Contents: Oxygen Deficiency Hazards (ODH), System Classification and Controls

Effective Date: **April 2001**
Point of Contact: Safety Engineering

Section	Overview of Content (see section for full process)
Introduction	

1. ODH Calculation and Control Measures	• Conduct quantitative assessment of fatality risk potential.
	• Calculate
	  ○ fatality factor based on the lowest oxygen concentration
	  ○ probability of event using equipment failure rates
	  ○ fatality rate
	• Ensure that the risk assessment is conducted.
	• Determine ODH Class by the predicted fatality rate.
	• Ensure that ODH control measures are implemented.
	• Update building's FUA.

2. Obtaining Medical Approval from the Occupational Medical Clinic (OMC)	• Evaluate employee for ODH work and notify supervisor if limitations apply.
3. Emergency Evacuation and Rescue	• Don PPE upon indication of ODH alarm. • Don SRSAR, then check that no one is trapped. • Evacuate area, if no one is trapped. • Ensure that victims don their own SRSARs, if trapped, and if possible. • Evacuate area, then dial 911 or 2222. • Wait to assist Emergency Services.
4. Reentry into ODH Areas after Alarm	• Test POMs and verify status of SRSARs before entering ODH Area. • Maintain contact with staff searching for and repairing leak. • Evaluate need for extra temporary ventilation to supply fresh air.

	• Resume normal operation if no leak is found. • Isolate and repair leak; access can be returned to normal.
5. Escorted Access into ODH Areas	• Inform person entering the ODH area of hazards. • Review alarms and evacuation routes. • Instruct those entering ODH 1 areas on use of POMs and SRSARs.

Definitions

Exhibits
Calculation of the Fatality Factor
Emergency Evacuation and Rescue Flowchart
Equipment Failure Rate Estimates
Fatality Rate Determination
ODH Control Measures
Oxygen Concentration in Ventilated Spaces

Forms
Effect Thresholds for Exposure to Reduced Oxygen

Training Requirements and Reporting Obligations

This subject area contains training requirements. See the Training and Qualifications Web Site.

This subject area does not contain reporting obligations.

References

29 CFR 1910.134, OSHA Respiratory Protection Standard

Confined Spaces subject area

ES&H Standard 5.1.0, Nonflammable Cryogenic Liquids

Training and Qualifications Web Site

Work Planning and Control for Experiments and Operations Subject Area

Standards of Performance

Managers shall analyze work for hazards, authorize work to proceed, and ensure that work is performed within established controls.

All staff and users shall identify, evaluate, and control hazards in order to ensure that work is conducted safely and in a manner that protects the environment and the public.

conducted safely and in a manner that protects the environment and the public.

All staff and users shall ensure that they are trained and qualified to carry out their assigned responsibilities, and shall inform their supervisor if they are assigned to perform work for which they are not properly trained or qualified.

Management System

This subject area belongs to the **Worker Safety and Health** management system.

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Introduction: Oxygen Deficiency Hazards (ODH), System Classification and Controls

Effective Date: **April 2001**
Point of Contact: Safety Engineering

The Occupational Safety and Health Administration (OSHA) Respiratory Protection Standard (29CFR1910.134) defines an oxygen-deficient atmosphere as an atmosphere with an oxygen content below 19.5% by volume.

Staff should not be exposed to an oxygen-deficient atmosphere under normal working conditions. If work needs to be performed in an oxygen-deficient atmosphere, specific work planning needs to be conducted to ensure compliance with OSHA requirements (see the Work Planning and Control for Experiments and Operations Subject Area).

Persons exposed to reduced-oxygen atmospheres may experience adverse health consequences, including unconsciousness, or death. The purpose of this subject area is to describe the methodology for assessing and classifying workplaces where abnormal conditions have the potential for producing an oxygen-deficient environment and controlling the associated hazards.

The use of compressed gases, liquefied gases, and volatile liquids is commonplace at Brookhaven National Laboratory (BNL). Introduction of these materials to the atmosphere can present a hazard. In particular, oxygen deficiency is important for those materials, which are neither acutely toxic nor flammable. Air normally contains about 21% oxygen with the remainder consisting mostly of nitrogen. Individuals exposed to reduced-oxygen atmospheres may suffer a variety of harmful effects. The exhibit Effect Thresholds for Exposure to Reduced Oxygen lists some of these effects and the sea level oxygen concentrations at which they occur. At higher altitudes, the same effects generally occur at greater volume concentrations since the partial pressure of oxygen is less. If exposure to reduced oxygen is terminated early enough, effects are generally reversible. If not, permanent central nervous system damage or lethality results. Major effects hindering escape from the vicinity of an oxygen deficiency are disorientation and unconsciousness. If it is possible for staff to be exposed to an atmosphere containing less than 19.5% oxygen, the hazards are to be identified and control measures implemented to minimize the risk.

This subject area is not applicable to areas defined as confined spaces. See Confined Spaces subject area.

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Subject Area: ***Oxygen Deficiency Hazards (ODH), System Classification and Controls***

1. ODH Calculation and Control Measures

Effective Date: **April 2001**
Point of Contact: Safety Engineering

Applicability

This information applies to all Line Managers or Principal Investigators (PI) who are responsible for operations or equipment that have the potential of producing an oxygen-deficient atmosphere in an occupied workspace.

Required Procedure

If under worst case conditions (i.e., without dilution from ventilation, the entire contents of the cryogenic dewar, refrigerator, target, or compressed gas cylinder is released into the workspace), oxygen concentrations do not fall below 19.5%, no ODH classification will be assigned. No further analysis or controls are required.

