CHAPTER 10

Nitrogen-Oxygen Diving Operations

10-1 INTRODUCTION

Nitrogen-oxygen (NITROX) diving is a unique type of diving using nitrogen-oxygen breathing gas mixtures ranging from 75 percent nitrogen/25 percent oxygen to 60 percent nitrogen/40 percent oxygen. Using NITROX significantly increases the amount of time a diver can spend at depth without decompressing. It also decreases the required decompression time compared to a similar dive made to the same depth using air. NITROX may be used in all diving operations suitable for air, but its use is limited to a normal depth of 140 fsw.

NITROX breathing gas mixtures are normally used for shallow dives. The most benefit is gained when NITROX is used shallower than 50 fsw, but it can be advantageous when used to a depth of 140 fsw.

10-1.1 Advantages and Disadvantages of NITROX Diving. The advantages of using NITROX rather than air for diving include:

- Extended bottom times for no-decompression diving.
- Reduced decompression time.
- Reduced residual nitrogen in the body after a dive.
- Reduced possibility of decompression sickness.
- Reduced Nitrogen Narcosis

The disadvantages of using NITROX include:

- Increased risk of CNS oxygen toxicity.
- Producing NITROX mixtures requires special equipment.
- NITROX equipment requires special cleaning techniques.
- Long-duration NITROX dives can result in pulmonary oxygen toxicity.
- Working with NITROX systems requires special training.
- NITROX is expensive to purchase.

10-2 EQUIVALENT AIR DEPTH

The partial pressure of nitrogen in a NITROX mixture is the key factor determining the diver’s decompression obligation. Oxygen plays no role. The decompression obligation for a NITROX dive therefore can be determined using the Standard Air Tables simply by selecting the depth on air that has the same partial pressure of nitrogen as the NITROX mixture. This depth is called the Equivalent Air Depth (EAD). For example, the nitrogen partial pressure in a 68% nitrogen 32% oxygen mixture at 63 fsw is 2.0 ata. This is the same partial pressure of nitrogen found in air at 50 fsw. 50 fsw is the Equivalent Air Depth.

10-2.1 Equivalent Air Depth Calculation.

The Equivalent Air Depth can be computed from the following formula:

$$EAD = \frac{(1 - O_2\%)\ (D + 33)}{0.79} - 33$$

Where:

EAD = equivalent depth on air (fsw)
D = diving depth on mixture (fsw)
$O_2\%$ = oxygen concentration in breathing medium (percentage decimal)

For example, while breathing a mixture containing 40 percent oxygen ($O_2\%$ = 0.40) at 70 fsw (D = 70), the equivalent air depth would be:

$$EAD = \frac{(1 - 0.40)\ (70 + 33)}{0.79} - 33$$

$$= \frac{(0.60)\ (103)}{0.79} - 33$$

$$= \frac{61.8}{0.79} - 33$$

$$= 78.22 - 33$$

$$= \mathbf{45.2\ fsw}$$

Note that with NITROX, the Equivalent Air Depth is always shallower than the diver's acual depth. This is the reason that NITROX offers a decompression advantage over air.

10-3 OXYGEN TOXICITY

Although the use of NITROX can increase the diver's bottom time and reduce the risk of nitrogen narcosis, using a NITROX mixture raises the concern for oxygen toxicity. For example, using air as the breathing medium, an oxygen partial pressure (ppO_2) of 1.6 ata is reached at a depth of 218 fsw. In contrast, when using the NITROX mixture containing 60 percent nitrogen and 40 percent oxygen, a ppO_2 of 1.6 ata is reached at 99 fsw. Therefore, oxygen toxicity must be considered when diving a NITROX mixture and is a limiting factor when considering depth and duration of a NITROX dive.

Generally speaking, there are two types of oxygen toxicity—central nervous system (CNS) oxygen and pulmonary oxygen toxicity. CNS oxygen toxicity is usually not encountered unless the partial pressure of oxygen approaches or exceeds 1.6 ata, but it can result in serious symptoms (see paragraph 3-10.2.2), including potentially life-threatening convulsions. Pulmonary oxygen toxicity may result from conducting long-duration dives at oxygen partial pressures in excess of 1.0 ata. For example, a dive longer than 240 minutes at 1.3 ata or a dive longer than 320 minutes at 1.1 ata may place the diver at risk if the exposure is on a daily basis. Pulmonary oxygen toxicity under these conditions can result in decrements of pulmonary function, but is not life threatening.

