Office of Environment, Health, Safety and Security
Operating Experience Level 3

OE-3: 2021-05 September 2021

Oxygen Deficient Atmosphere Hazards at DOE Facilities

Purpose

This Operating Experience Level 3 (OE-3) document is to raise awareness of the potential for worker exposure to oxygen deficient atmospheres across the Department of Energy (DOE) Enterprise and to promote learning from operating experience with this significant hazard at DOE facilities.

The Seven Guiding Principles and Five Core Functions of DOE's Integrated Safety Management (ISM) policy (DOE Policy 450.4A, *Integrated Safety Management System Policy*) and the hazard identification and prevention requirements of 10 CFR part 851, *Worker Safety and Health Program* provide the basis to analyze this hazard and establish the needed controls that prevent potential injuries and fatalities.

Background

An oxygen deficient atmosphere, which can cause asphyxiation, is defined by the Occupational Safety and Health Administration (OSHA) as one containing less than 19.5% oxygen by volume. OSHA considers this as immediately dangerous to life or health, or IDLH. While oxygen deficient atmospheres are frequently associated with confined spaces, the potential exists more broadly in research, production, and maintenance operations across DOE. This includes the use of inert gases in laboratories, manufacturing settings, and indoor storage of compressed gas cylinders (e.g., nitrogen, oxygen, carbon dioxide, argon, hydrogen, helium, acetylene). A small leak from a loose fixture or deteriorated tubing can quickly lower the oxygen level in an enclosed room or create a low airflow area, thereby presenting an asphyxiation hazard. According to the U.S. Chemical Safety Board, "breathing an oxygen deficient atmosphere can have serious and immediate effects, including unconsciousness after only one or two breaths. The exposed person has no warning and cannot sense that the oxygen level is too low." See Table 1.

Atmospheric[1] O_2 Concentration (%)	Possible Results
20.9	*Normal*
19.0	*Some unnoticeable adverse physiological effects*
16.0	*Increased pulse and breathing rate, impaired thinking and attention, reduced coordination*
14.0	*Abnormal fatigue upon exertion, emotional upset, faulty coordination, poor judgment*
12.5	*Very poor judgment and coordination, impaired respiration that may cause permanent heart damage, nausea, and vomiting*
<10	*Inability to move, loss of consciousness, convulsions, death*

Table 1: Effects of Oxygen Deficiency on the Human Body (Compressed Gas Association, 2001)

[1] Note: The partial pressure and biological availability of O_2 due to altitude variability must also be considered.

Recent documented DOE worker events demonstrate the need for vigilance in operating practices, facility maintenance, and respect for alarms to detect and prevent adverse consequences. Due to the severity of the issue, some of the incidents described in this OE-3 document resulted in Worker Safety and Health enforcement actions by the Department.

Operational History

In the incidents that follow, workers were exposed to oxygen deficient atmospheres during routine facility inspection and maintenance activities. When analyzing hazards for a seemingly routine scope of work, consider all potential normal and abnormal exposure pathways.

On June 14, 2021, a maintenance worker at the Kansas City National Security Campus opened the side panel on a Remstar Shuttle XP500 cabinet for maintenance troubleshooting. The cabinet was filled with an inert nitrogen atmosphere to protect products stored inside. Upon opening the cabinet, the worker's exposure to nitrogen resulted in a momentary loss of consciousness which caused the employee to fall backward and strike their head and neck on nearby equipment. The fall resulted in a bump on the lower head/neck and a mild concussion. There may have been prolonged exposure to an oxygen deficient atmosphere and more significant consequences had the employee fallen forward instead. *(NA--KCFO-AS-KCNSC-2121-0001, Employee Exposed to Nitrogen Loses Consciousness Causing Fall)*