This procedure is not applicable to confined spaces. See Confined Spaces subject area.

No assessment is required for areas temporarily used during transport of cryogenic dewars or compressed gases. Staff exposure to oxygen concentrations less than 19.5% will be controlled as required by the OSHA Respiratory Protection Standard (29 CFR 1910.134).

Step 1	Before conducting operations that are physically capable of exposing staff to an oxygen-deficient atmosphere, the Department/Division or project conducts a quantitative assessment of the fatality risk potential from such exposure. ODH Class is based on the calculated probability of a fatality. This is the product of the fatality factor due to the total oxygen concentration and the failure rate of equipment.
Step 2	The Department/Division or project calculates the fatality factor based on the lowest oxygen concentration; see the exhibit on Calculation of the Fatality Factor. For nonventilated spaces, the lowest oxygen level is easily calculated. For ventilated spaces, see the exhibit on Oxygen Concentration in Ventilated Spaces for examples of calculations.

<table>
<tr><td>Step 3</td><td>The Department/Division or project calculates the probability of the event using equipment failure rates, if they are known. If they are unknown, see the exhibit on Equipment Failure Rate Estimates.</td></tr>
<tr><td>Step 4</td><td>Once the fatality factor and the probability are known, the Department/Division or project calculates the fatality rate using the exhibit on Fatality Rate Determination.</td></tr>
<tr><td>Step 5</td><td>Each Line Manager or PI ensures that the risk assessment is conducted and that the Environmental Safety and Health Coordinator reviews the calculations using the Experimental Safety Committee Review process. See the Work Planning and Control for Experiments and Operations Subject Area. For cryogenic designed (engineered) systems, the Cryogenic Safety Committee (CSC) reviews and approves calculations per ES&H Standard 5.1.0, Nonflammable Cryogenic Liquids.</td></tr>
<tr><td>Step 6</td><td>The Department/Division or project determines the ODH Class by the predicted fatality rate in step 4. The following are ODH Classes:
<table>
<tr><th>ODH Class</th><th>Fatalities/Hr</th></tr>
<tr><td>No Classification Required</td><td>0 (Oxygen concentration not less than 18%)</td></tr>
<tr><td>0</td><td>$<10^{-7}$ [note 1]</td></tr>
<tr><td>1</td><td>$>=10^{-7}$ but $<10^{-5}$</td></tr>
<tr><td>2</td><td>$>=10^{-5}$ but $<10^{-3}$</td></tr>
<tr><td>3</td><td>$>=10^{-3}$ but $<10^{-1}$</td></tr>
<tr><td>4</td><td>$>=10^{-1}$</td></tr>
</table>
Note 1: Areas that have Departmental/Divisional controls established that can demonstrate the fatality rate is less than 10^{-9} by engineering/safety analysis, may not have to have an ODH classification (SME concurrence required).</td></tr>
<tr><td>Step 7</td><td>Based on the determination of the ODH classifications, the ES&H Coordinator ensures that the appropriate ODH control measures are implemented. See the exhibit on ODH Control Measures.</td></tr>
<tr><td>Step 8</td><td>The Line Manager or PI contacts the Building Manager to update the building's Facility Use Agreement (FUA).</td></tr>
</table>

References

29 CFR 1910.134, OSHA Respiratory Protection Standard

Work Planning and Control for Experiments and Operations Subject Area

Confined Spaces Subject Area

ES&H Standard 5.1.0, Nonflammable Cryogenic Liquids

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Subject Area: ***Oxygen Deficiency Hazards (ODH), System Classification and Controls***

2. Obtaining ODH Medical Approval from the Occupational Medical Clinic (OMC)
Effective Date: **April 2001**
Point of Contact: Safety Engineering

Applicability

This information applies to all staff engaged in ODH operations Class 1 or greater.

Required Procedure

Staff obtain medical approval to ensure that they are medically fit to escape from an oxygen-deficient situation when properly warned.

Step 1	The supervisor notifies the OMC via a Job Assessment Form that the employee will require access to ODH Class 1 or greater areas. The supervisor ensures that employees complete their routine physical examinations as scheduled.
Step 2	The OMC evaluates the employee for ODH work and notifies the supervisor if any limitations apply to the employee. If there are limitations, the OMC notifies the supervisor via the Physical Limitations Form (Long-term) or the Limited Time Work Restriction Form (Short-term).
Step 3	The Environmental Safety and Health Coordinator periodically provides the OMC with a list of employees who are maintained in the ODH protocol. The OMC advises the Department/Division on the status of those employees in response to requests from Departments/Divisions.

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Subject Area: ***Oxygen Deficiency Hazards (ODH), System Classification and Controls***

3. Emergency Evacuation and Rescue
Effective Date: **April 2001**
Point of Contact: Safety Engineering

Applicability

This information applies to all unescorted BNL staff in ODH operations Class 1 or greater areas.

Required Procedure

Emergency Evacuation and Rescue Flowchart shows the following process.

Step 1	Before entering an ODH Class 1 or greater area, obtain the appropriate personal protective equipment (PPE) from your supervisor. **Note:** Supervisors must arrange for ODH training for BNL staff through the Training Coordinator who has jurisdiction over the ODH operation(s) of interest. For non-BNL staff, the BNL representative for the non-BNL staff member arranges training. For training in oxygen hazards and associated safety measures, see the Training and Qualifications Web Site.
Step 2	Upon indication of an area ODH alarm, or multiple personal oxygen monitors (POM), don your PPE. If your single POM goes off, inform area personnel and evacuate the area.
Step 3	First, don your own Self-Rescue Supplied Atmosphere Respirator (SRSAR), then check that no one is trapped in the area.
Step 4	If no one is trapped, evacuate the area.
Step 5	If someone is trapped, ensure that the victim donned his/her own SRSAR, then evacuate the area and notify Emergency Services immediately by dialing 2222 or 911. **Do not try to move the victim.** **Note:** If it will take longer than one minute to assist the victim with the SRSAR, or if someone is unaccounted for, evacuate the area immediately and contact Emergency Services.
Step 6	After evacuating, wait to assist Emergency Services.