The NITROX Equivalent Air Depth (EAD) Decompression Selection Table (Table 10-1) was developed considering both CNS and pulmonary oxygen toxicity. Normal working dives that exceed a ppO_2 of 1.4 ata are not permitted, principally to avoid the risk of CNS oxygen toxicity. Dives with a ppO_2 less than 1.4 ata, however, can be conducted using the full range of bottom times allowed by the air tables without concern for CNS or pulmonary oxygen toxicity.

Supervisors must keep in mind that pulmonary oxygen toxicity may become an issue with frequent, repetitive diving. The effects of pulmonary oxygen toxicity can be cumulative and can reduce the underwater work performance of susceptible individuals after a long series of repetitive daily exposures. Fatigue, headache, flu-like symptoms, and numbness of the fingers and toes may also be experienced with repetitive exposures. Table 10-1 takes these repetitive exposures into account, and therefore problems with oxygen toxicity should not be encountered with its use. If symptoms are experienced, the diver should stop diving NITROX until they resolve.

10-3.1 **Selecting the Proper NITROX Mixture.** Considerable caution must be used when selecting the proper NITROX mixture for a dive. The maximum depth of the dive must be known as well as the planned bottom time. Once the maximum depth is known, the various NITROX mixtures can be evaluated to determine which one will provide the least amount of decompression while also allowing for a maximum bottom time. If a diver's depth exceeds that allowed for a certain NITROX mixture, the diver is at great risk of life-threatening oxygen toxicity.

10-4 NITROX DIVING PROCEDURES

10-4.1 **NITROX Diving Using Equivalent Air Depths.** NITROX diving is based upon the current U.S. Navy Air Decompression Tables. The actual schedule used is adjusted for the oxygen percentage in the breathing gas. To use the EAD Decompression Selection Table (Table 10-1), find the actual oxygen percentage of the breathing gas in the heading and the diver's actual depth in the left column to determine the appropriate schedule to be used from the U.S. Navy Air Decompression Tables. The EAD decompression schedule is where the column and row intersect. Dives using NITROX may be used with any schedule from the U.S. Navy Air Decompression Tables (No-Decompression Limits for Air, Standard Air Decompression, Surface Decompression using Air or Surface Decompression Using Oxygen). When using Table 10-1, round all gas mixtures using the standard rounding rule where gas mixes at or above 0.5% round up to the next whole percent and mixes of 0.1% to 0.4% round down to the next whole percent. Once an EAD is determined and a Navy air table is selected, follow the rules of the Navy air table using the EAD for the remainder of the dive.

Table 10-1. Equivalent Air Depth Table.

Diver's Actual Depth (fsw)	EAD Feet															
	25% O_2	26% O_2	27% O_2	28% O_2	29% O_2	30% O_2	31% O_2	32% O_2	33% O_2	34% O_2	35% O_2	36% O_2	37% O_2	38% O_2	39% O_2	40% O_2
20	20	20	20	20	20	20	20	15	15	15	15	15	10	10	10	10
30	30	30	30	30	30	30	30	25	25	25	20	20	20	20	20	20
40	40	40	40	40	40	40	40	35	30	30	30	30	30	30	25	25
50	50	50	50	50	50	50	50	40	40	40	40	40	35	35	35	35
60	60	60	60	60	60	60	50	50	50	50	50	50	50	50	40	40
70	70	70	70	70	70	60	60	60	60	60	60	60	50	50	50	50
80	80	80	80	80	70	70	70	70	70	70	70	60	60	60	60	60
90	90	90	90	90	80	80	80	80	80	80	70	70	70 (:107)	70 (:80)	70 (:61)	70 (:47)
100	100	100	100	90	90	90	90	90	90	80 (:113)	80 (:82)	80 (:61)	80 (:46)	80 (:36)	80 (:29)	70 (:23)
110	110	110	110	100	100	100	100	100 (:96)	100 (:69)	90 (:51)	90 (:39)	90 (:30)				
120	120	120	120	110	110	110 (:91)	110 (:64)	110 (:47)	100 (:35)	100 (:27)						
130	130	130	120	120 (:95)	120 (:65)	120 (:47)	120 (:35)	110 (:26)								
140	140	140 (:109)	130 (:73)	130 (:50)	130 (:36)											
150	150 (:89)	150 (:59)	140 (:41)													
160	160 (:50)	160 (:35)														

EAD = Equivalent Air Depth - For Decompression Table Selection Only Rounded to Next Greater Depth

= 1.4 ata Normal working limit.

