**Administrative Information**

|  |  |  |  |
| --- | --- | --- | --- |
| School |  | Department |  |
| PI name |  | PI email |  |
| Lab manager name (if applicable) |  | Lab manager email (if applicable) |  |
| Locations covered by this SOP (buildings/rooms) |  | | |
| SOP version number |  | SOP approval date |  |
| Reviewed and approved by (name) |  | Reviewed and approved by (initials) |  |
| **Emergency contact name** |  | **Emergency contact phone\*** |  |
| Secondary emergency contact name |  | Secondary emergency contact phone\* |  |
| \* Provide emergency contact phone numbers that will be active both during normal work hours and after hours, e.g., personal mobile phone. Alternatively, give separate daytime and after-hours numbers for both contacts. | | | |

SOP Requirements

|  |  |
| --- | --- |
| **Instructions Document** | You are responsible for reading the [SOP Instructions](https://tiny.cc/usc-sop-instructions) outlining roles, responsibilities, and other important safety information. In addition, you must include that document as part of your records. |
| **Recordkeeping** | Acknowledgement forms for this SOP and any associated training are included at the end of this document. Additional copies of the forms are available online ([SOP Acknowledgement](https://tiny.cc/usc-sop-acknowledgement), [Internal Training Record](https://tiny.cc/usc-sop-training)). |
| **Customization** | It is intended that personnel add lab-specific information to the SOP template to produce a finished and functional SOP. Suggested places to add customization are highlighted in yellow throughout the document. Information which is not relevant to a specific lab/facility may be optionally deleted for clarity. |

|  |  |  |  |
| --- | --- | --- | --- |
| Standard (Safe) Operating Procedure: Simple Asphyxiants and Carbon Dioxide | | | |
| **Scope and Application** | | This SOP outlines the asphyxiation and CO2 toxicity hazards which may arise from a potential oxygen-deficient or high carbon dioxide atmosphere. Within USC research spaces, this risk most commonly arises from storage or use of cryogens, dry ice, high pressure carbon dioxide cylinders, or refrigerated liquid carbon dioxide. **To avoid confusion or duplication, this SOP does NOT cover (or only minimally covers) other hazards posed by these materials, including frostbite, over-pressurization, fire risk from liquid air condensation, etc. Therefore, it is essential for other hazards/risks to be adequately covered by additional lab-specific SOPs (e.g. based on the** [**Cryogens and Dry Ice SOP**](http://tiny.cc/usc-cryo-sop) **template).**  The SOP is complementary to the program document [*Simple Asphyxiants and Carbon Dioxide Program: Hazards, Risk Assessment, and Mitigation*](http://tiny.cc/usc-simasphyx-co2-program). All managers/supervisors of spaces deemed to be at risk of low-O2 or high-CO2 atmosphere are strongly recommended to familiarize themselves with the program document. | |
| **Scope: Confined Spaces and Clinical Areas** | | This SOP is NOT intended to cover spaces which fall within the scope of Cal-OSHA [*§5157. Permit-Required Confined Spaces*](https://www.dir.ca.gov/title8/5157.html). A “Confined Space” is a space which has all three of the following characteristics: 1) Large enough for an employee to enter and perform assigned work; and 2) Has limited or restricted means for entry or exit; and 3) Is not designed for continuous employee occupancy. A permit-required confined space is a confined space which has potential to contain one or more of several specified hazards, including an oxygen-deficient atmosphere. Normal laboratory rooms are not confined spaces as they have unrestricted entry/exit via doorways and they have the requisite infrastructure (ventilation, etc) to allow occupation by workers. However, some (uncommon) research equipment such as large storage tanks, reaction vessels, or inert atmosphere chambers may fall under confined space regulations if of a size which a human (or human torso or head) can enter. Entry to permit required confined spaces is subject to strict safety protocols laid out in the [USC Confined Space Entry Program Document](http://tiny.cc/usc-csep-manual); furthermore, EH&S Occupational Health maintains a registry of all USC permit-required confined spaces. Please email [injuryprevention@usc.edu](mailto:injuryprevention@usc.edu) for more information on this subject.  This SOP is not designed for use in clinical areas. | |
| **Introduction** | | This SOP provides basic information and education on safety roles and responsibilities, oxygen deficiency hazards and carbon dioxide toxicity, the general manner in which these hazards may arise in labs, and an overview of the various safety controls which can be used to manage the hazard. Following this is a section intended to be annotated with lab-specific information, safety rules, and work practices. Lastly, there is a section on emergency response, which should also be annotated with lab-specific emergency procedures.  It is intended that managers and users read the entire SOP as a coherent whole, as an integral part of their safety training. | |
| Program Document | | What follows here is a brief overview of the hazards posed by simple asphyxiants and carbon dioxide. The *Simple Asphyxiants and High CO2 Program Document* contains more detailed information, including tables correlating gas concentrations with physiological effects. It is recommended that all users of this SOP read the program document. | |
| Roles and Responsibilities | | Owners (generally a School or Department) of facilities which fall within the scope of this SOP shall ensure said facilities are adequately managed, and that the assigned managers are apprised of their safety oversight responsibilities. Most commonly the manager will be a PI or core facilities manager, but some areas with potential low-O2/high-CO2 hazards may be assigned to building managers, School/Department Safety Officers, or other staff, as deemed appropriate by the School, Department, or Institute. In no case shall an area with potential low-O2/high-CO2 hazard be left in limbo without an unambiguous safety management structure in place. Schools/Departments/Institutes retain ultimate responsibility for safety; therefore, they should exert high-level oversight of their managers and facilities to ensure satisfactory safety standards are maintained.  The manager of a space falling under the scope of this SOP is responsible for:   1. Customizing this SOP with lab/facility-specific information, or providing that information in additional SOPs (e.g. SOPs on equipment use, based on the manufacturer’s operating manual). 2. Approving SOPs. 3. Providing safety training to new users and refresher training to existing users    1. At a minimum, users of the space will need to be trained on the contents of this SOP, especially hazard awareness and emergency response.    2. If users will be conducting hazardous operations, they will require additional training, which may need to include a hands-on component.    3. Manager is responsible for assessing an individual’s competence in safe work practices before approving them as an authorized user or superuser. 4. Retaining internal training records, including but not limited to SOP and refresher training signed acknowledgement forms. 5. Monitoring safety behavior and correcting where needed by retraining or other suitable measures. 6. Ensuring needed safety equipment (hazardous atmosphere alarms, PPE, etc) is provided, used appropriately, and maintained in line with manufacture’s recommendations. 7. Keeping calibration and maintenance logs for alarms.   Managers (PI, facilities manager, etc) may delegate one or more of their day-to-day safety management tasks to suitably experienced individuals (e.g. professional lab manager, senior postdoc, etc); however, the manager retains ultimate responsibility for safety. To this end, the manager must ensure that safety tasks are only delegated to persons with suitable experience/knowledge/training, and the manager must thereafter actively manage and monitor delegates to ensure they fulfil their safety duties to the appropriate standard. | |