Guidelines

All staff working or entering in an ODH Class 1 or greater area should know the total number of employees in the area.

References

Training and Qualifications Web Site

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Subject Area: ***Oxygen Deficiency Hazards (ODH), System Classification and Controls***

4. Reentry into ODH Areas after Alarm

Effective Date: **April 2001**

Point of Contact: Safety Engineering

Applicability

This information applies to the safe reentry into ODH Class 0 and 1 areas after a low-oxygen alarm. It applies to supervisors and other staff required to enter the ODH area for repair, diagnosis, and/or mitigation of hazards. Reentry into ODH Class 2 or greater areas require job-specific work planning. This information does not apply to Emergency Services staff under emergency conditions.

Required Procedure

the source of the cryogen or gas can be localized, then the flow should be stopped from outside the area. If the source cannot be localized from outside the area, then ODH-qualified staff are permitted to enter the area upon meeting the following requirements:

Step 1	Before entering the ODH area, staff test the operation of their personal oxygen monitors (POM) and verify the status of their Self-Rescue Supplied Atmosphere Respirators (SRSARs). The POM is calibrated using fresh air and tested for alarm function. It is used to test the air at head level ahead of the staff member entering. Staff entering the area must have a POM and an SRSAR. **Note:** Supervisors must arrange for ODH training for BNL staff through the Training Coordinator who has jurisdiction over the ODH operation(s) of interest. For non-BNL staff, the BNL representative for the non-BNL staff member arranges training. For training in oxygen hazards and associated safety measures, see the Training and Qualifications Web Site.
Step 2	An ODH-qualified staff member stations him/herself at the entrance of the area with an oxygen monitor and an SRSAR and maintains contact with all staff searching for and repairing the leak (visually and/or by radio).
Step 3	If applicable, the supervisor switches the exhaust fans to manual on as quickly as possible. The supervisor evaluates the need for extra temporary ventilation to supply fresh air into the area. If oxygen levels are less than 19.5%, all staff must evacuate, and the supervisor ensures that the area is ventilated with fresh air for a minimum of 15 minutes before a second attempt to reenter. If oxygen levels remain less than 19.5%, reentry will require specific work planning. See the Work Planning and Control for Experiments and Operations Subject Area.
Step 4	Staff search the area for the leak while maintaining constant surveillance of oxygen content of the air with their POMs.
Step 5	If staff do not locate a leak and the detection system is in the alarm state, the supervisor notifies the Environmental Safety and Health Coordinator. The supervisor and the ES&H Coordinator initiate a work plan to determine further action.

	Coordinator initiate a work plan to determine further action.
Step 6	If no leak is found and the sensors automatically reset themselves, then staff resume normal operation, only if the alarms are not again activated.
Step 7	If staff locate the leak and the flow can be stopped, they run the exhaust fans for 15 minutes before they can start repairs. If the cryogen or gas flow cannot be stopped, then staff run exhaust fans and set up a local fan to supply fresh air into the work area until the alarm clears.
Step 8	Repair staff maintain direct contact with staff out of the affected area.
Step 9	After staff isolate and repair the leak and oxygen concentrations are above 20%, access to the area can be returned to normal.

References

Training and Qualifications Web Site

Work Planning and Control for Experiments and Operations Subject Area

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Subject Area: ***Oxygen Deficiency Hazards (ODH), System Classification and Controls***

5. Escorted Access into ODH Areas

Effective Date: **April 2001**

Point of Contact: Safety Engineering

Applicability

This information applies to escorts and to BNL staff and non-BNL staff escorted into ODH Class 0 and 1 Areas.

Required Procedure

Untrained staff may access ODH Class 0 Areas with a trained escort, but only for short-term operational needs and informational tours. An escort is not to be used as a substitute for training.

Untrained staff are one-to-one escorted by an ODH-qualified person into ODH Class 1 Areas.

No untrained person may enter an ODH area to investigate an ODH alarm.

Step 1	The escorts informs the person entering the ODH area of the hazards of oxygen deficiency and reviews alarms and evacuation routes. Instruct any person entering a Class 1 area on the use of a Self-Rescue Supplied Atmosphere Respirator (SRSAR) and Personal Oxygen Monitor (POM). Everyone must carry an SRSAR and POM.

Guidelines

ODH Class 0 Areas

- Persons with frequent escorted accesses to ODH Class 0 Areas should be reported to the Environmental Safety and Health Coordinator.
- No more than two persons per escort should be escorted into an area for short-term work.
- Up to six persons may be escorted for an informational tour. Tours of more than six persons should be pre-approved by the Department/Division.

ODH Class 1 Areas

- Informational tours are permissible; a tour route, which minimizes the risk to staff, should be established and approved by the Department/Division.