= Depth exceeds the normal working limit, requires the Commanding Officer's authoration and surface-supplied equipment. Repetitive dives are not authorized. Times listed in parentheses indicate maximum allowable exposure.

Note[1]: **Depths not listed are considered beyond the safe limits of NITROX diving**.

Note[2]: The EAD, 1.4 ata Normal Working Limit Line and Maximum Allowable Exposure Time for dives deeper than the Normal Working Limit Line are calculated assuming the diver rounds the oxygen percentage in the gas mixture using the standard rounding rule discussed in paragraph 10-4.1. The calculations also take into account the allowable ± 0.5 percent error in gas analysis.

10-4.2 **Scuba Operations.** For Scuba operations, analyze the nitrox mix in each bottle to be used prior to every dive.

10-4.3 Special Procedures. In the event there is a switch to air during the NITROX dive, using the diver's maximum depth and bottom time follow the U.S. Navy Air Decompression Table for the actual depth of the dive.

10-4.4 Omitted Decompression. In the event that the loss of gas required a direct ascent to the surface, any decompression requirements must be addressed using the standard protocols for "omitted decompression." For omitted decompression dives that exceed the maximum depth listed on Table 10-1, the diving supervisor must rapidly calculate the diver's EAD and follow the omitted decompression procedures based on the diver's EAD, not his or her actual depth. If time will not permit this, the diving supervisor can elect to use the diver's actual depth and follow the omitted decompression procedures.

10-4.5 Dives Exceeding the Normal Working Limit. The EAD Table has been developed to restrict dives with a ppO_2 greater than 1.4 ata and limits dive duration based on CNS oxygen toxicity. Dives exceeding the normal working limits of Table 10-1 require the Commanding Officer's authorization and are restricted to surface-supplied diving equipment only. All Equivalent Air Depths provided below the normal working limit line have the maximum allowable exposure time listed alongside. This is the maximum time a diver can safely spend at that depth and avoid CNS oxygen toxicity. Repetitive dives are not authorized when exceeding the normal working limits of Table 10-1.

10-5 NITROX REPETITIVE DIVING

Repetitive diving is possible when using NITROX or combinations of air and NITROX. Once the EAD is determined for a specific dive, the Standard Navy Air Tables are used throughout the dive using the EAD from Table 10-1.

The Residual Nitrogen Timetable for Repetitive Air Dives will be used when applying the EAD for NITROX dives. Determine the Repetitive Group Designator for the dive just completed using either Table 9-7, Unlimited/No-Decompression Limits and Repetitive Group Designation Table for Unlimited/No-Decompression Air Dives or Table 9-7, U.S. Navy Standard Air Decompression Table.

Enter Table 9-7, Residual Nitrogen Timetable for Repetitive Air Dives, using the repetitive group designator. If the repetitive dive is an air dive, use Table 9-7 as is. If the repetitive dive is a NITROX dive, determine the EAD of the repetitive dive from Table 10-1 and use that depth as the repetitive dive depth.

10-6 NITROX DIVE CHARTING

The NITROX Diving Chart (Figure 10-1) should be used for NITROX diving and filled out as described in Chapter 4. The NITROX chart has additional blocks for the EAD and the percentage of gas in the NITROX mix.

DIVING CHART - NITROX

				DATE
NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)	PERCENTAGE
NAME OF DIVER 1	DIVING APPARATUS	TYPE DRESS	EGS (PSIG)	PERCENTAGE

TENDERS (DIVER 1)			TENDERS (DIVER 2)	
LEFT SURFACE (LS)	DEPTH (FSW)	E A D	REACHED BOTTOM (RB)	DESCENT TIME
LEFT BOTTOM (LB)	TOTAL BOTTOM TIME (TBT)		TABLE & SCHEDULE USED	TIME TO FIRST STOP
REACHED SURFACE (RS)	TOTAL DECOMPRESSION TIME (TDT)		TOTAL TIME OF DIVE (TTD)	REPETITIVE GROUP

