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ACCIDENT PREVENTION AND RESPONSE FOR CRYOGENIC CHEMICALS

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This document describes the principal hazards and appropriate safety procedures associated with three cryogenic liquids commonly used in the poultry and egg industry: liquid nitrogen (N_2), carbon dioxide (CO_2), and liquid oxygen (O_2). The safe handling of cryogenic liquids involves understanding the unique properties of these materials and ensuring that appropriate safety precautions are taken at all times.

Disclaimer

This pamphlet was produced by the U.S. Poultry & Egg Association (USPOULTRY) and the National Association of SARA Title III Officials (NASTTPO) for its members and summarizes select publicly-available guidance for the prevention and response to accidental cryogenic releases. This pamphlet is for informational purposes only and is general in nature. Users should carefully consider application of any of the information contained herein. Proper use of the information contained in this pamphlet requires extensive knowledge of the applicable rules and regulations. In addition, users must have an understanding of the limitations of personal protective equipment, safe handling and disposal techniques, and atmospheric monitoring utilized with cryogenic chemicals. This pamphlet is not exhaustive and may not be applicable in all situations. Some of the information may be dated and may not reflect the most current legal or regulatory developments.

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Cryogenic Liquids

Cryogenic liquids are materials with a boiling point of less than – 100 °F (-73 °C). Examples include liquid nitrogen, carbon dioxide, liquid oxygen and dry ice. Cryogenic liquids undergo large volume expansion upon transition to the gas phase. For example, when liquid nitrogen vaporizes into nitrogen gas, its volume expands by a factor of 695. Consequently, when a cryogenic liquid warms in a sealed container, internal pressure increases, which may rupture the container if the pressure rating is exceeded.

Hazards of cryogenic liquids include fire (in the case of flammable or oxidizing materials), pressure build-up, explosion, as well as severe frostbite (on contact with skin), and asphyxiation (due to displacement of available oxygen). Additionally, cryogenic liquids, such as liquid nitrogen, have boiling points below that of oxygen and are capable of condensing atmospheric oxygen, resulting in a localized, oxygen-enriched environment through the formation of liquid oxygen. Liquid oxygen in combination with many organic (oxidizable) materials can result in a violent reaction.

Physical Properties

The below table indicates several physical properties of liquid nitrogen, carbon dioxide and liquid oxygen. These cryogenic liquids have extremely low boiling points and are generally used at atmospheric pressure. Thus, they are constantly boiling during use.

Cryogen	**Boiling Point (1 atm) ºC (ºF)**	**Critical Pressure (Pounds Per Square Inch) PSI**	**Liquid Density, g/L**	**Gas Density (27ºC), g/L**	**Liquid-to-Gas Expansion Ratio**	**Type of Gas**
Liquid Nitrogen	-196 (-321)	492	808	2.25	695	Inert
Liquid Oxygen	-183 (-297)	736	1410	1.4	875	Flammable
Carbon Dioxide	-79 (-108)	1071	100	20	535	Inert

Also, note that the liquid to gas expansion ratios shows how much air is displaced by a given amount of gas. For example, one liter of liquid nitrogen expands to 695 liters of gas when exposed to the atmosphere. Even a tiny leak of cryogenic gases can quickly displace all the breathable air in an enclosed area.

Cryogenic liquids are typically odorless and colorless when vaporized to the gaseous state. Most of them have no color as a liquid, although liquid oxygen is light blue.

Cryogenic Liquid Uses in Food Processing

Liquid N_2, liquid CO_2, and solid CO_2 (dry ice) is used in food processing in several applications, including grinding, mixing, coating, freezing, and packaging foods. Food processors may use liquid nitrogen to produce a variety of foods, such as meat, poultry, seafood, fruits, vegetables, baked goods, and prepackaged meals. In a few instances, liquid oxygen O_2 may be utilized in lieu of liquid N_2 or CO_2 in the freezing process. Responders should be aware of this possibility.