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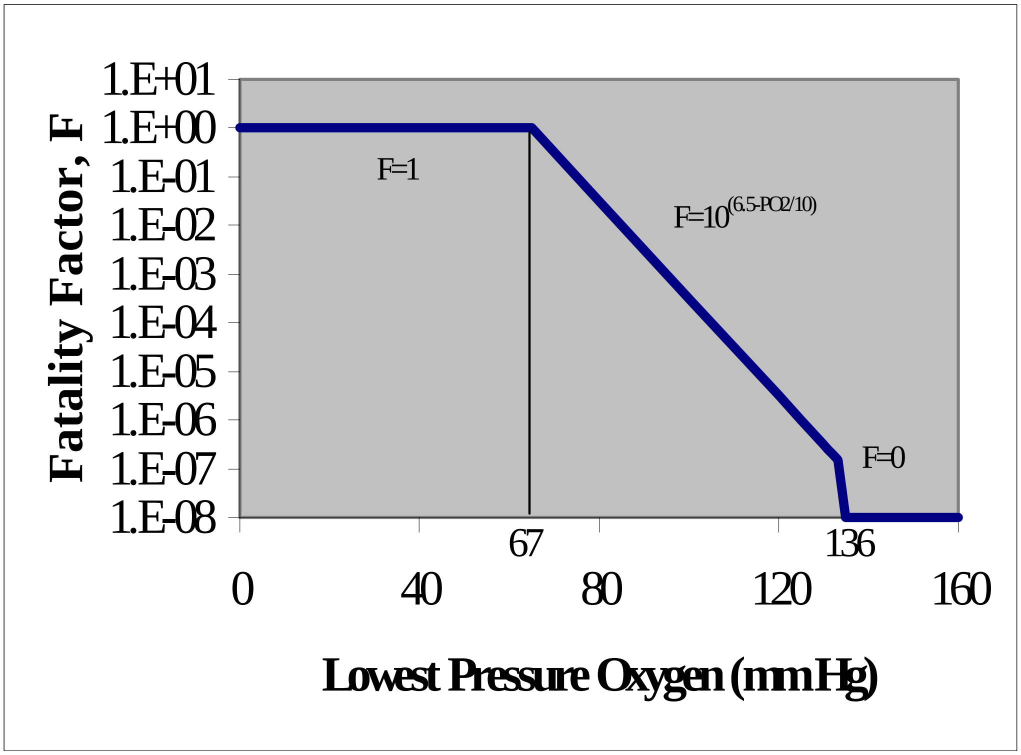
Calculation of the Fatality Factor, F

All exposures above 18% (137 mm Hg) are defined to be "safe" and to not contribute to fatality, therefore the value of F is zero. That is, if the lowest attainable oxygen concentration is 18%, then the value of F is 10^{-7}. This value would result in one fatality in 10 million hours. An expected rate of occurrence of the event of 1 per hour would result in F=1. At decreasing concentrations, the value of F should increase until, at some point, the probability of fatality becomes unity. That point was selected to be 8.8% (67 mm Hg) oxygen, the concentration at which one minute of consciousness is expected.

Figure A-1.



Fatality factor (F_i) versus the lowest attainable oxygen concentration

The value of F depends on the oxygen concentration, the duration of exposure and the difficulty of escape. For convenience of calculation, Figure A-1 defines the relationship between the value of F and the lowest attainable oxygen concentration. This relationship should be used when no better estimate of the probability of fatality from a given event is available. The lowest concentration is used rather than an average.