DESCENT	ASCENT	DEPTH OF STOPS	DECOMPRESSION TIME		TIME	
			WATER	CHAMBER	WATER	CHAMBER
		10			L	
					R	
		20			L	
					R	
		30			L	
					R	
		40			L	
					R	
		50			L	
					R	
		60			L	
					R	
		70			L	
					R	
		80			L	
					R	
		90			L	
					R	
		100			L	
					R	
		110			L	
					R	
		120			L	
					R	
		130			L	
					R	

PURPOSE OF DIVE	REMARKS
DIVER'S CONDITION	DIVING SUPERVISOR

Figure 10-1. NITROX Diving Chart.

10-7 FLEET TRAINING FOR NITROX

A Master Diver shall conduct training for NITROX diving prior to conducting NITROX diving operations. Actual NITROX dives are not required for this training. The following are the minimum training topics to be covered:

- Pulmonary and CNS oxygen toxicity associated with NITROX diving.
- EAD tables and their association with the Navy air tables.
- Safe handling of NITROX mixtures.

NITROX Charging and Mixing Technicians must be trained on the following topics:

- Oxygen handling safety.
- Oxygen analysis equipment.
- NITROX mixing techniques.
- NITROX cleaning requirements (MILSTD 1330 Series).

10-8 NITROX DIVING EQUIPMENT

NITROX diving can be performed using a variety of equipment that can be broken down into two general categories: surface-supplied or closed- and open-circuit scuba. Closed-circuit scuba apparatus is discussed in Chapter 17.

10-8.1 Open-Circuit Scuba Systems. Open-circuit scuba systems for NITROX diving are identical to air scuba systems with one exception: the scuba bottles are filled with NITROX (nitrogen-oxygen) rather than air. There are specific regulators authorized for NITROX diving, which are identified on the ANU list. These regulators have been tested to confirm their compatibility with the higher oxygen percentages encountered with NITROX diving.

10-8.1.1 **Regulators.** Scuba regulators designated for NITROX use should be cleaned to the standards of MILSTD 1330. Once designated for NITROX use and cleaned, the regulators should be maintained to the level of cleanliness outlined in MIL-STD 1330.

10-8.1.2 **Bottles.** Scuba bottles designated for use with NITROX should be oxygen cleaned and maintained to that level. The bottles should have a NITROX label in large yellow letters on a green background. Once a bottle is cleaned and designated for NITROX diving, it should not be used for any other type of diving (Figure 10-2).

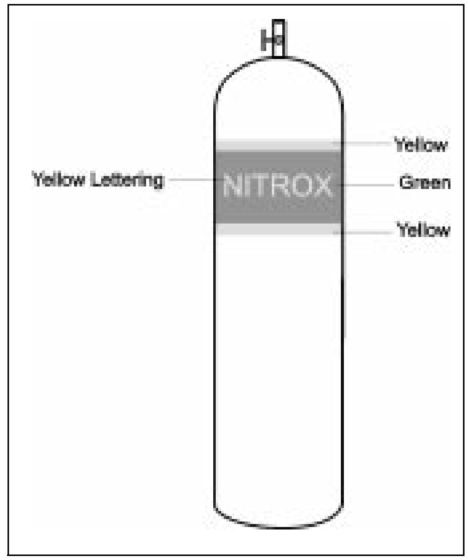

Figure 10-2. NITROX Scuba Bottle Markings.

10-8.2 General. All high-pressure flasks, scuba cylinders, and all high-pressure NITROX charging equipment that comes in contact with 100 percent oxygen during NITROX diving, mixing, or charging evolutions much be cleaned and maintained for NITROX service in accordance with the current MILSTD 1330 series.

10-8.3 Surface-Supplied NITROX Diving. Surface-supplied NITROX diving systems must be modified to make them compatible with the higher percentage of oxygen found in NITROX mixtures. A request to convert the system to NITROX must be forwarded to NAVSEA 00C for review and approval. The request must be accompanied by the proposed changes to the Pre-survey Outline Booklet (PSOB) permitting system use with NITROX. Once the system is designated for NITROX, it shall be labeled NITROX with large yellow letters on a green background. MILSTD 1330.D outlines the cleanliness requirements to which a surface-supplied NITROX system must be maintained.

