

would inform divers of the remaining supply of breathing-gas ingredients (*i.e.*, O<sub>2</sub> and air or nitrogen), thereby preventing an unexpected loss of breathing gas during a dive; Low gas supplies would alert the divers to an unusually high consumption of breathing gas, indicating a possible problem with the rebreather. A gas loss also could increase the need for a diver to make a rapid (*i.e.*, emergency) ascent to the surface during a dive, which could result in over-pressurization of the lungs associated with AGE.

OSHA believes that temperature sensors improve diver safety. Water-temperature sensors alert divers to the possibility of hypothermia. In addition, the efficiency of the CO<sub>2</sub>-sorbent material deteriorates with decreasing temperatures (see Reference (4), Section III below). Breathing-loop temperature sensors and water-temperature sensors allow divers to estimate the duration of their CO<sub>2</sub>-sorbent material. When divers are able to estimate the duration of their CO<sub>2</sub>-sorbent material, they can judge how long they can continue diving even if their CO<sub>2</sub> sensors malfunction.

(b) *O<sub>2</sub> sensors.* Under this proposed condition, employers must ensure that at least two O<sub>2</sub> sensors are located in the inhalation side of the breathing loop, and that these O<sub>2</sub> sensors function continuously, are temperature compensated, and approved by the rebreather manufacturer. OSHA believes that this proposal would provide the divers with critical information regarding O<sub>2</sub> levels in the breathing gas, thereby preventing O<sub>2</sub> deficiency or O<sub>2</sub> toxicity resulting, respectively, from low or high O<sub>2</sub> levels in the breathing-gas mixture. By assuring appropriate levels of O<sub>2</sub>, the proposed condition would minimize the need for emergency escape and, as a consequence, reduce the risk of developing AGE.

(c) *Calibrating O<sub>2</sub> sensors.* Proposed Condition 2(c) specifies that employers, before the start of each day's diving operations, and more often when necessary, must calibrate O<sub>2</sub> sensors as required by the sensor manufacturer's instructions. Therefore, before they place a rebreather in operation, employers must: (i) Ensure that the equipment and procedures used to perform the calibration are accurate to within 1% of the O<sub>2</sub> fraction by volume; (ii) maintain the accuracy of the calibration equipment as required by the manufacturer of the equipment; (iii) ensure that the sensors are accurate to within 1% of the O<sub>2</sub> fraction by volume; (iv) replace O<sub>2</sub> sensors when they fail to meet the accuracy requirements specified above in proposed Condition 2(c)(iii); and (v) ensure that the replacement O<sub>2</sub> sensors meet the

accuracy requirements specified above in proposed Condition 2(c)(iii).

As noted under proposed Condition 3 below, maintaining accurate O<sub>2</sub> levels in the breathing loop is critical to a diver's safety and health. To assure effective operation of O<sub>2</sub> sensors for this purpose, the introduction to proposed Condition 2(c) would require the employer to assess the accuracy of O<sub>2</sub> sensors before the start of each day's diving operations, and more often when necessary. Such an approach is consistent with the usual and customary practices of the rebreather community (see Ex. 3-4, pp. 4-1 through 4-13, and 14-2). In addition, the introduction proposes that the calibration procedures conform to the sensor manufacturer's instructions; this proposal would ensure that the sensors measure accurately the partial pressure of O<sub>2</sub> in the breathing loop.

Proposed Condition 2(c) would provide assurance that divers always have accurate information regarding the level of O<sub>2</sub> in the breathing loop, thereby enabling them to take corrective action should the O<sub>2</sub> level exceed the parameters proposed below in Condition 3 (*e.g.*, decrease O<sub>2</sub> concentration, switch to the "bail-out system" and egress to the surface (see proposed Condition 7 below)).<sup>4</sup> Therefore, accurate information regarding the O<sub>2</sub> level is critical to preventing the central nervous system and pulmonary effects of O<sub>2</sub> toxicity (see proposed Condition 3 below for a detailed discussion of these effects).

In view of the harmful effects that can result from breathing high levels of O<sub>2</sub>, OSHA believes that O<sub>2</sub> sensors and associated calibrating equipment and procedures need to be accurate to "within 1% of the O<sub>2</sub> fraction by volume." Assuming that the O<sub>2</sub> sensor and calibrating equipment-procedure each underestimate O<sub>2</sub> at the maximum proposed rate of 1%, and that the diver is breathing a nitrox mix containing 40% O<sub>2</sub> by volume or an O<sub>2</sub> partial pressure of 1.40 ATA (the maximum O<sub>2</sub> concentrations permitted under proposed Condition 3 below), the error would be  $\pm 0.8\%$  when the O<sub>2</sub> gauge shows the O<sub>2</sub> level in the breathing loop to be 40% by volume, or  $\pm 0.028$  ATA when it shows the O<sub>2</sub> level to be 1.40 ATA. The Agency believes that this level of error is acceptable, and well within the O<sub>2</sub> toxicity limits demonstrated by the available evidence (see proposed Condition 3 below). Therefore, this level of accuracy would provide an adequate safety margin for

<sup>4</sup> Although low O<sub>2</sub> levels are rare under nitrox breathing conditions, the sensors also would detect levels of O<sub>2</sub> less than 22% by volume (see proposed Condition 3 below).

the divers to detect anomalous O<sub>2</sub> concentrations, to attempt to identify the cause and adjust breathing-system controls, and to ascend to the surface when necessary.

(d) *Controlling O<sub>2</sub> delivery.* This proposed condition requires employers to ensure that closed-circuit rebreathers have: (i) A gas-controller package with electrically-operated solenoid O<sub>2</sub>-supply valves; (ii) a pressure-activated regulator with a second-stage diluent-gas addition valve; (iii) a manually-operated gas-supply bypass valve to add O<sub>2</sub> and diluent gas to the breathing loop; and (iv) separate O<sub>2</sub> and diluent-gas cylinders to supply the breathing-gas mixture. Under this proposed condition, closed-circuit rebreathers must automatically inject O<sub>2</sub> into the breathing loop to maintain the pre-established O<sub>2</sub> partial pressure in the breathable gas, and automatically add diluent gas (*i.e.*, nitrogen or air) through the regulator to compensate for decreases in gas volume during descent. The diver must also be able to control these functions manually using gas-supply bypass valves provided on the equipment. This equipment would maintain O<sub>2</sub> levels in the breathable gas within the range of partial pressures specified by proposed Condition 3 below, thereby providing assurance that sufficient and reliable breathing-gas pressure are available to deliver breathable gas to the diver without adversely affecting the diver's breathing effort. By reducing the diver's breathing effort, these proposed conditions would reduce CO<sub>2</sub> accumulation caused by an increased rate of breathing and, in turn, would lower the risk of CO<sub>2</sub> toxicity. In addition, by maintaining O<sub>2</sub> in the breathing loop at pre-established levels, this proposal would ensure that divers conform to the pre-established 24-hour single-exposure O<sub>2</sub> limit selected under proposed Condition 4 below.

Paragraph (iv) of proposed Condition 2 requires that employers use separate cylinders to provide the O<sub>2</sub> and diluent gas in the breathing-gas mixture. This proposal would give the diver independent control of these breathing-gas components; such control could be automatic or manual, or some combination of these two modes.

### 3. O<sub>2</sub> Concentration in the Breathing Gas

Under this proposed condition, employers must ensure that the fraction of O<sub>2</sub> in the nitrox breathing-gas mixture exceeds the fraction of O<sub>2</sub> in compressed air (*i.e.*, more than 22% by volume). For rebreathers, the fraction of O<sub>2</sub> must never exceed an O<sub>2</sub> partial