Oxygen concentrations can be converted to partial pressures by,

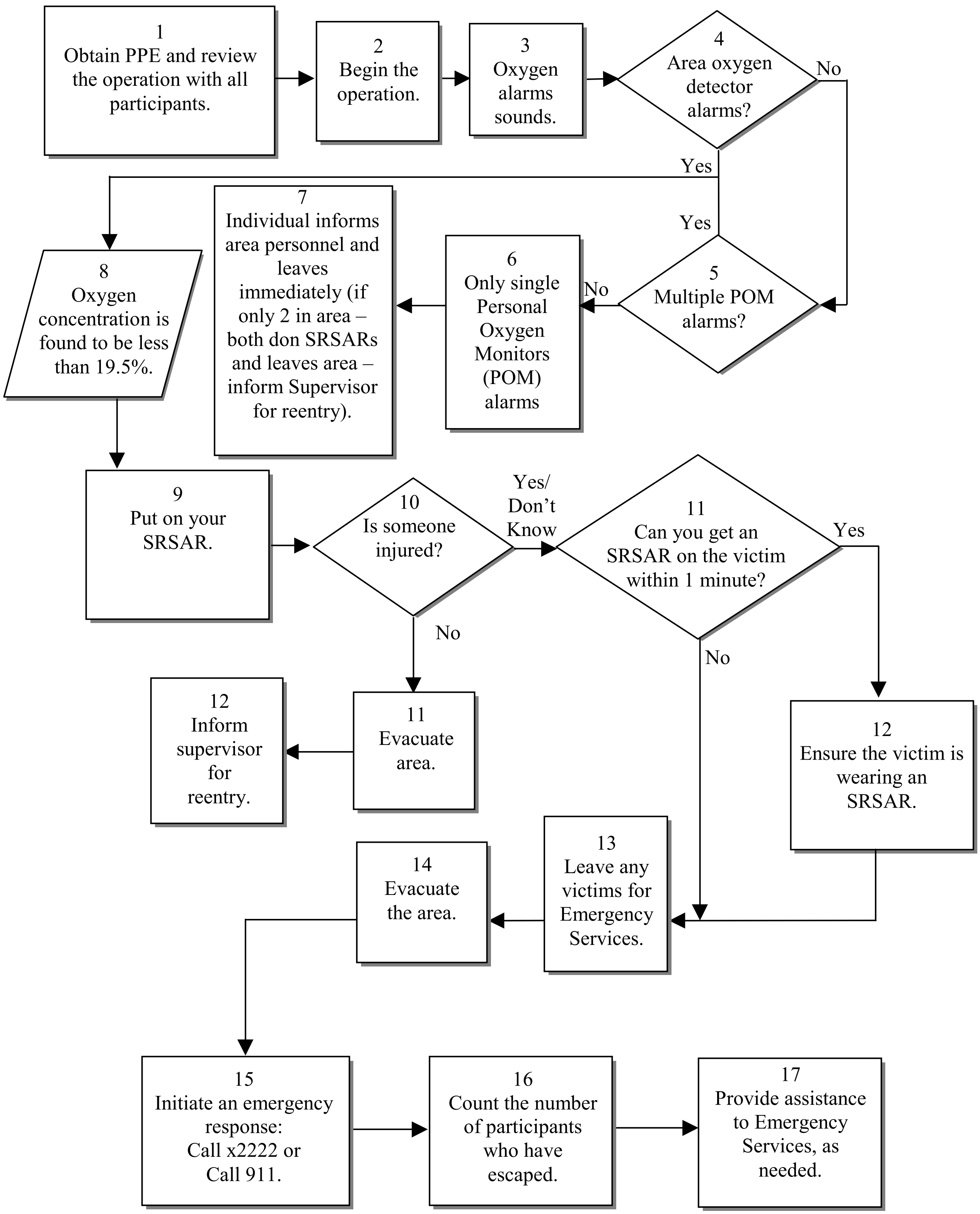
$$Po_2 = CPa$$

Where, C = oxygen concentration (volume %)

Po_2 = oxygen partial pressure (mm Hg)

Pa = atmospheric pressure (mm Hg), approximately 760 mm Hg at BNL

Emergency Evacuation and Rescue Flowchart



EQUIPMENT FAILURE AND HUMAN ERROR RATES

Additional Risk Assessment Data

Table B-I gives estimates of cryogenic equipment failure rates. These data are median estimates collected from past ODH risk assessments performed on systems at Fermilab. This data has been updated to include the revised failure rate estimates as described by B. Soyars (Fermilab) report, " Appendix: Rationale for Table 1 – Fermilab Equipment Failure Rate Estimates," dated January 26, 2000. Table B-II shows failure rates for various equipment types derived from the nuclear power industry that may be useful as input data (MOV – Manually operated valves/SOV - Solenoid operated valves/AOV – Automatically operated valves). General human error rate estimates are presented in Table B-III. Table B-IV lists conservative estimates of the rate of human error as a function of task type and time limit.

TABLE B-I
FERMILAB EQUIPMENT FAILURE RATE ESTIMATES

Component	Failure Mode	Estimated Median Failure Rate
Compressor (Cryogenic)	Leak Rupture	5×10^{-6}/HR 3×10^{-7}/HR
Dewar	Leak or Rupture	1×10^{-6}/HR
Electrical Power Failure (unplanned)	Time Rate Demand Rate Time Off	1×10^{-4}/HR 3×10^{-4}/Demand 1 HR
Fluid Line (Cryogenic)	Leak Rupture	5×10^{-7}/HR 2×10^{-8}/HR
Magnet (Cryogenic, Powered, unmanned)	Leak or Rupture	2×10^{-7}/HR
Magnet (Cryogenic, Not Powered, unmanned)	Leak or Rupture	2×10^{-8}/HR
Header Piping Assembly	Rupture	1×10^{-8}/HR
Change of Equipment with Bayonet Fitting (Cryogenic Release)	Small Event Large Event	3×10^{-2}/Demand 1×10^{-3}/Demand

TABLE B-II
U.S. NRC EQUIPMENT FAILURE RATE ESTIMATES

COMPONENT	FAILURE MODE	FAILURE RATE
Battery Power Supplies	No Output	$3x10^{-6}$/hr
Circuit Breakers	Failure to Operate	$1x10^{-3}$/demand
	Premature Transfer	$1x10^{-6}$/hr
Diesel (Complete Plant)	Failure to Start	$3x10^{-2}$/demand
	Fails to Run (Emergency loads)	$3x10^{-3}$/hr
	Fails to Run (Engine Only)	$3x10^{-4}$/hr
Electric Motors	Failure to Start	$3x10^{-4}$/demand
	Fails to Run	$1x10^{-5}$/hr
	Fails to Run (Extreme Environment)	$1x10^{-3}$/hr
Fuses	Premature Open	$1x10^{-6}$/hr
	Failure to Open	$1x10^{-5}$/demand
Gaskets	Leak	$3x10^{-6}$/hr
Flanges/Closures/Elbows	Leak/Rupture	$3x10^{-7}$/hr
Instrumentation (Amplification, Annunciators, Transducers, Calibration, Combination)	Failure to Operate	$1x10^{-6}$/hr
	Shifts	$3x10^{-5}$/hr
Pipes >3” (High Quality)	Rupture (section)	$1x10^{-10}$/hr
Pipes <3” (High Quality)	Rupture	$1x10^{-9}$/hr
Pumps	Failure to Start	$1x10^{-3}$/demand
	Fails to Run	$3x10^{-5}$/hr
	Fails to Run (Extreme Environment)	$1x10^{-3}$/hr
Relays	Failure to Energize	$1x10^{-4}$/demand
	Failure NO Contact to Close	$3x10^{-7}$/hr
	Short Across NO/NO Contacts	$1x10^{-8}$/hr
	Open NC Contact	$1x10^{-7}$/hr
Solid State Devices (High Power Applications)	Failure to Function	$3x10^{-6}$/hr
	Shorts	$1x10^{-6}$/hr
Solid State Devices (Low Power Applications)	Failure to Function	$1x10^{-6}$/hr
	Shorts	$1x10^{-7}$/hr
Transformers	Open	$1x10^{-6}$/hr
	Short	$1x10^{-6}$/hr
Switches	Limit - Fails to Operate	$3x10^{-4}$/demand
	Torque - Fails to Operate	$1x10^{-4}$/demand
	Pressure - Fails to Operate	$1x10^{-4}$/demand
	Manual - Fails to Transition	$1x10^{-5}$/demand
	Manual – Contact Shorts	$1x10^{-8}$/hr
Valves: MOV	Fails to Operate	$1x10^{-3}$/demand
	Fails to Remain Open (plug)	$1x10^{-4}$/demand
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: SOV	Fails to Operate	$1x10^{-3}$/demand
Valves: AOV	Fails to Operate	$3x10^{-4}$/demand
	Fails to Remain Open (plug)	$1x10^{-4}$/demand
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: Check	Fails to Operate	$1x10^{-4}$/demand
	Reverse Leak	$3x10^{-7}$/hr
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: Vacuum	Fails to Operate	$3x10^{-5}$/demand
	Rupture	$1x10^{-8}$/hr
Valves: Orifices, Flow Meters	Rupture	$1x10^{-8}$/hr