| Policies/Guidelines | | Please refer to the following authoritative policies and guidelines on safety roles and responsibilities at USC:  USC Managers Gateway: *Managing workplace health and safety* <https://managers.usc.edu/health/>  Policy: *Research Personnel Protection*, <https://policy.usc.edu/research-personnel-protection/>.  Policy: *Injury and Illness Prevention*, <https://policy.usc.edu/injury-and-illness-prevention/>. | |
| **Simple Asphyxiant Gases, Carbon Dioxide, Cryogens, and Dry Ice**  Low-O2/High-CO2 Hazards | | | |
| Simple Asphyxiants and CO2 | | Gases which have no toxic action but cannot support respiration, which is to say non-toxic gases excluding oxygen, are known as simple asphyxiants or just asphyxiants. Mixing any asphyxiant gas with air dilutes the overall oxygen concentration and may result in an oxygen deficiency hazard (ODH). The most common simple asphyxiants likely to be used in sufficient quantity to make ODH a potential concern are nitrogen and helium. Other examples of simple asphyxiant gases include nitrous oxide, argon, hydrogen, gaseous hydrocarbons (methane, ethane, etc), carbon tetrafluoride, sulfur hexafluoride, and refrigerant gases such as hydrofluorocarbons (HFCs).  Carbon dioxide has a definite toxic effect at high concentrations, making it a somewhat more potent hazard than simple asphyxiant gases. Toxic effects become serious at CO2 concentrations insufficient to produce oxygen deficiency; thus, for CO2 the health hazard is most accurately described as carbon dioxide toxicity rather than ODH.  However, at extremely high, rapidly fatal, carbon dioxide concentrations, oxygen deficiency occurs concurrently with the toxic effects. | |
| Oxygen Deficiency Hazard | | Normal atmosphere contains 21% oxygen by volume. Healthy adults should be able to tolerate oxygen concentrations down to 17% without perceptible physiological effects. Adverse physiological effects such as impaired coordination and judgment occur increasingly rapidly and seriously if the oxygen concentration falls further. Dangerous acute hypoxia occurs around 13% oxygen and unconsciousness and death are likely outcomes if the concentration drops an additional 2-3%.  Oxygen deficiency is an insidious hazard. Human bodies do NOT contain adequate systems for measuring oxygen levels in blood, rather, respiration is regulated via feedback mechanisms based on sensing of blood carbon dioxide concentration. In an oxygen deficient atmosphere, CO2 is breathed out as normal so there is zero sensation of suffocation or breathing difficulty. If the asphyxiant gas in the atmosphere has no taste or smell, which is the case for the commonest simple asphyxiants, an individual entering a dangerous atmosphere will not have any immediate indications that there is a hazard present.  The heart and especially the brain are the human organs most sensitive to oxygen deficiency. After entering a hazardously oxygen deficient atmosphere, an individual will experience increasing loss of mental faculties. This state impedes proper decision making and commonly prevents the affected individual from recognizing that anything is wrong. Unfortunately, there are numerous examples of oxygen deficiency incidents in the safety literature, often causing death or permanent injury, where the affected individuals were put into a dulled mental state by the first stages of oxygen deficiency, meaning they did not perceive the danger and/or were not able to make any effectual effort to escape.  Sudden unconsciousness may occur after one or two breaths on entering a severely oxygen deficient atmosphere. Brain damage and death will occur rapidly thereafter. It is not even necessary to fully enter an oxygen deficient atmosphere for this to happen. Death has occurred in industrial accidents when an individual has merely poked their head into an opening in a vessel filled with a severely oxygen deficient atmosphere. Unconsciousness can occur too quickly for the affected person to pull their head out in time, and if the opening is in a position where the head stays in when the person collapses, the individual will die without rapid rescue. (See [CSB Safety Bulletin No. 2003-10-B (June 2003)](https://www.csb.gov/file.aspx?DocumentId=5636) for more information and case studies.) | |
| Carbon Dioxide Toxicity | | Carbon dioxide is not a simple asphyxiant, although it is often mistaken for one. Although a normal component of the human body and completely non-toxic in low concentrations, breathing high enough concentrations in air will cause physiological distress, including respiratory stimulation, headache, dizziness, inability to concentrate, and unconsciousness.  These effects occur at CO2 concentrations in air which are substantial, but not high enough to cause dangerous oxygen deficiency. In extremely high concentration, such as might occur if dry ice (frozen carbon dioxide) is stored in an unventilated space such as a cold room, almost immediate unconsciousness and likely rapid death will occur as a result of combined oxygen deficiency and CO2 toxicity.  Disturbing physiological effects begin at around 30,000 ppm CO2 (3 vol. %). Severe symptoms including extremely accelerated breathing, headache, and dizziness occur at 75,000 ppm CO2 (7.5 %). 100,000 ppm (10 %) causes unconsciousness and potential fatality. Note that an atmosphere containing 7.5% CO2 still contains 18.9% O2, clearly demonstrating that CO2 toxicity arises well before oxygen deficiency. | |
| Regulations and Exposure Limits | | | |
| Oxygen Deficiency Regulations | | **In California, Cal-OSHA does not allow employers to expose employees to an atmosphere containing less than 19.5% oxygen unless the employees are protected by suitable respirators.** This is explicitly laid out in [8 CCR §5149](https://www.dir.ca.gov/title8/5149.html), “*Oxygen Deficiency*”, which states “*Except in extreme emergency involving imminent peril to life, employees shall not be permitted to work without approved respiratory equipment where the oxygen content of the air is less than 19 1/2 percent by volume (dry basis).*” This regulation applies universally across USC. **At USC, no person shall enter an oxygen deficient atmosphere with the exception of suitably trained and equipped first responders (i.e. USC Hazmat and LAFD).** As a corollary, upon activation of a local oxygen alarm (at the standard setpoint of 19.5% O2), it is MANDATORY for everyone in the room to stop work and evacuate the space. | |
| CO2 Exposure Limits | | [Cal-OSHA *Table AC-1*](https://www.dir.ca.gov/title8/5155table_ac1.html) defines two mandatory exposure limits for CO2. The 8-hour Permissible Exposure Limit (PEL) is 5000 ppm, this being the maximum time-weighted average concentration an individual may be exposed for the duration of an 8-hour working day. There is also a 15-minute time-weighted Short Term Exposure Limit (STEL) of 30,000 ppm, which shall not be exceeded during any 15-minute period.  A concentration of 40,000 ppm is considered to be Immediately Dangerous to Life or Health (IDLH) by [NIOSH](https://www.cdc.gov/niosh/idlh/124389.html). | |
| Hazard Classification, Safety Data Sheets (SDSs), Other Safety Information Sources | | | |