Cryo-mechanical freezing utilizes liquid nitrogen or liquid CO_2 to prevent moisture loss and minimize damage to wet or sticky foods. Cryogenic freezing tunnels or immersion freezers encapsulate the outer surface of products, preserve moisture, help prevent microbial growth that can lead to food spoilage, and maintain the foods' original freshness and texture.

Hazards of Cryogenic Liquids

Contact with and Destruction of Living Tissues

Since all cryogenic liquids and their boil-off vapors are extremely cold, they can rapidly freeze human tissue and cause frostbite. Even brief contact with a cryogenic liquid is capable of causing tissue damage similar to that of thermal burns. Prolonged contact may result in blood clots.

The touching of uninsulated containers or other materials that have been cooled by cryogenic liquids can cause serious skin injuries. The extremely cold surface of the super-cooled material will cause the flesh to stick fast and tear when one attempts to withdraw from the surface. Even non-metallic materials are dangerous to touch at low temperatures. In addition to the hazards of frostbite or flesh sticking to cold materials, soft and pliable objects at room temperature are easily broken because they become hard and brittle at extremely low temperatures and easily fracture.

Pressure Build-Up/Explosions

Cryogenic liquids exhibit large volume exchange ratios, which can cause rapid pressure changes. One volume of liquid nitrogen, for example, will vaporize to a gaseous state and expand its volume by a factor of 695 when warmed to room temperature at normal atmospheric pressure. In addition, all cryogens can condense sufficient moisture from the air to form ice that can block inlet and outlet valves in storage vessels. This condition can result in an explosion caused by the build-up of trapped vapor in the container. As a result, it is critical to contain these liquids in insulated containers with pressure relief valves (see "Safe Handling Procedures" below).

Boiling and Splashing

Cryogenic liquids can boil or splash when added to a warm container or when inserting warm objects into the liquid. Always perform these operations slowly to minimize boiling and splashing.

All applications that use cryogenic gases require safety monitoring of oxygen in atmospheric air, established by the Occupational Safety and Health Administration (OSHA). Atmospheric air, which normally contains 20.9% oxygen, is monitored for the displacement or enrichment of oxygen. If the oxygen content is below 19.5%, the oxygen level is considered insufficient or displaced. If the oxygen content is above 23.5%, the oxygen level is too high or enriched.

Oxygen Enrichment

Cryogenic liquids with a boiling point below that of liquid oxygen, like nitrogen, have the ability to condense oxygen out of the air if exposed to the atmosphere. Violent reactions (e.g., rapid combustion or explosions) may occur if the system or process is not compatible with liquid oxygen (see below).

Oxygen Deficiency/Asphyxiation

All cryogenic liquids have a significant potential for creating an oxygen-deficient environment. Because of their large liquid to gas expansion ratios, even small quantities of liquefied gas can expand to displace large amounts of oxygen, rendering the atmosphere lethal in a confined area. Without adequate oxygen, one could lose consciousness in a few seconds and die of asphyxiation in a few minutes.

Accelerating Combustion Effect of Liquid Oxygen

Although oxygen itself is not flammable, it vigorously accelerates and supports combustion. Substances that burn in air will burn more vigorously in oxygen. Do not permit liquid oxygen or oxygen-rich atmosphere to come into contact with organic materials or flammable substances of any kind. Some organic materials which can react violently with liquid oxygen include oil, grease, asphalt, kerosene, cloth, tar and any organic debris.

Personal Protective Equipment

Eye Protection

Safety glasses must be worn at all times while handling cryogenic liquids, because the liquid is almost always boiling and can splash into the eyes. Safety goggles provide the best protection for the eyes. Face shields must also be worn when filling containers or transferring cryogenic liquids from one container to another.

Hand Protection

The most likely cause of frostbite to the hands and body is contact with cold metal surfaces of vessels that contain cryogenic liquids. Frostbite is likely to occur almost instantaneously when touching surfaces where cryogenic liquids have cooled. Hand protection is primarily the method to guard against the hazard associated with touching cold surfaces. Loose, non-asbestos insulating gloves that can be easily removed may be worn. The use of an insulated potholder is the preferred method of handling cold surfaces. Never use rags to touch cold surfaces.