TABLE B-II **U.S. NRC EQUIPMENT FAILURE RATE ESTIMATES**		
COMPONENT	FAILURE MODE	FAILURE RATE
Valves: Manual	Fails to Remain Open (plug)	$1x10^{-4}$/demand
Valves: Relief	Fails to Open	$1x10^{-5}$/demand
	Premature Open	$1x10^{-5}$/hr
Welds	Leaks	$3x10^{-9}$/hr
Wires	Open	$3x10^{-6}$/hr
	Short to Ground	$1x10^{-7}$/hr
	Short to Power	$1x10^{-8}$/hr

TABLE B-III **HUMAN ERROR RATE ESTIMATES**	
Estimated Error Rate (Demand^{-1})	Activity
10^{-3}	Selection of a switch (or pair of switches) dissimilar in shape or location to the desired switch (or pair of switches), assuming no decision error. For example, operator actuates large handled switch rather than small switch.
3×10^{-3}	General human error of commission, e.g., misreading label and therefore selecting wrong switch.
10^{-2}	General human error of omission where there is no display in the control room of the status of the item omitted, e.g., failure to return manually operated test valve to proper configuration after maintenance.
3×10^{-3}	Errors of omission, where the items being omitted are embedded in a procedure rather than at the end as above.
1/x	Given that an operator is reaching for an incorrect switch (or pair of switches), he selects a particular similar appearing switch (or pair of switches), where x = the number of incorrect switches (or pair of switches) adjacent to the desired switch (or pair of switches). The 1/x applies up to 5 or 6 items. After that point, the error rate would be lower because the operator would take more time to search. With up to 5 or 6 items he doesn't expect to be wrong and therefore is more likely to do less deliberate searching.
10^{-1}	Monitor or inspector fails to recognize initial error by operator. Note: With continuing feedback of the error on the annunciator panel, the high error rate would not apply.
10^{-1}	Personnel on different work shift fail to check condition of hardware unless required by check or written directive.
5×10^{-1}	Monitor fails to detect undesired position of valves, etc., during general walk-around inspection, assuming no check list is used.
.2 - .3	General error rate given very high stress levels where dangerous activities are occurring rapidly.
$2^{(n-1)}x$	Given severe time stress, as in trying to compensate for an error made in an emergency situation, the initial error rate, x, for an activity doubles for each attempt, n, after a previous incorrect attempt, until the limiting condition of an error rate of 1.0 is reached or until time runs out. This limiting condition corresponds to an individual's becoming completely disorganized or ineffective.

TABLE B-IV

HUMAN ERROR RATE AS A FUNCTION OF RESPONSE TIME

	Response Time in Seconds		
Maximum Estimated Error Rate ($Demand^{-1}$)	Skill Based Task	Rule Based Task	Knowledge Based Task
10^{-4}	37	600	18,000
10^{-3}	26	300	10,000
10^{-2}	16	130	4,900
10^{-1}	8.7	42	1,800
5×10^{-1}	4.0	10	550

Skill-Based Task – An individual initiates a single-step, learned response upon receipt of an unambiguous sensor cue (i.e., a lone worker initiates escape upon hearing an oxygen deficiency alarm).

Rule-Based Task – An individual or small group of individuals diagnoses and initiates corrective actions for a simple problem given limited or ambiguous input (i.e., several workers decide whether or not to escape given that one of them passes out but no oxygen deficiency alarms sound).

Knowledge-Based Task - A group of individuals diagnoses and initiates corrective actions for novel and/or complex problem.

Fatality Rate Determination

The goal of ODH risk assessment is to estimate the fatality rate due to exposure to oxygen-deficient atmosphere. Since the level of risk is tied to the nature of the operation, the excess fatality rate shall be determined on an operation-by-operation basis. For a given operation several events may cause an oxygen deficiency. Each event has an expected rate of occurrence and each occurrence has an expected probability of causing fatality. The oxygen deficiency hazard fatality rate is defined as:

$$\Phi = \sum_{i=1}^{n} P_i F_i$$

Where:
Φ = the ODH fatality rate (per hour),
P_i = the expected rate of the i^{th} event (per hour), and
F_i = the fatality factor for the i^{th} event.

The summation shall be taken over all events that may cause oxygen deficiency and result in fatality. When possible, the value of P_i shall be determined from empirical data; otherwise data from similar systems or other relevant reference values shall be used.