| **Hazard Classification** | | The Cal-OSHA GHS hazard classification of simple asphyxiants and cryogens is briefly covered in Section 6 of the [CHP](http://tiny.cc/chem-hygiene-plan) (pages 6.10-6.11 and 6.13 in the 2023 edition). More detailed information on the hazards of simple asphyxiants and carbon dioxide is provided in the document [*Simple Asphyxiants and Carbon Dioxide Program: Hazards, Risk Assessment, and Mitigation*](http://tiny.cc/usc-simasphyx-co2-program). It is recommended that users of this SOP peruse the program document.  **All personnel who agree to abide by this SOP are required to familiarize themselves with the contents of Section 6 of the CHP.** | |
| **SDS** | | Personnel shall be familiar with Safety Data Sheets (SDSs) for hazardous materials they will be using, including cryogens, compressed gases, and dry ice. Safety data sheets should be obtained from reputable sources; for example, major gas companies including Linde, Matheson, Praxair, and Air Products have good SDSs available online. For convenience, it is recommended the appropriate SDSs be appended to this SOP, or stored in the same electronic or physical location. | |
| Other Safety Info Sources | | Suppliers of carbon dioxide and simple asphyxiants, and of equipment which stores, handles, or uses these materials (e.g. pressurized cryogen cylinders, tubing, tube fittings, valves, regulators) often provide useful safety guidance documents, technical data sheets (TDSs), or authoritative operating manuals which detail safe working procedures. Documents of this type should be obtained and retained for new and existing equipment and installations.  Air Products has informative safety documents (“Safetygrams”) [online](https://www.airproducts.com/company/sustainability/safetygrams), covering a wide range of specific topics including handling of cryogenic liquids, specific cryogens (e.g. liquid nitrogen, liquid helium), liquid nitrogen freezers for cryo-preservation, various gases, oxygen deficiency hazards, and cryogenic liquid containers.  The Compressed Gas Association (CGA) provides safety information on dry ice, liquid nitrogen, simple asphyxiant gases, and a wide range of other gas-related safety topics; please refer to [this webpage](https://www.cganet.com/resources/safety-information/) for more information. | |
| ***Sources of Simple Asphyxiants and CO2: Cryogens, Gas Cylinders, Refrigerated Liquid CO2, and Dry Ice*** | | | |
| Cryogens | | Cryogens are substances of low boiling point, below −150 °C, −153 °C, or −180 °C (123 K, 120 K, or 93 K, respectively) depending on the definition chosen, and which are liquid (as opposed to gaseous) by virtue of the low temperature. In a laboratory setting, cryogenic liquids are commonly held in insulated containers and kept cold only by their heat of evaporation, which means they continually boil away at a rate proportional to the heat flux flowing into the container.  Liquid cryogen boiling points at atmospheric pressure are as follows: Helium 4.2 K; neon 27.1 K; nitrogen 77.3 K; air 79-82 K (boiling range, since it is a mixture); argon 87.3 K; oxygen 90.2 K.  Vacuum-insulated Dewar vessels are usually used for storage. Open-neck Dewars store liquid at atmospheric pressure; the opening is usually covered by a loose-fitting cap which excludes contaminants while allowing free escape of gas.  Pressurized Dewars (often called pressurized cryogen cylinders) are closed vessels fitted with a pressure-relief valve which controls the level of pressure maintained by liquid boil-off.  In some advanced cryogenic setups, active refrigeration may be used to prevent boil-off, or the boil-off gas may be re-liquefied by a mechanical system. (This is mostly encountered with liquid helium systems (e.g. attached to NMR or MRI superconducting magnets), due to the high cost of helium.) | |
| Cryogens vs. Gas Cylinders | | Full-size cylinders of “permanent” gases (i.e. gases which cannot be liquefied by pressure alone at room temperature) generally contain 200-300 cu. ft of gas (measured at atmospheric pressure). The most common simple asphyxiant permanent gases are nitrogen, argon, and helium.  Typical use of cylinders of simple asphyxiant gases in labs does not pose significant oxygen deficiency hazard/risk. However, please contact [labsafety@usc.edu](mailto:labsafety@usc.edu) for a risk assessment if simple asphyxiant gas cylinders are to be used under any of the following conditions:   * Large numbers of cylinders manifolded together * Poor ventilation or no ventilation of room * Extremely high flow of gas will be released * Siphon cylinders used to supply pipework or equipment with liquefied gas   Cryogenic liquids (nitrogen, helium, argon) generally have much greater potential to create oxygen deficiency hazards than gas cylinders, for the following reasons:   1. Large volumes of gas generated. One liter of cryogenic liquid produces approximately 25-30 cu. ft of gas on boiling, representing a volume increase of about 700-840 times.[[1]](#footnote-1) A 160 L pressurized liquid nitrogen container stores a colossal 3936 cu. ft of nitrogen gas. Compare this to a T-size nitrogen cylinder (the biggest size) which stores 304 cu. ft at a fill pressure of 2640 psig. 2. Continuous gas evolution. Cryogens evaporate into the atmosphere slowly but continuously during storage (“boil-off”), regardless of whether stored in open or pressurized containers. This is in marked contrast to gas cylinders, which do not continually vent to the atmosphere. 3. Rapidity and ease of gas evolution from cryogens. Cryogens boil rapidly during many common operations (e.g. refilling Dewars) or when spilled. Thus, large volumes of simple asphyxiant gas can be rapidly (and often silently) generated when handling cryogens. This is in marked contrast to gas cylinders, where even a loud hissing leak (e.g. from an improperly installed pipe fitting) represents only a moderate gas flow. To match the gas output of a few liters of spilled cryogen (a not improbable event), a gas cylinder or the attached regulator would have to undergo dramatic catastrophic failure (an extremely improbable event). | |
| CO2: Cylinders vs Dry Ice | | Cylinders of CO2 contain liquid, either at room temperature and high pressure in strong steel cylinders or refrigerated liquid at lower pressure in insulated cylinders. As such, carbon dioxide cylinders have a higher capacity than cylinders of “permanent gases” (gases which cannot be liquefied by pressure at room temperature, including He, Ar, and N2); a typical high-pressure cylinder (K size) contains 64 lb CO2, equivalent to 561 cu. ft of gas.[[2]](#footnote-2) Refrigerated liquid cylinders are much larger, often 300 lb or more of carbon dioxide.[[3]](#footnote-3)  Cylinders of refrigerated liquid carbon dioxide continually emit boil-off gas when not in use, similar to cryogens.[[4]](#footnote-4) Room temperature high pressure carbon dioxide cylinders are sealed and do not vent gas.  Dry ice is frozen carbon dioxide. At atmospheric pressure, it sublimes directly to gas at −78.5 °C (194.7 K).[[5]](#footnote-5) Although the temperature of dry ice is too high to fall under the cryogen definition, the hazards are broadly similar to cryogens.  Dry ice (frozen carbon dioxide) sublimes slowly on storage so must be stored in areas of adequate size and ventilation. On spillage, dry ice evaporates far more slowly than cryogenic liquids, and in general it is used in smaller quantities than liquid nitrogen. Thus, atmospheric hazards from dry ice are generally low provided it is not taken into unventilated spaces (e.g. basements, cold rooms), small closets, or other enclosed volumes such as passenger vehicles. One pound of dry ice sublimes to [8.76 cu. ft of gas](https://www.lindedirect.com/resources/gases/pure-gases/carbon-dioxide). | |
