattended Operations SOP. Added revision history.