ODH CONTROL MEASURES

	ODH Hazard Class				
Environmental Controls	**0**	**1**	**2**	**3**	**4**
1. Warning signs	X	X	X	X	X
2. Ventilation			X	X	X
ODH-Qualified Personnel Controls					
3. Medical approval as ODH-qualified		X	X	X	X
4. ODH training	X	X	X	X	X
5. Personal oxygen monitor		X	X	X	X
6. Self-rescue supplied atmosphere respirator		X	X	X	
7. Multiple personnel in communication			X		
8. Unexposed observer				X	X
9. Self-contained breathing apparatus					X

X = Required

KEY TO ODH CONTROL MEASURES

1. Warning Signs - ODH signs shall be posted to warn potentially exposed individuals. See your ES&H Coordinator for signs.
2. Ventilation - The minimum ventilation rate during occupancy should be at least one volume change per hour. This may be accomplished by any reliable means.
3. Medical Approval as ODH-Qualified - These precautions shall only apply to individuals who have been classified as ODH-qualified by the Occupational Medical Clinic (OMC).
4. ODH Training - Individuals shall receive training in oxygen deficiency hazards and safety measures associated with the operation. Annual retraining shall be required. Training is the responsibility of the Department/Division in charge of operations.
5. Personal Oxygen Monitor - The Department/Division issuing personal oxygen monitors is responsible for having a program in place to insure that they are in compliance with this policy.

    - Personal oxygen monitors shall not be used beyond the date they are due for re-calibration. If past due, the monitor shall be returned to the individual or organization that issued it to arrange for re-calibration.
    - Each monitor shall have a unique identifying number and a sticker indicating the date due for calibration. The date is to be the last day of the month indicated on the calibration sticker.
    - An ODH-qualified individual using a personal oxygen monitor is responsible for inspecting the calibration sticker on the monitor before use and insuring that it is not past due for calibration.
    - An ODH-qualified escort is responsible for insuring that the personal oxygen monitor(s) of those being escorted are not past due for calibration.

6. Self-Rescue Supplied Atmosphere Respirator - Individuals shall have ready access to self-rescue supplied atmosphere respirators during the operation unless this requirement was found inappropriate in the risk analysis.
7. Multiple Personnel in Communication - More than one individual shall be present; all of who shall meet requirement (3), (4), and (5) above.
8. Unexposed Observer - All personnel engaged in the operation shall be in continuous communication with an observer who cannot be exposed to an oxygen deficiency. The purpose of the observer shall be to summon the Fire/Rescue Group in case of need.
9. Self-Contained Breathing Apparatus - Individuals shall be wearing a self-contained breathing apparatus (SCBA) during the operation. Prior designation as medically fit to wear an SCBA by the OMC is required before training in SCBA.

Oxygen Concentration in Ventilated Spaces

The oxygen concentration in a confined volume during and after a release of an inert gas may be approximated for three different cases:

A. Ventilation fan(s) blowing into the confined volume.
B. Ventilation fan(s) drawing from the confined volume with the ventilation rate greater than the spill rate.
C. Ventilation fan(s) drawing from the confined volume with the ventilation rate less than or equal to the spill rate.

For each case, the differential equation and its solution is given, based on an oxygen mass balance for the confined volume. The following definitions and assumptions are common for each case.

Definitions

C = oxygen concentration
C_r = oxygen concentration during the release
C_e = oxygen concentration after the release has ended
Q = ventilation rate of fan(s), (cfm or m^3/s)
R = spill rate into confined volume, (scfm or m^3/s)
t = time (minutes or seconds), beginning of release is at t=0
t_e = time when release has ended, (minutes or seconds)
V = confined volume, (ft^3 or m^3)

Assumptions

- Complete and instantaneous mixing takes place in the confined volume.
- Q, R, and V remain constant
- Pressure in the confined volume remains constant and very near atmospheric pressure through the use of louvers or natural leakage.
- Gas entering from outside the confined volume is air with an oxygen concentration of 0.21 (21% by volume).

Case A: Ventilation fan(s) blowing into the confined volume.

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21Q - (R+Q)C$$

The solution for the boundary condition of C=0.21 at t=0 is

$$C_r(t) = \left[\frac{0.21}{Q+R}\right]\left[Q + \mathrm{Re}^{[-(Q+R)t/V]}\right]$$

Case B: <u>Ventilation fans(s) drawing from the confined volume with the ventilation rate greater than the spill rate</u> (Q>R).

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21(Q-R) - QC$$

The solution with the boundary condition of C=0.21 at t=0 is

$$C_r(t) = 0.21\left\{1 - \frac{R}{Q}\left[1 - e^{(-Qt/V)}\right]\right\}$$

Case C <u>Ventilation fan(s) drawing from the confined volume with the ventilation rate less than or equal to the spill rate.</u>

Differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = -RC$$

The solution with the boundary condition of C=0.21 at t=0 is

$$C_r(t) = 0.21e^{[-Rt/V]}$$

Case D <u>After Release has ended</u>

The oxygen concentration in the confined volume after the release has ended, Ce (t), can be approximated by one equation for all three cases.