Protective Clothing

Always wear thermal protective clothing when handling refrigerated/cryogenic liquids or solids. Closed-toed shoes are required when handling cryogenic liquids. Long, cuffless trousers that cover the shoes' neck should also be worn. Long sleeve shirts are also recommended for arm protection.

Safe Handling and Storage Practices

- Cryogenic tanks must be clearly labeled to indicate the contents.
- Large liquid nitrogen tanks and other vessels containing cryogenic liquids should be secured to prevent sliding, rolling or tipping over.
- Always wear appropriate personal protective equipment to prevent skin and eye contact. Insulated, loose-fitting gloves (special cryogenic gloves are available), safety glasses, and a face shield are strongly recommended.
- Handle objects in contact with cryogenic liquids with the proper gloves.
- Keep liquid oxygen away from organic materials and ignition sources.
- Only work with cryogenic liquids in well-ventilated areas to avoid localized oxygen depletion or flammable or toxic gas build-up.
    - Refrigerated rooms generally recycle room air, making it vital for adequate ventilation when cryogenic chemicals are used to prevent a dangerous condition as a result of an accumulation of cryogenic liquids or dry ice in these rooms.
- Cryogenic liquid/dry ice baths should be open to the atmosphere with adequate ventilation to avoid pressure build-up.

- Systems that incorporate liquid nitrogen traps must never be opened to the atmosphere until the coolant is removed from the trap.
- Containers and systems holding cryogenic liquids should have pressure relief mechanisms.
- Cryogenic liquid cylinders and other containers should be filled to no more than 80% of their capacity to protect against rupture from thermal expansion beyond the container's capacity.
- Store in a well-ventilated area to prevent the build-up of flammable gases or prevent facilitating an environment for air displacement.
- Keep storage containers from having contact with sources of moisture to prevent ice plugging of pressure relief devices.
- Keep all sources of ignition away from cryogenic liquids.

First Aid for Cryogenic Exposures

If medical attention is needed following skin or eye exposure to a cryogenic liquid, immediately call 911. All personnel using cryogenic liquids must also be familiar with first aid procedures for treating frostbite:

A. Warm the affected area of the body rapidly by immersion in water not to exceed 105 ^{o}F, with body heat or by exposure to warm air. Maintain the affected area of the victim at normal body temperature until medical help arrives. In the event of massive exposure, the emergency shower should be used to warm the body. All clothing must be removed before showering.
B. Calm the victim and avoid aggravating injury. Do not rub or massage the affected parts of the body. People with frostbitten feet should not walk on them.
C. If affected, flush the victim's eyes with warm water for 15 minutes.
D. For long-term first aid, be sure to prevent infection. Use a mild soap to clean the affected area. Dressings need not be applied if the skin is intact.

Cryogenic Gas Safety Tools

While liquid nitrogen is important in food processing, it is not without risk. When liquid nitrogen and carbon dioxide are exposed to the air (e.g., during normal operations, sanitation, and when leaks occur), they will evaporate, changing from a liquid to a gas that can rapidly displace oxygen. In the event of a liquid nitrogen or carbon dioxide leak, food processing workers could become disoriented, lose consciousness or even suffocate from breathing oxygen-deficient air. Oxygen deprivation can put employees in real danger if there are leaks from pressurized freezer lines, exhaust systems or on-site storage containers. Oxygen enrichment can create an explosive atmosphere. Since liquid nitrogen and carbon dioxide are both odorless and colorless, workers would have no way of knowing that there has been a leak without appropriate monitoring.

Best safety practice calls for oxygen monitors to be installed anywhere there is a risk of liquid nitrogen, oxygen and carbon dioxide gas leaks. By utilizing oxygen monitoring equipment, food plant personnel can observe oxygen levels and detect leaks before a worker's health is jeopardized. Monitors should be placed wherever liquid cryogenics are stored and in all areas where liquid cryogenics are used. Monitoring equipment should include visual and audible alarms and relay triggering systems, which can control an HVAC system and notify safety personnel in the event of a catastrophic failure. Company-identified employees need to be trained in emergency response measures and how to use the monitoring equipment that would be activated in the event of liquid cryogenic leaks and/or an increase in oxygen levels.