On March 5, 2021, a maintenance worker performing routine inspections at the Nevada National Security Site (NNSS) noticed and reported a rotten egg smell in the A-1 Uninterrupted Power Supply battery room. Machine Shop personnel later responding to the incident also entered the battery room and reported the odor and burning eyes. The June 2021 NNSS Lessons Learned article (DOE OPEXShare: *Expiring Uninterrupted Power Supply Batteries May Lead to a Potential Oxygen Deficient Exposure,* Nevada National Security Site) reported that batteries overheating and off-gassing can result in low oxygen levels in an enclosed room. Industrial hygiene monitoring confirmed a low oxygen atmosphere coupled with the presence of carbon monoxide and hydrogen sulfide. It was also determined that the workers did not understand the hazardous condition or have or follow safe practices when the odor was recognized. The Lessons Learned article reinforced exercising Stop Work Authority when encountering unexpected conditions such as an odor, stepping back, and discussing potential hazards and a path forward. *(NA--NVSO-MSTS-LV-2021-0002, Potential Oxygen Deficiency Exposure)*

In 2015, Environmental Management's Moab Uranium Mill Tailings Remedial Action (UMTRA) project found carbon monoxide and volatile organic compound build-up in a tightly enclosed tent structure being used as a mechanics shop. The resulting oxygen deficient atmosphere was attributed to the use of propane-fired heaters and vapors from solvent-containing rags. UMTRA's Lessons Learned article recommended that structures, especially tight tent structures using ventless infrared propane-fired heaters, should be tested for oxygen levels periodically, and specifically after periods of closure. Solvent and oil containing rags, even when placed safely in an oily rag self-closing, fire-rated container, should be disposed of at the end of each shift to prevent the accumulation of vapors. (DOE OPEXShare: *Low Oxygen Level in Maintenance Tent,* Moab UMTRA, Environmental Management)

DOE experience also reinforces the importance of designing engineering controls, monitors, and alarms based on the identified hazards and performing routine inspection and maintenance to ensure those systems operate as expected in preventing exposure to oxygen deficient atmospheres.

On March 31, 2009, a nitrogen purge was being planned for the beam line located in the Linear Coherent Light Source Front End Enclosure when an oxygen deficiency alarm sounded. Workers immediately evacuated until the area was deemed safe by Industrial Hygiene staff.
The investigation found that fire dampers in the supply air duct were in the closed position and there was no make-up airflow to the area, which was necessary to prevent the oxygen deficient atmosphere. An engineering solution was to be developed to correct the lack of make-up airflow. *(SC--SSO-SU-SLAC-2009-0006, Possible Oxygen Deficiency Hazards (ODH) Issue During Nitrogen Purge Activity in LCLS Front End Enclosure)*

On October 13, 2011, an initial evaluation by a Los Alamos National Laboratory (LANL) industrial hygienist determined that a catastrophic failure of the nitrogen supply system at the Weapons Engineering Tritium Facility could result in a potential asphyxiation hazard in certain rooms of the facility. Investigators discovered that the potential hazard had been previously identified in 2002 and 2008 with a recommendation to install oxygen monitors. The oxygen monitors were never installed. The Weapons Facility Operations Director declared a management concern existed because a potential oxygen deficient atmosphere had been identified and corrective actions were not implemented. Actions were subsequently taken to address the hazard. *(NA--LASO-LANL-TRITFACILS-2011-0013, Management Concern: Recommendation to Install Oxygen Monitors Not Implemented)*

During a testing evolution in 2014, the Brookhaven National Laboratory (BNL) Collider-Accelerator Department found that an Oxygen Deficiency Hazard monitoring and alarm unit would not enunciate at a low oxygen condition using its alarm relay output if the oxygen level goes too low. The manufacturer reproduced and confirmed BNL's results. In their Lessons Learned document, BNL recommended that an external system (relays or PLC) with a different power source to enunciate alarms is required if the unit fails to activate its alarm (low O2) condition or has a system failure (power loss, O2<5%, low flow, etc.). (DOE OPEXShare: *Oxygen Deficiency Hazard Monitoring and Alarm Unit Will Not Enunciate if Oxygen Level is Too Low.* Brookhaven National Laboratory (BNL), Office of Science).

In October 2010, a liquid nitrogen (LN2) valve leak and drip from the ceiling into the basement of a building at Sandia National Laboratory resulted in oxygen levels below 14%. Oxygen monitor alarms activated, and the event was properly reported to management, the safety coordinator, and Emergency Management. The investigation identified a LN2 purge valve that was open and that the phase-separator (keep-full) on this LN2 line may have been faulty. The LN2 then entered an exhaust duct on the southwest side of the building, found its way to the ducting in the ceiling above the men's locker room, and leaked out resulting in the low oxygen levels. *(NA--SS-SNL-1000-2010-0011, Liquid Nitrogen Leak, in Bldg. 891, Basement Men's Locker Room)*

Several recent events involved inadequate and unsafe responses to oxygen alarms, representing work outside of established facility controls.