| CO2: High Pressure Cylinder Types | | High pressure carbon dioxide cylinders come in two varieties, which are NOT interchangeable; regular cylinders and *siphon cylinders* (also known as *dip-tube cylinders*). Regular cylinders dispense gas from the vapor space at the top of the cylinder. Siphon cylinders have the cylinder valve connected to an internal tube which takes liquid carbon dioxide from the bottom of the cylinder.  Using a siphon cylinder with equipment designed for gaseous carbon dioxide may present a serious safety hazard. Passage of liquid CO2 into regulators and piping designed for gas may cause over-pressurization due to rapid boiling of liquid. Conversely, using a regular cylinder in an application where a siphon cylinder is specified (e.g. freezer backup) is unlikely to be a safety hazard, but will probably result in the equipment not working properly (e.g. gas rather than liquid will be passed to freezer and there will be no effective cooling).  When ordering CO2 cylinders be sure to specify the correct cylinder type. When cylinders are delivered, double-check that the cylinder is the correct type before using. If labelling or markings are in doubt, contact the supplier for guidance. (Terminology (“siphon cylinder”, “cylinder with dip tube”, etc) and cylinder labeling/marking conventions may vary between vendors.)  All CO2 cylinders shall be used in the upright position. If not upright, a regular cylinder may unexpectedly dispense liquid and potentially cause a serious hazard, or a siphon cylinder may fail to dispense liquid and cause a malfunction. | |
| ***Potential for Low-O2/High-CO2 Hazards in Laboratories*** | | | |
| **Hazards** | | An oxygen deficiency / CO2 toxicity hazard may arise in one the following general ways:   1. By rapid release of a large quantity of asphyxiant gas into the air of a normally ventilated room of almost any size (e.g. typical medium or large size lab). Gas evolution on this scale should only be possible as a result of major failure, for example, a superconducting magnet quench, or failure of a pressurized cryogen cylinder. 2. By rapid release of a moderate or small quantity of asphyxiant gas into a room which is normally ventilated but small in volume. For example, the spillage of a few liters of liquid nitrogen from a handheld Dewar may result in a low-oxygen atmosphere in a small microscope room. 3. By slow or rapid release of asphyxiant gas into an unventilated room. Rooms which are normally unventilated are not suitable for activities or equipment which may discharge asphyxiant gases or carbon dioxide. Thus, cryogens, refrigerated carbon dioxide, or dry ice may not be stored in unventilated rooms as the boil-off/sublimation gas will build up. 4. By routine release of asphyxiant gas into a room which is normally ventilated, but which has become unventilated due to a prolonged HVAC failure or power outage. Routine gas release may occur as a result of continuous boil-off during storage of cryogenic liquids, refrigerated liquid CO2, or dry ice. Routine gas release may also occur as a result of routine work (e.g. refilling of liquid nitrogen freezers and Dewars), although as a general rule routine work shall not be conducted during HVAC failure.    * Although not exactly “routine”, gas release may also occur during power cuts (and thus HVAC outage) in rooms which contain freezers fitted with CO2 or liquid nitrogen backup cooling systems. 5. By stratification of a dense asphyxiant gas near the floor, in low-lying spaces such as floor wells, or in vessels with a top opening large enough for an individual to insert their head into. Note that gases which normally have a similar density to air, or which are slightly less dense (e.g. nitrogen) may stratify if significantly colder than the surrounding atmosphere. Thus, cold nitrogen gas evolved from boiling liquid nitrogen may stratify for a time before it gradually warms up and mixes with the surrounding air.    * Chests used to store dry ice are filled with cold carbon dioxide gas — DO NOT allow your head to enter when reaching for the last blocks of dry ice.   Please refer to the program document, section *Lab Safety and CO2/Simple Asphyxiants*, for further details on how oxygen deficiency/CO2 toxicity hazards may manifest in laboratories.  Other hazards, including liquefaction of air, frostbite, and over-pressurization of vessels due to cryogen/CO2 evaporation, are covered in the *Cryogens and Dry Ice* SOP, available on the [EH&S website](http://tiny.cc/usc-cryo-sop). | |
| Risk Banding and SOP and Other Safety Requirements | | | |
| EH&S is responsible for risk-banding spaces with potential for low-O2 or high-CO2 atmospheres, in accordance with the guidelines laid down in *Simple Asphyxiants and Carbon Dioxide Program: Hazards, Risk Assessment, and Mitigation* (especially Tables 6 and 7). Table 1, below, summarizes some of the essential information and how it relates it to SOP requirements: | | | |
| **Hazard Band** | **Meaning** | | **SOP and Other Requirements** |
| A | Worst case incidents cannot produce hazardous atmosphere | | No specific requirements for low-O2 SOP. Other SOPs as needed to cover hazards present (e.g. cryogens), and to cover appropriate safe work practices, equipment operating instructions, etc. |
| B | Only incident which can produce a hazardous atmosphere is sudden total failure of cryogen containment or superconducting magnet quench, with a fatality rate according to the model of 10-7 per hour or less. | | No specific requirements for low-O2 SOP. Other SOPs as needed to cover hazards present (e.g. cryogens), and to cover appropriate safe work practices, equipment operating instructions, etc.  No low-O2 hazard mitigation required (i.e. no alarm needed, etc). |
| C | Spaces shall be assigned this risk category if one or more of the following is true:   * Routine operation is calculated to approach (but not become less than) 19.5% oxygen (when the hazard is a simple asphyxiant) * Quantity of stored cryogen is sufficiently large that continuous boil-off significantly reduces the equilibrium oxygen concentration * Hazardous atmosphere may result from one of a number of foreseeable incidents (refer to program document for details). | | Low O2 hazard requires alarm,\* signage, training of users on hazard awareness and emergency response, and low-O2 SOP. Other SOPs as needed to cover hazards present (e.g. cryogens), and to cover appropriate safe work practices, equipment operating instructions, etc.  Facility owner to maintain and calibrate alarms in accordance with manufacture’s recommendations. Maintenance/calibration logs to be kept. |
| C2 | Spaces which receive piped liquid nitrogen from large external storage tanks, e.g. automatically-refilled liquid nitrogen freezer farms. | | All requirements as for band C. In addition, engineering safety controls such as automatic shut-off valves and emergency ventilation systems may be required for large installations. Installations should be designed and commissioned by specialist engineers. |
| D | Routine operations have significant potential to create hazardous atmosphere. | | It is not generally acceptable for a routine operation to have significant potential to generate a hazardous atmosphere. Thus, band D spaces have all of the requirements of band C, plus a requirement to make changes to take the space out of class D. Changes may include:   * Reduction of cryogen inventory * New work practices (documented in an SOP)†   Facility redesign‡ |