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21Q - QC$$

The solution with the boundary condition of C=Cr (te) at t=te , where (t-te) is the time duration since the release ended is

$$C_e(t) = 0.21 - \left[0.21 - C_r(t_e)\right]e^{[-Q(t-t_e)/V]}$$

EFFECT THRESHOLDS FOR EXPOSURE TO REDUCED OXYGEN (Normal Individuals at Rest at Sea Level)	
Volume Oxygen %	Oxygen Effect
17	Night vision reduced Increased breathing volume Accelerated heartbeat
16	Dizziness Increased time doubled for novel tasks
15	Impaired attention Impaired judgment Impaired coordination Intermittent breathing Rapid fatigue Loss of muscle control
12	Very faulty judgment Very poor muscular coordination Loss of consciousness Permanent brain damage
10	Inability to move Nausea Vomiting
6	Spasmodic breathing Convulsive movements Death in 5 - 8 minutes

Definitions: Oxygen Deficiency Hazards (ODH), System Classification and Controls

Effective Date: **April 2001**

Point of Contact: Safety Engineering

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>mm Hg</td><td>Millimeters of mercury representing or measuring a pressure by relating it to the weight of a liquid mercury column (1 mm Hg = 1 Torr).</td></tr>
<tr><td>ODH-qualified</td><td>Staff who are ODH trained and medically fit to participate in all ODH Class operations.</td></tr>
<tr><td>ODH-restricted</td><td>Staff who are ODH trained and medically fit to participate in ODH Class 0 only.</td></tr>
<tr><td>oxygen concentration</td><td>The molar fraction of a gaseous mixture represented by oxygen. It is also equal to the ratio of the partial pressure of oxygen to the total mixture pressure.</td></tr>
<tr><td>oxygen-deficient atmosphere</td><td>An atmosphere with an oxygen content below 19.5% by volume (as defined by the OSHA Respiratory Protection Regulation, 29CFR1910.134).</td></tr>
<tr><td>oxygen deficiency hazard (ODH)</td><td>The condition where the body does not absorb sufficient oxygen from the atmosphere to support the biochemical activity of the brain and other vital organs. This is typically recognized when the partial pressure of atmospheric oxygen is less than 110 mm Hg (represents an altitude of 10,000 feet).</td></tr>
<tr><td>oxygen deficiency hazard class</td><td>
<table>
<tr><th>ODH Class</th><th>Fatalities/Hr</th></tr>
<tr><td>No Classification Required</td><td>0 (Oxygen concentration not less than 18%)</td></tr>
<tr><td>0</td><td>$<10^{-7}$ note 1</td></tr>
<tr><td>1</td><td>$>=10^{-7}$ but $<10^{-5}$</td></tr>
<tr><td>2</td><td>$>=10^{-5}$ but $<10^{-3}$</td></tr>
<tr><td>3</td><td>$>=10^{-3}$ but $<10^{-1}$</td></tr>
<tr><td>4</td><td>$>=10^{-1}$</td></tr>
</table>
Note 1: Areas that have Departmental/Divisional controls established that can demonstrate the fatality rate is less than 10^{-9} by engineering/safety analysis, may not have to have an ODH classification (SME concurrence required).</td></tr>
<tr><td>parts per million (ppm)</td><td>The number of parts of a particular gas in a million parts of air. Use of ppm as a volumetric measurement (not a weight measurement) avoids the use of awkward decimals required to express low concentrations.</td></tr>
<tr><td>personal oxygen monitor (POM)</td><td>A direct-reading alarming monitor that measures the oxygen concentration as a percentage of air.</td></tr>
<tr><td>personal protective</td><td>Devices used by staff to control or mitigate a hazard, including gas concentration</td></tr>
</table>

personal protective equipment (PPE)	Devices used by staff to control or mitigate a hazard, including gas concentration self-monitors (such as POM or Bacharach Oxygen Monitor) and Self-Rescue Supplied Atmosphere Respirators.
Self-Rescue Supplied Atmosphere Respirator (SRSAR)	A device containing breathing air to be used for escape during an ODH event.
Torr	A unit of pressure equal to 1 mm Hg; 760 Torr = 29.92 in of Hg (normal atmospheric pressure at sea level).
unrestricted	Areas that have been evaluated for ODH but have a fatality rate of less than 10^{-7} per hour.
volume concentration	The ratio of the volume of a specific gas to the total volume occupied by a mixture of gases at any temperature and pressure. It is used when the volume parameter has definite physical significance. In the case of explosive or oxygen-enriched atmospheres, volume concentration serves as a useful criterion for evaluating a potentially hazardous condition. Volume concentration is calculated as follows: Volume concentration (in percent) = {(Partial Pressure/Total Pressure) x 100}.

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Revision History: Oxygen Deficiency Hazards (ODH), System Classification and Controls

Point of Contact: Safety Engineering

Revision History of this Subject Area

Date	Description	Management System
April 2001	This subject area was revised in response to an assessment from the DOE Brookhaven Area Office (CC2001-1559). The title of the subject area was changed from Oxygen Deficiency Hazards (ODH) to Oxygen Deficiency Hazards (ODH), System Classification and Controls, to clarify the purpose of the subject area. The subject area describes the classification procedure for oxygen-deficient atmospheresand the required controls based on the classification. It does not specify requirements for working in areas where oxygen concentrations would require respiratory protection. References to 29 CFR 1910.134, OSHA Respiratory Protection Standard, Work Planning and Control for Experiments and Operations Subject Area, and ES&H Standard 2.2.4, Confined Space entry requirements were specified. The subject area also was revised to remove discrepancies with the OSHA Respiratory Protection Standard, which defines an oxygen-deficient atmosphere at 19.5% oxygen concentration. Requirements for medical approval for visitors in ODH 1 or greater areas were deleted based on OSHA interpretation dated 03/08/1999, "Medical Evaluation not Required for the Use of Escape Only Respirators." The section on ODH Training was also deleted. Sections 3. Emergency Evacuation and Rescue and 4. Reentry into ODH Areas after Alarm were revised to include requirements for training.	Worker Safety and Health
November 1999	This information was developed by a team using the process for Standards-Based Management development. This is a new subject area.	Worker Safety and Health

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