On August 12, 2019, LANL workers entered the high bay room while a low oxygen alarm was activated. This was contrary to safety postings and operating requirements. The workers entered the room to isolate a liquid nitrogen leak from a vent pipe, which was believed to be the cause of the low oxygen alarm. The oxygen monitor indicated an oxygen level of about 19%, confirming that workers entered an oxygen deficient area. *(NA--LASO-LANL-NUCSAFGRDS-2019-0003, Near Miss: Worker Enters Room During Low Oxygen Alarm Activation)*

Another event at LANL, on November 4, 2019, identified inadequate awareness and procedures for response to an oxygen alarm. A worker entered a laboratory while an alarm was activated. After ten minutes of investigation, the worker identified the source of the alarm as a low oxygen alarm, exited the room, consulted a co-worker and the Integrated Work Document (IWD). The IWD instructed them to return to the room and reset the alarm, returning them to a potentially low oxygen environment. While the investigation later showed that the oxygen monitor was malfunctioning and the workers were not exposed to a hazard in this instance, the IWD did not contain appropriate alarm response instructions. *(NA--LASO-LANL-ACCCOMPLEX-2019-0008, Worker Inadvertently Enters Room While Low Oxygen Monitor Alarming)*

On September 13, 2017, a LANL Subject Matter Expert (SME) entered a room while a low oxygen alarm was activated contrary to requirements. The work requirements specified that if alarms are activated, personnel are to evacuate the room, close the valve on the liquid nitrogen tank located outside of the building, and contact Emergency Management and Response (EM&R). The SME responding to the alarm identified a relief valve on the Thermal Vacuum System releasing liquid nitrogen inside the room. The SME entered the room, isolated the relief valve by turning the supply valve off, placed the system in a safe configuration, and then he left the room. The low oxygen alarm stopped within twenty minutes of the SME isolating the relief valve. Further review found that EM&R was not contacted because the situation had been mitigated. A January 2018 LANL lessons learned article on this event (DOE *OPEXShare: Worker Enters Room During Low Oxygen Alarm Activation*) reinforced that when responding to alarms, it is important to pause and analyze the situation first. Mitigating the situation without thoughtful consideration of hazards and work requirements can place workers at risk. *(NA--LASO-LANL-PHYSCOMPLX-2017-0001, Near Miss: Worker Enters Room During Low Oxygen Alarm Activation)*

RECOMMENDATIONS

- Recognize that oxygen deficient atmospheres can be dynamic and exist outside of confined spaces. Analyze all potential facility conditions and implement protections with the hierarchy of controls.
- Design and engineer facilities to prevent or control oxygen deficient atmospheres using interlocks, ventilation, gas controls and robust monitoring and alarms. Warning signs are not enough.
- Ensure facilities are designed so workers can hear or see alarms and lights at a safe distance from the hazardous condition.
- Conduct routine facility inspections to ensure engineered systems will function properly and as expected (e.g., ventilation, valves, and alarms are set correctly and are functional).
- Track and confirm the implementation and effectiveness of controls to address deficiencies and support continuous improvement.
- Stop work if unexpected conditions are encountered. Exit potentially hazardous areas until confirmed safe.
- Ensure all procedures and postings, including building Emergency Plans, are correct and consistent regarding informing workers of the actions to be taken when an alarm is activated.
- Train affected employees on response procedures including awareness of the visual and/or audible signals produced by each alarm and actions to take if an alarm is activated.
- Conduct emergency drills to reinforce response to abnormal/alarm conditions.

SUMMARY

Oxygen deficient atmospheres can be managed by applying DOE ISM Guiding Principles and Core Functions (see Figure 1) in work planning and execution at both the facility and activity levels. This includes the combination of robust hazard analyses, a focus on engineered controls in facility design, system inspection and maintenance, reliable operating practices, training, and a strong safety culture.