| \* In a small number of cases, if the facility would fall into band A or B but for one rare operation (e.g. filling a liquid nitrogen freezer from empty, as opposed to filling weekly), EH&S may allow (on a case-by-case basis) for no alarm to be present, provided that a safe work practice (documented in an SOP) be instituted for the rare operation. For example, requiring that the unusual filling-from-empty of a liquid nitrogen freezer be conducted extra-slowly with doors open and a portable oxygen sensor on hand.  † Example of workaround / new work practice: A facility falls into category D due to the “rare routine” operation of filling a liquid nitrogen freezer from empty, but recalculation based on the usual procedure of filling the freezer weekly results in a hazard band of C. An SOP is instituted for the rare operation of filling from empty, which may include such work practices as extra-slow filling. Signage forbidding filling from empty without appropriate precautions and permission from the facility manager would also be required, and should be specified in the SOP.  ‡ Examples of redesign: a) Removing the door from a very small room containing a liquid nitrogen filling station, or replacing it with a fully-louvred door. b) Higher-capacity ventilation system. | | | |
| Quantitative risk banding is not as straightforward when the risk is from carbon dioxide; therefore, EH&S will semi-quantitatively risk-assess on a case-by-case basis. The following is an extremely general guide:   * Presumed to not pose a risk of high-CO2 atmosphere:   + CO2 gas piped into normally-ventilated room (unless exceptionally small)   + Individual high-pressure CO2 cylinders (gas discharge, as opposed to siphon cylinders)   + Dry ice (frozen carbon dioxide) stored or used in normally-ventilated room (unless room is exceptionally small) * May pose a risk of high-CO2 atmosphere:   + Multiple high-pressure CO2 cylinders manifolded together   + Refrigerated liquefied CO2 cylinders   + CO2 freezer backup systems   + Systems which conduct liquified CO2 through pipework   + CO2 storage (especially dry ice or refrigerated liquefied CO2) or discharge of CO2 gas in rooms which are exceptionally small and/or poorly- or non-ventilated. | | | |
| Low-O2/High-CO2 Risk Mitigation and Safety Controls  **General Information** | | | |
| Equipment Specifications | | When designing or building systems to handle gases, consult manufacturer’s technical data sheets and manuals to ensure that tubing, pipe fittings, valves, and all other equipment has appropriate pressure ratings, that items of equipment are compatible with each other and with the gas, and that all the equipment, valves, and tubing are being used within the bounds of their technical specifications and in accordance with manufacturer’s installation and operating instructions. If in any doubt, or if high-pressures are to be used, seek expert advice from the equipment vendor, certified engineer, or qualified pipefitter. **Ultimately, the PI is responsible for the safety of lab-built equipment.**  Pipework to handle cryogenic liquids requires strategically-placed pressure relief valves in each section which can be isolated via valves, otherwise liquid trapped in isolated sections will cause the pipes or vessels to explode from over-pressurization as the cryogen evaporates. For this and other reasons, all systems in which cryogens are conducted through pipework (as opposed to being handled in open vessels) shall be designed and constructed to recognized industry (e.g. CGA) standards under the supervision of a suitably experienced individual (preferably a qualified engineer). | |
| Tubing and Fittings | | Do NOT use mismatched tubing and fittings. In particular, a common mistake is to inappropriately use compression fittings designed for metal pipes (e.g. Swagelok™ fittings) with unsupported soft plastic tubing (e.g. Tygon™). When a metal olive is crimped onto the exterior of a soft plastic pipe with no internal support, the pipe merely contacts in diameter with no significant restoring force to ensure a tight seal. Furthermore, polyethylene, PVC, PTFE, and numerous other polymers are liable to either cold-flow or take a permanent set when deformed, meaning the already-unreliable seal will become worse over time. This is not a theoretical hazard; inappropriate tubing and fittings has caused gas leaks in labs.  Without specifically endorsing Swagelok™ fittings, they are a common brand in USC labs; therefore, more information on their use with rigid and flexible tubing is provided in Appendix 1. Furthermore, Appendix 1 provides information on flexible tubing assemblies and special fitting for PFA tubing also manufactured by the Swagelok Company.  With regards to threaded joints for handling gases under pressure, ensure that threads are compatible (e.g. do not intermix ISO tapered threads with NPT threads). It is incumbent upon users to understand the correct application of tapered threads versus parallel threads, and the appropriate use of sealing tapes, sealing compounds, gaskets, O-rings, etc. Consult manufacturer’s technical information and manuals, online resources (e.g. <https://georgia.swagelok.com/en/Blog/Basic-Pipe-Threads-Explained-11-19>), or an expert (e.g. qualified pipefitter) for guidance. | |
| Low-O2/High-CO2 Alarms | | Low-oxygen or high-CO2 alarms may be recommended or required in simple asphyxiant or carbon dioxide storage and use areas, depending on quantity of asphyxiant/CO2, room volume, local ventilation, and other considerations. If an alarm is needed, it must be accompanied by appropriate signage inside and outside the room. Alarm recommendations/requirements may be determined by EH&S as part of a risk assessment, or may be determined by a qualified consultant (e.g. lab design engineer), though in the latter case the decision shall still be approved by EH&S before being put into effect. Alarms must meet EH&S and regulatory requirements. Please refer to the Simple Asphyxiants and High CO2 Program Document for further details including set points, horn strobe requirements, and appropriate sensor positioning.  The owner of an alarmed space is responsible for maintenance (e.g. sensor replacement), calibration (not less than annually), and testing in accordance with the manufacture’s operating instructions. The owner is also responsible for keeping a written logbook, which should cover maintenance, calibration, testing, and alarm activations. The log shall be available for inspection by EH&S and Fire Safety.  Please refer to Program Document for information on appropriate alarm setpoints for oxygen and carbon dioxide alarms. In the case of low-O2 alarms, in all instances there should be 19.5% oxygen setpoint to trigger a local alarm to clear the room, because this is the oxygen concentration below which Cal/OSHA regards the atmosphere as hazardous. Depending on the facility, an additional lower setpoint triggering a floor-wide or building-wide evacuation may also be required. | |
| HVAC Failure or Power Cut | | In general, laboratory buildings should be evacuated during HVAC (i.e. ventilation) failure or power cut and not re-entered until a reasonable period (e.g. one hour) has elapsed after HVAC/power is restored. This is for several reasons, not least that failure of HVAC or power will render fume hoods inoperative, giving potential for a harmful atmosphere to develop.  In the specific case of areas where cryogens, dry ice, or liquid carbon dioxide are stored or used, or areas where a significant flow of CO2 or simple asphyxiant gas is discharged into a room, fume hood, or snorkel, it is particularly important for no person to be present during HVAC failure or power cut, or for a reasonable time period after HVAC reactivation. Gas evolved by continual cryogen boil-off or dry ice sublimation may generate a hazardous atmosphere in the absence of normal ventilation (this is one of the scenarios considered during EH&S risk assessment). | |