A NITROX system must not be used for air diving except in an emergency. Once a designated NITROX system is used with air, it must be re-cleaned to MILSTD 1330 series prior to use with NITROX. An exception to this would be if the air used in the banks is charged with an oil-free NITROX-approved compressor or if the air meets the purity requirements of oil-free air.

The EGS used in surface-supplied NITROX diving shall be filled with the same mixture that is being supplied to the diver ± 0.5 percent.

10-9 EQUIPMENT CLEANLINESS

Cleanliness and the procedures used to obtain cleanliness are a concern with NITROX systems. MILSTD 1330 is applicable to anything with an oxygen level higher than 25 percent by volume. Therefore, MILSTD 1330 must be followed when dealing with NITROX systems. Personnel involved in the maintenance and repair of NITROX equipment shall complete an oxygen clean worker course, as described in MILSTD 1330. Even with oxygen levels of 25 to 40 percent, there is still a greater risk of fire than with compressed air. Materials that would not normally burn in air may burn at these higher O_2 levels. Normally combustible materials require less energy to ignite and will burn faster. The energy required for ignition can come from different sources, for example adiabatic compression or particle impact/spark. Another concern is that if improper cleaning agents or processes are used, the agents themselves can become fire or toxic hazards. It is therefore important to adhere to MILSTD 1330 to reduce the risk of damage or loss of equipment and injury or death of personnel.

10-10 BREATHING GAS PURITY

It is essential that all gases used in producing a NITROX mixture meet the breathing gas purity standards outlined in Volume 3. If air is to be used to produce a mixture, it must be compressed using an oil-free NITROX-approved compressor or meet the purity requirements of oil-free air. Prior to diving, all NITROX gases shall be analyzed using an approved O_2 analyzer accurate to within ± 0.5 percent.

10-11 NITROX MIXING

NITROX mixing can be accomplished by a variety of techniques to produce a final predetermined nitrogen-oxygen mixture. The techniques for mixing NITROX are listed as follows:

1. **Continuous Flow Mixing**. There are two techniques for continuous flow mixing:

   a. **Mix-maker**. A mix-maker uses a precalibrated mixing system that proportions the amount of each gas in the mixture as it is delivered to a common mixing chamber. A mix-maker performs a series of functions that ensures accurate mixtures. The gases are regulated to the same temperature and pressure before they are sent through precision metering valves. The valves are precalibrated to provide the desired mixing pressure. The final mixture can be provided directly to the divers or be compressed using an oil-free compressor into storage banks.

   b. **Oxygen Induction**. Oxygen induction uses a system where low pressure oxygen is delivered to the intake header of an oil-free compressor, where it is mixed with the air being drawn into the compressor. Oxygen flow is adjusted and the compressor output is monitored for oxygen content. When the desired NITROX mixture is attained the gas is diverted to the storage banks for diver use while being continually monitored for oxygen content (Figure 10-3).

2. **Mixing by Partial Pressure**. Partial pressure mixing techniques are similar to those used in helium-oxygen mixed gas diving and are discussed in Chapter 16.