Emergency Response Collaboration

In order to increase the benefit of emergency action planning, poultry processors are encouraged to coordinate their planning efforts with local emergency planning committees and emergency first responders.

The benefits of engaging in a planning process with all community members that might be impacted by an accident are numerous. It is unreasonable to assume local emergency planning and response personnel will understand the potential hazards in a poultry processing facility. Processors willing to cooperate and coordinate with emergency planning and response professionals can facilitate a process that provides the community with a broader understanding of the hazards.

Just as important, the process of cooperating and coordinating provides the emergency response community with the opportunity to advance their knowledge of poultry processing facilities and the operations that occur within them. This in turn can benefit their response efforts and enhance their safety if an event occurs that requires a response by emergency personnel.

Additionally, collaborating with emergency planning and response professionals can give processers a better sense of the accident preparedness capabilities available within their community. The information sharing that occurs through cooperation and coordination can drive improvements in the emergency planning and response capabilities of communities. It also can assist communities with identifying capability gaps, which can ultimately contribute to minimizing the consequences of an accident.

Emergency Response Procedures

- More than half of deaths associated with asphyxiation in confined spaces involve would-be rescuers. Do not enter unknown conditions without the proper personal protective equipment. If experiencing any symptoms, such as lightheadedness, dizziness or confusion, immediately seek fresh air and medical attention. If an individual becomes unconscious in an area that employs the use of cryogenic chemicals, contact 911 immediately and let emergency first responders retrieve personnel involved.

- Only individuals trained in responding to a release of cryogenic liquids shall attempt any emergency response.

- If any spill occurs, **IMMEDIATELY EVACUATE** the area and call 911. Emergency first responders will monitor the atmosphere to determine when it is safe to return to the building. If trained to do so, monitor oxygen concentrations beyond the visible edge of the vapor cloud, and barricade/restrict access to the affected areas. Since the altered oxygen content can extend beyond the visible edge of the vapor cloud, monitoring shall determine where the oxygen concentration is acceptable to permit emergency response activities.

  If the spill is nitrogen or carbon dioxide, an oxygen-deficient atmosphere can be created. If oxygen is spilled, an oxygen-enriched atmosphere can be created. If monitoring, prohibit personnel entry into areas of concern with oxygen concentrations greater than 23.5% or concentrations less than 19.5% oxygen without appropriate breathing apparatus.

- All vehicles shall be kept out of the affected area of the release and vapor cloud.

- Ensure that all personnel wear the correct personal protective equipment (PPE).

- Limit emergency services personnel in the affected area to the minimum number necessary to carry out emergency control.

- If it can be performed safely, shut off the source of the spill. If equipped with a remotely operated valve, shutoff shall be done remotely.

- If possible, direct cryogenic liquid release away from occupied areas, process equipment, machinery, carbon steelwork, buildings, open drains (such as storm drains/culverts), and confined areas. Compatible materials can be used as physical barriers.

- A water fog spray may be used to knock down vapors; never use a full water spray.

- Whenever possible, control the direction of the vapor cloud. Attempt to direct it away from buildings where an asphyxiating atmosphere could be produced. Control of the vapor cloud can usually be achieved by using a water curtain formed by water from fire hoses fitted with spray or fog nozzles. Keep ventilators operating on any equipment enclosures or buildings that withdraw air and take in fresh air on any side of the building not affected by the vapor cloud.

- Do not direct water at the source of the leak or safety devices, as icing will likely occur.

- Never allow the trapping of a cryogenic liquid between two points without a safety relief valve. The expansion from liquid to gas can cause the failure of piping and related equipment and present a serious safety hazard.

References

- U.S. Food & Drug Administration (FDA) – 2017 FDA Food Code “Liquid nitrogen and dry ice in food” published 10/31/2018.

- 2020 Emergency Response Guidebook, Guide 120 Gases – Inert (Including Refrigerated Liquids)

- Compressed Gas Association - CGA P-69—2018 Guideline For Emergency Response To Cryogenic Liquid Releases First Edition