| Freezer Backup | | Freezers using CO2 or liquid nitrogen backup may discharge large quantities of gas to the atmosphere during an extended power cut and concomitant HVAC shutdown. Rooms containing freezers with CO2 or liquid nitrogen backup systems should be clearly signed to reflect this hazard, and that the area is off-limits during power outages, and should not be re-entered until cleared as safe by EH&S. | |
| Transportation | | Personnel shall follow the directions given in the [Cryogens and Dry Ice Fact Sheet](https://tiny.cc/usc-ehs-cryo-fs). Due to the hazards posed by spillage and by boil-off gas, **cryogens, dry ice, and refrigerated liquid carbon dioxide cylinders shall NOT be transported within any enclosed space in a vehicle (e.g. passenger compartment or trunk), or in elevators with occupants.** | |
| Labeling | | Cylinders and Dewars of gases and cryogens, and dry ice storage chests shall be labelled with the contents. Additionally, storage locations and/or individual containers should be labelled with the name of the owner if different from the party responsible for the room, or if the room is a shared space.  Cal/OSHA ([*§3321. Identification of Piping.*](https://www.dir.ca.gov/Title8/3321.html)) requires that pipework used to convey hazardous materials, including gases, “*...be identified at points where confusion would introduce hazards to employees.*” Thus, labelling should be placed at any points where there is potential for ambiguity, especially at valves, inlet points, outlet points, at intervals along long pipe runs, and wherever multiple pipes run together.  Color-coding of pipework and valves is permissible provided a color code is “.*..posted at those locations where confusion would introduce hazards to employees.*” Lettering or tags on the pipes and valves are also acceptable. Legibility of labels shall be maintained.  It is recommended pipework be marked in accordance with [ANSI/ASME A13.1](https://www.asme.org/codes-standards/find-codes-standards/a13-1-scheme-identification-piping-systems), which requires markings incorporating a flow-direction marker every 25-50 ft along straight runs, on both sides of any bend, on both sides of any wall or floor penetration, and next to all flanges and valves (please see this [guide](https://www.creativesafetysupply.com/content/public/Guide-Pipe_Marking.pdf) for more information). ANSI-standard pipe markers incorporate lettering, a flow arrow, and use a standard color code; they are widely available from industrial suppliers including [Grainger](https://www.grainger.com/category/safety/signs-facility-identification-products/pipe-valve-conduit-wire-markers-labels/pipe-markers-labels), [McMaster-Carr](https://www.mcmaster.com/pipe-markers/), [Uline](https://www.uline.com/BL_2921/Pipe-Markers), and specialist safety suppliers, e.g. [here](https://www.creativesafetysupply.com/pipe-marking-supplies/).  Note: ANSI/ASME A13.1 does NOT apply to medical gases in clinics; instead, [CGA C-9](https://portal.cganet.com/Publication/Details.aspx?id=C-9) and [NFPA 99](https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=99) both apply. | |
| Signage | | Areas where there is potential for development of a hazardous low-O2/high-CO2 atmosphere shall be appropriately signed to specify: (1) the nature of the hazard; (2) the presence of an alarm and actions to be taken if alarm is sounding; (3) any special safety requirements for room entry (e.g., only authorized individuals trained on the SOP may enter); (4) any conditions under which room entry is prohibited (e.g., do not enter if the ventilation has failed). Signage should be compliant with [8 CCR §3340](https://www.dir.ca.gov/title8/3340.html), displayed both inside the room and outside all entrances, and approved by EH&S. Please refer to the Program Document for more information.  Other required signage includes a lab door sign (i.e., door sign/placard from EHSA or RSS) containing contact information for the responsible party for the room/space placed on the exterior door before people enter the room. | |
| Unattended Experiments | | Unattended hazardous experiments should be signed according to the requirements of the [Unattended Experiments Fact Sheet](https://tiny.cc/usc-unattended-operations). | |
| Personal Protective Equipment | | There is NO PPE available to the general USC community which will protect against the hazards of a low-oxygen or high-CO2 atmosphere.[[6]](#footnote-6) Personnel SHALL NOT enter or remain in an atmosphere of this nature; rather, a space shall be immediately evacuated if a low oxygen or high carbon dioxide alarm sounds, or if an incident occurs which may pose a low-O2/high-CO2 hazard (e.g. superconducting magnet quench, cryogen spill, HVAC failure, etc).  Please refer to the Cryogens and Dry Ice SOP for details of PPE suitable for the frostbite, over-pressurization, and other hazards these materials possess.  Compressed gases pose projectile hazards to eyes; therefore, at a minimum, safety glasses shall be worn when working with compressed gases.  Hearing protection shall be worn if potential venting of high-pressure gas might produce sound of a harmful volume. Please see [Hearing Conservation and Noise Control Fact Sheet](http://tiny.cc/usc-ehs-hearcnsrv-fs) for more information. Please contact [injuryprevention@usc.edu](mailto:injuryprevention@usc.edu) if a quantitative noise survey may be needed. | |
| Laboratory/Facility-Specific Information, Work Practices, and Safety Rules  Instructions | | | |
| This section should be amended as appropriate to adequately cover the safety requirements of the specific laboratory or facility to which this SOP applies. Subsections which do not apply to the specific facility may be deleted. | | | |
| **Laboratory/Facility-Specific Risk Assessment** | | [If provided by EH&S, facility-specific risk assessment information should be entered here or attached to the SOP as a supporting document and referenced here.] | |
| Specific Substances | | [Add details of specific substances you will be using in the lab under this SOP.] | |
| Documentation | | [It is recommended the appropriate manufacturer’s safety documentation (e.g. Air Products “Safetygrams”), SOPs, operating manuals (or excepts therefrom), and technical data sheets (TDSs) be appended to this SOP, or to the cryogens SOP, or be incorporated into a dedicated lab-specific or equipment-specific SOP, as appropriate for the hazards and risks. This is especially important for higher-hazard equipment, or when higher-hazard operations are to be conducted, e.g. filling of pressurized cryogen cylinders. It is also especially important for equipment which has requirements for periodic preventative maintenance, inspection, or calibration, such as hazardous atmosphere alarms, and some pressurized cryogen cylinders.  If safety information is included in additional documents (SOPs, etc), they should be listed here. All supplementary documents should be stored in the same physical and/or electronic locations as this SOP. All electronic copies should be manually backed-up unless stored in a location with adequate automated backup and protection from accidental deletion by users.] | |
| Logbooks | | Use of logbooks is recommended for both documenting equipment use/maintenance, and to act as a safety reminder/checklist for users. For an example of the latter, see below under “safety-critical supplies”.] | |