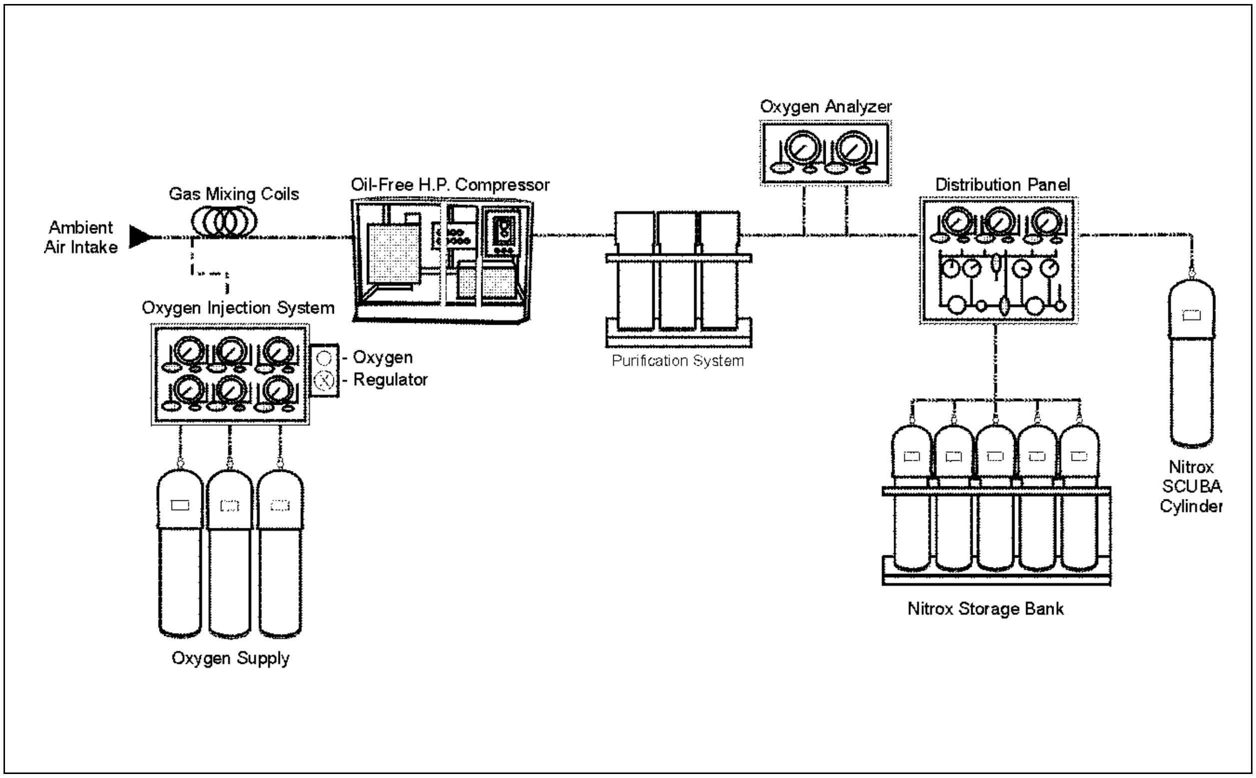

Figure 10-3. Nitrox O_2 Injection System.

a. **Partial Pressure Mixing with Air.** Oil-free air can be used as a Nitrogen source for the partial pressure mixing of NITROX using the following procedures:

- Prior to charging air into a NITROX bottle, the NITROX mixing technician shall smell, taste, and feel the oil-free air coming from the compressor for signs of oil, mist, or particulates, or for any unusual smell. If any signs of compressor malfunction are found, the system must not be used until a satisfactory air sample has been completed.

- Prior to charging with oxygen, to produce a NITROX mix, the NITROX-charging technician shall charge the bottle to at least 100 psi with oil-free air. This will reduce the risk of adiabatic compression temperature increase. Once 100 psi of oil-free air has been added to the charging vessel, the required amount of oxygen should then be added. The remaining necessary amount of oil-free air can then be safely charged into the bottle. The charging rate for NITROX mixing shall not exceed 200 psi per minute.

WARNING **Mixing contaminated or non-oil free air with 100% oxygen can result in a catastrophic fire and explosion.**

- Compressed air for NITROX mixing shall meet the purity standards for "Oil-Free Air," (Table 10-2). All compressors producing air for NITROX mixing shall have a filtration system designed to produce oil-free air that has been approved by NAVSEA 00C3. In addition, all compressors producing oil-free air for NITROX charging shall have an air sample taken within 90 days prior to use.

Table 10-2. *Oil-Free Air.*

Constituent	Specification
Oxygen (percent by volume)	20-22%
Carbon dioxide (by volume)	500 ppm (max)
Carbon monoxide (by volume)	2 ppm (max)
Total hydrocarbons [as Methane (CH_4) by volume]	25 ppm (max)
Odor	Not objectionable
Oil, mist, particulates	0.1 mg/m^3 (max)
Separated Water	None
Total Water	0.02 mg/1 (max)
Halogenated Compounds (by volume):	
Solvents	0.2 ppm (max)

3. **Mixing Using a Membrane System**. Membrane systems selectively separate gas molecules of different sizes such as nitrogen or oxygen from the air. By removing the nitrogen from the air in a NITROX membrane system the oxygen percent is increased. The resulting mixture is NITROX. Air is fed into an in-line filter canister system that removes hydrocarbons and other contaminants. It is then passed into the membrane canister containing thousands of hollow membrane fibers. Oxygen permeates across the membrane at a controlled rate. The amount of nitrogen removed is determined by a needle valve. Once the desired nitrogen-oxygen ratio is achieved, the gas is diverted through a NITROX-approved compressor and sent to the storage banks (see Figure 10-4 and Figure 10-5). Membrane systems can also concentrate CO_2 and argon.