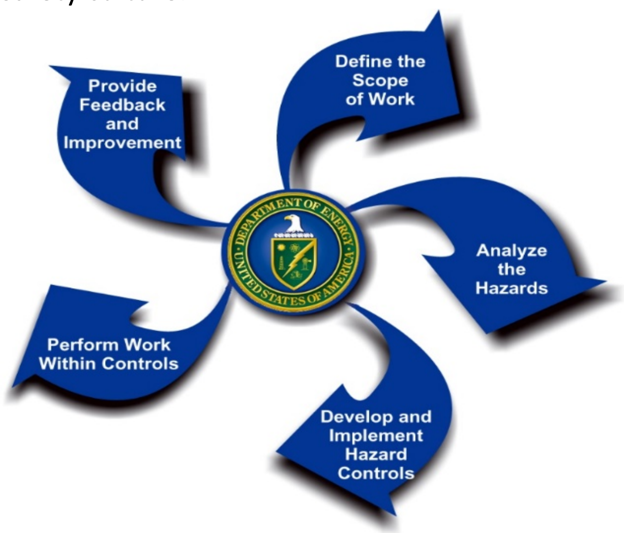

Figure 1. DOE Integrated Safety Management System Core Functions

These expectations are further reinforced by the requirements in 10 CFR part 851 for hazard identification and assessment, hazard prevention and abatement, and training and information.

REFERENCES

DOE Policy 450.4A Chg 1 (MinChg), Integrated Safety Management System Policy

10 CFR part 851, Worker Safety and Health Program

U.S. Chemical Safety and Hazard Investigation Board, 2003. *Safety Bulletin: Nitrogen Asphyxiation Hazards*, No. 2003-10-B.

Compressed Gas Association, Inc., 2001. *Safety Bulletin, Oxygen Deficient Atmospheres*, SB-2, 4th edition.

ORPS Report NA--KCFO-AS-KCNSC-2121-0001, *Employee Exposed to Nitrogen Loses Consciousness Causing Fall*

ORPS Report NA--NVSO-MSTS-LV-2021-0002, *Potential Oxygen Deficiency Exposure*

ORPS Report NA--LASO-LANL-TRITFACILS-2011-0013*, Management Concern: Recommendation to Install Oxygen Monitors Not Implemented*

ORPS Report NA--SS-SNL-1000-2010-0011, *Liquid Nitrogen Leak, in Bldg. 891, Basement Men's Locker Room*

ORPS Report SC--SSO-SU-SLAC-2009-0006, *Possible Oxygen Deficiency Hazards (ODH) Issue During Nitrogen Purge Activity in LCLS Front End Enclosure*

ORPS Report NA--LASO-LANL-NUCSAFGRDS-2019-0003, *Near Miss: Worker Enters Room During Low Oxygen Alarm Activation*

ORPS Report NA--LASO-LANL-ACCCOMPLEX-2019-0008, *Worker Inadvertently Enters Room While Low Oxygen Monitor Alarming*

ORPS Report NA--LASO-LANL-PHYSCOMPLX-2017-0001, *Near Miss: Worker Enters Room During Low Oxygen Alarm Activation*

DOE OPEXShare: *Expiring Uninterrupted Power Supply Batteries May Lead to a Potential Oxygen Deficient Exposure,* Nevada National Security Site, June 3, 2021

DOE OPEXShare: *Low Oxygen Level in Maintenance Tent*, Moab UMTRA, Environmental Management, March 2, 2016

DOE OPEXShare: *Worker Enters Room During Low Oxygen Alarm Activation*, January 25, 2018

DOE OPEXShare: *Oxygen Deficiency Hazard Monitoring and Alarm Unit Will Not Enunciate if Oxygen Level is Too Low.* Brookhaven National Laboratory (BNL), Office of Science, April 17, 2014

National Nuclear Security Administration (NNSA) Safety Advisory, NNSA Office of Safety (NA-51), June 22, 2021

Consent Order, Triad National Security, LLC, WCO-2021-01, June 10, 2021

National Nuclear Security Administration, Preliminary Notice of Violation (WEA-2018-02) to Los Alamos National Security, LLC, December 20, 2018

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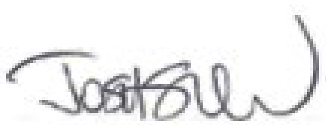
This OE-3 document requires no follow-up report or written response.



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