| Safety-Critical Supplies | | [Use this section to specify any specific supplies which are required for safe operation, for example, whether high-pressure carbon dioxide cylinders should be siphon cylinders or regular cylinders. Other things which may be important to specify could include gas purity, cylinder size, and cylinder pressure (the latter is particularly important for pressurized cryogen cylinders, as there is a huge difference between a low-pressure cryogen cylinder (typically 22 psig setpoint; suitable for filling of open-neck Dewars) and a high-pressure cryogen cylinder (typically 230 psig, though 350 and 500 psig are also available)).  If it is safety-critical for the appropriate supplies to be used, this section should additionally specify a procedure for ensuring that supplies are positively identified as correct before use.  For example, a suitable defined work practice might be to have the user complete a logbook each time a cylinder is changed out, with columns in the book to record that identity of substance, cylinder type, and cylinder pressure have all been identified as correct before connecting the cylinder to the equipment, plus columns for initials (or signature) and date/time.  Logbooks can also be useful for troubleshooting, by helping identify periods of unusually high gas use.] | |
| Operating instructions | | [Use this section to specify step-by-step safe operating instructions for equipment, with photographs or diagrams where needed. Alternatively, list out the various equipment and procedures and provide references to the appropriate documents or section of documents where the safe operating procedures are specified. All supplementary documents should be stored in the same physical and/or electronic locations as this SOP.  If reference is made to manufacturer’s operating manuals, this section should additionally be used to specify any lab/equipment/procedure-specific safety practices which need to be followed in addition to the manufacturer’s instructions.] | |
| Safety rules | | [Please specify any lab-specific safety rules not adequately covered elsewhere, e.g., restrictions on working alone.] | |
| PPE | | [Please specify any lab-specific PPE rules or requirements here. (Equipment/procedure-specific PPE requirements may be listed here or covered as part of appropriate work practices, whichever is clearest for the users.)] | |
| Alarm | | [As previously stated, the owner of an alarmed space is responsible for maintenance (e.g. sensor replacement), calibration (not less than annually), and testing in accordance with the manufacture’s operating instructions. The owner is also responsible for keeping a written logbook, which should cover maintenance, calibration, testing, and alarm activations. Use this section to specify (and to reference documents (e.g. alarm SOP) which specify) alarm-related work procedures. Also use this section to specify alarm type, maintenance requirements, sensor locations, etc, or provide references to other documentation. Alarm setpoints should also be specified in this section. Whether or not alarm systems run on uninterruptible power supplies should be specified, as should any maintenance or testing requirement associated with said power supply.] | |
| Other | | [Please consider adding any other relevant safety information here.] | |
| Emergency Response (General and Lab-Specific) | | | |
| Customization | | This SOP template as-provided provides only generic emergency response information. Where appropriate, this section should be amended to include lab-specific emergency procedures.  Suggested places to include this information are highlighted in yellow. | |
| Cryogen Spill Response | | A small cryogen liquid spill (e.g. one liter of liquid nitrogen in a large room) should simply be allowed to evaporate. If the liquid pools in one place it may freeze the floor and damage it — move the liquid around with a brush if this appears to be happening.  If more is spilled, if the room is very small or badly ventilated, or if in doubt evacuate the room and call DPS.  Spilled dry ice should be picked up with dustpan and brush, DO NOT pick up with hands. Place it in a fume hood or well-ventilated area and leave to evaporate.  **A large cryogen spill (e.g. a burst Dewar, NMR magnet quench, or pressurized Dewar with the outlet valve frozen open) may rapidly create a harmful or fatal low oxygen atmosphere. A small spill in a confined area may do the same. IMMEDIATE evacuation of the affected area is critical. Close all doors behind you. If any personnel become unconscious DO NOT attempt rescue as you will likely become another victim.** Remember, oxygen deficiency is not clearly sensed by humans and may cause loss of consciousness suddenly with no prior symptoms or warning. Call DPS and state the nature of the emergency. If necessary, first responders will be dispatched with oxygen monitors and self-contained breathing equipment.  [Please enter any lab-specific cryogen spill / magnet quench emergency response instructions here.] | |
| Low-O2/High-CO2 Alarm | | **If a low oxygen or high carbon dioxide alarm sounds, IMMEDIATELY evacuate the area and close all doors behind you. If any personnel become unconscious DO NOT attempt rescue as you will likely become another victim.** Remember, oxygen deficiency is not clearly sensed by humans and may cause loss of consciousness suddenly with no prior symptoms or warning. Call DPS stating the nature of the emergency. If necessary, first responders will be dispatched with oxygen/CO2 monitors and self-contained breathing equipment.  **If you are outside a room in which a low-O2/high-CO2 alarm is sounding, do NOT open the door and DO NOT ENTER, even if you think there may be a casualty in the room.** Call DPS.  The manager/PI with responsibility for the space should be notified of any alarm activation (please refer to lab door sign for name and contact details of responsible party). Alarm activations should be entered into the alarm log book, including the identified reasons for the activation.  [Add lab-specific alarm response protocols here.  For many facilities, particularly those with small-volume rooms in which cryogens are used, an appropriate response to local alarm activation in the absence of a catastrophic cryogen leak may be to vacate the room until the atmosphere returns to normal and the alarm resets itself and stops sounding. For larger-scale facilities such as liquid nitrogen freezer farms, the volume of gas needed to activate the alarm may be sufficient to create a widespread hazard; therefore, evacuation of the floor may be warranted. Some facilities may have the oxygen/CO2 alarm linked to the building alarm, in which case there may differing setpoints for local alarm to clear the room versus alarming the entire floor or building. For these higher-hazard facilities, there should be a separate response SOP agreed between the stakeholders (facility owner, EH&S Hazmat, DPS, FPM, etc), which should also include full alarm information, including how it interacts with the building alarm. Any separate response SOP should be referenced here.] | |
| Freezer Backup Activation | | Freezers using CO2 or liquid nitrogen backup may discharge large quantities of gas to the atmosphere during an extended power cut and concomitant HVAC shutdown. Adequate signage, training of occupants, and other safety controls (including alarms) is required to ensure room is evacuated during power shut down and for an adequate time after power and HVAC are positively known to be restored.  [Lab-specific emergency procedures for these spaces should be approved by EH&S and should be specified here.] | |