4. **Mixing Using Molecular Sieves**. Molecular sieves are columns of solid, highly selective chemical absorbent which perform a similar function to membrane systems, and are used in a similar fashion. Molecular sieves have the added advantage of absorbing CO_2 and moisture from the feed gas.

5. **Purchasing Premixed NITROX**. Purchasing premixed NITROX is an acceptable way of obtaining a NITROX mixture. When purchasing premixed NITROX it is requisite that the gases used in the mixture meet the minimum purity standards listed in volume 3.

10-12 NITROX MIXING, BLENDING, AND STORAGE SYSTEMS

Nitrox mixing, blending, and storage systems shall be designed for oxygen service and constructed using oxygen-compatible material following accepted military and commercial practices in accordance with either ASTM G-88, G-63, G-94, or MILSTD 438 and 777. Commands should contact NAVSEA 00C for specific guidance on developing NITROX mixing, blending, or storage systems. Commands are not authorized to build or use a NITROX system without prior NAVSEA 00C review and approval.

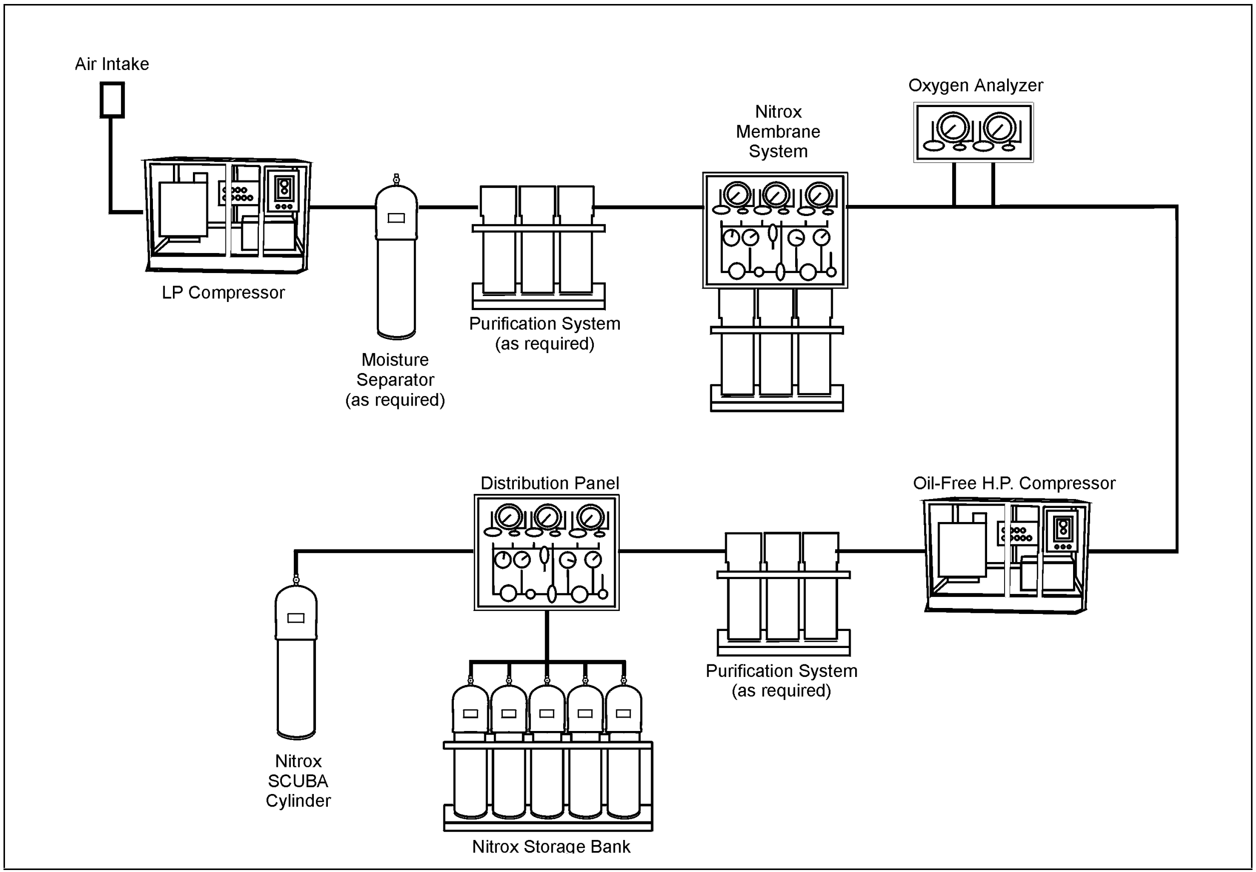

Figure 10-4. LP Air Supply NITROX Membrane Configuration.

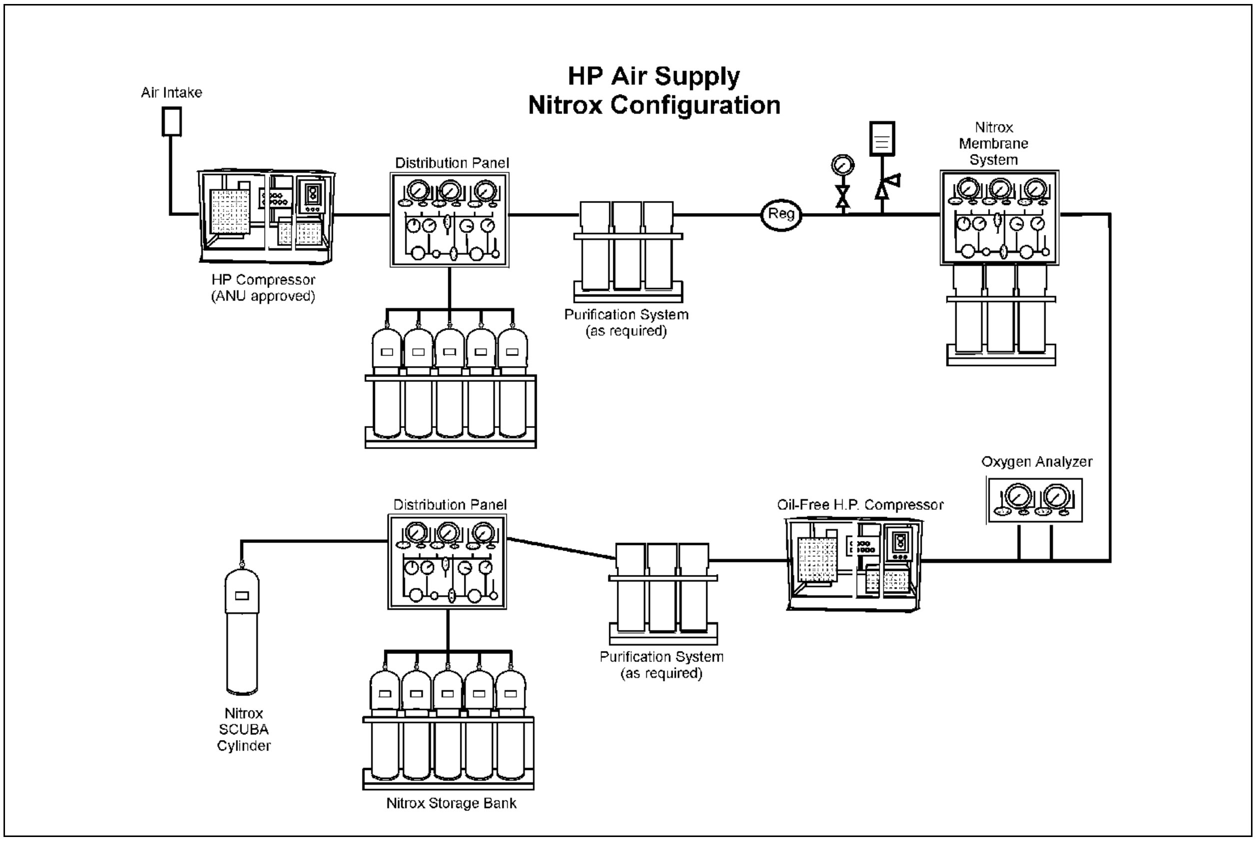

Figure 10-5. HP Air Supply NITROX Membrane Configuration.

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