| General Emergency Response | | **Before starting work, review the** [**EH&S emergency webpage**](https://tiny.cc/usc-injury) **and the** [**1-2-3 poster**](https://tiny.cc/usc-123)**. Ensure that the 1-2-3 poster is posted in the lab.** **All personnel operating under this SOP shall familiarize themselves with these documents and webpage.**  **All personnel operating under this SOP shall have downloaded and read Section 10 of the** [**CHP**](http://tiny.cc/chem-hygiene-plan) (“*Emergency Response / Injury and Illness Reporting*”). This section provides information on chemical exposure response, spill response, and injury reporting.  **The 1-2-3 poster, CHP Section 10, and the EH&S emergency webpage are hereby incorporated into this SOP by reference.**  **All personnel operating under this SOP shall have the DPS emergency number programed into their phone** (UPC 213-740-4321; HSC 323-442-1000).  **Phone the DPS emergency line in an emergency!!** DPS have 24 h/day immediate communication access to primary and backup personnel on the EH&S and Hazmat on-call rota. **Do NOT call the EH&S general phone line or individual EH&S personnel in an emergency as access is not guaranteed.** | |
| Appendix 1. Tube and Fittings | | | |
| Without wishing to specifically endorse Swagelok™ fittings, they are a common brand in USC labs and therefore more information on their use is provided here. This information is for general awareness only and up-to-date technical data sheets and usage instructions provided by the manufacturer should always be consulted before using pipe fittings.  Swagelok™ fittings are an excellent design when used properly, and have high working pressures, but only when used with the specific metal tubing they are designed for. In the absence of the appropriate tubing insert, Swagelok fittings are NOT appropriate for use with non-metallic tubing, and even with the tubing insert, operating pressures are low (see Image A1.1, below). Information on appropriate types of metal tubing to use with these fittings is to be found in this [tubing data sheet](https://www.swagelok.com/downloads/webcatalogs/en/ms-01-107.pdf).  Please refer to the documents on the [Swagelok Tube Fitters Manual](https://www.swagelok.com/en/Supplemental/Tube-Fitting-Manual-Digital-Supplement) web page for more information.  Image A1.1. Two appropriate methods of terminating soft PVC tubing according to Swagelok™ (from p81 in [this online catalogue](https://www.swagelok.com/downloads/webcatalogs/en/ms-01-180.pdf)). However, working pressures are LOW (40 psi for 1/8” ID / 1/4” OD tubing down to only 10 psi for1/2” ID / 5/8” OD tubing). (The barbed connectors to use with hose clamps and the tubing inserts to use with Swagelok fittings are shown a few pages later in the same catalogue.)  In the absence of the appropriate tubing insert, Swagelok fittings are NOT appropriate for use with non-metallic tubing.  Image A1.2. Typical method of professionally terminating polymer tubes, where the termination has an inner metal tube, and an outer metal cover which is crimped down to trap the polymer tube in the annulus (picture from p 96 in in [this online catalogue](https://www.swagelok.com/downloads/webcatalogs/en/ms-01-180.pdf)). Professionally-terminated flexible tubing assemblies with high safe working pressures are available, particularly for tubing reinforced with wire or high-strength cords. Assemblies can be purchased in standard or custom sizes; please contact vendors for details.  Image A1.3. Swagelok makes special fittings for flexible PFA (perfluoroalkoxyalkane) polymer tubing; see [this catalogue](https://www.swagelok.com/downloads/webcatalogs/en/ms-01-05.pdf) (image copied from p4). When these fitting are used with Swagelok PFA tubing, operating pressures are substantial, e.g. at 37°C, the 1/4” thicker-wall tubing has a working pressure of 245 psi and the ½” tubing has a working pressure of 115 psi.  Regular Swagelok™ fittings are NOT suitable for use with PFA tubing.    Image A1.4. Flexible “convoluted” metal tubing more suited to low-temperature applications than polymer tubing. (Image taken from p37 of the [Swagelok Hose and Flexible Tubing catalogue](https://www.swagelok.com/downloads/webcatalogs/en/ms-01-180.pdf).) | | | |

SOP Acknowledgement

The undersigned acknowledge by their signature that they:

1. Have read, understood, have access to, and agree to abide by this SOP, AND;
2. Have read and understood the emergency response resources incorporated into this SOP by reference (“[**1-2-3 poster**](https://tiny.cc/usc-123)”, [**CHP Chapters 6 and 10**](http://tiny.cc/chem-hygiene-plan), and [**EH&S emergency webpage**](https://tiny.cc/usc-injury)), AND;
3. Will download, store, read, and thoroughly familiarize themselves with safety data sheets (SDSs) for all the hazardous materials they intend to use within the scope of this SOP.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **USC ID** | **Email** | **Signature** | **Date** |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

Internal Training Record

If hazards are high or complex, or personnel have limited prior experience or training, then hands-on training should be provided on the contents of this SOP. For convenience, the training may be documented using this form, although PIs are free to keep internal training records in other formats if desired. Training may be conducted by the PI, or the PI may delegate a suitably experienced and knowledgeable lab member (e.g. lab manager or senior postdoc) as the trainer. If delegated, the PI still retains management responsibility for the quality and adequacy of the safety training.

|  |  |  |  |
| --- | --- | --- | --- |
| Trainer name |  | Trainer position |  |
| Trainer USC ID |  | Trainer email |  |
| Trainee #1 name |  | Trainee #1 USC ID |  |
| Trainee #1 email |  | Trainee #1 signature |  |
| Trainee #2 name |  | Trainee #2 USC ID |  |
| Trainee #2 email |  | Trainee #2 signature |  |
| Trainee #3 name |  | Trainee #3 USC ID |  |
| Trainee #3 email |  | Trainee #3 signature |  |
| Trainee #4 name\* |  | Trainee #4 signature |  |
| Trainee #4 email |  | Trainee #4 USC ID |  |
| Date training started |  | Date training completed |  |
| Type of training (delete as appropriate) | **Initial training**  **Refresher training** | Type of training (delete as appropriate) | **Classroom training**  **Hands-on laboratory training** |
| If refresher training, provide date of initial training |  | If refresher training, was the initial training hands-on in the lab? | **YES 🞏 NO 🞏** |
| Signature of trainer confirming the above named trainees have successfully completed safety training on the contents of this SOP (and any additional subjects listed below) | |  | |
| Date of signing by trainer | |  | |
| Additional subjects covered by safety training |  | | |
| \* If there are more than four trainees, please append an additional sign-in sheet. | | | |

1. One liter of cryogenic liquid (or solid for dry ice) will produce the following approximate number of liters of gas on warming to room temperature at ambient pressure: Helium 700; neon 1300; nitrogen 700; argon 800; carbon dioxide 750; oxygen 800. One cubic foot is approximately equal to 28.3 L. [↑](#footnote-ref-1)
2. Carbon dioxide cylinder pressure at 21°C is 838 psig (<https://www.lindedirect.com/resources/gases/pure-gases/carbon-dioxide>). [↑](#footnote-ref-2)
3. Typical carbon dioxide refrigerated liquid cylinders operate at 350 psig and come in the following sizes: 170L / 384 lb; 200 L / 426 lb; 275 L / 503 lb (<https://www.lindedirect.com/resources/gases/pure-gases/carbon-dioxide>). [↑](#footnote-ref-3)
4. The liquid carbon dioxide boils away at a rate proportional to the heat flux entering the cylinder. It is the boiling of liquid and consequent venting of gas which provides the cooling effect which keeps the contents cold. [↑](#footnote-ref-4)
5. Liquid carbon dioxide can exist only above the triple-point pressure of 5.19 bar and triple point temperature of 216.6 K (−56.6 °C) (<https://webbook.nist.gov/cgi/inchi?ID=C124389&Mask=4>). [↑](#footnote-ref-5)
6. Self-contained breathing apparatus will protect against atmospheres of this type, but at USC, such equipment shall only be used by specially trained, approved, medically-cleared emergency response teams (e.g. Hazmat, LAFD). [↑](#footnote-ref-6)