

**NEW BREATHING RESISTANCE
STANDARDS
USED IN THE U.S. NAVY
ARE DIVER FOCUSED**

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BACKGROUND:

Historically, the levels of breathing resistance deemed acceptable in an underwater breathing apparatus (UBA) were based on the performance of the best UBAs that were commercially available around 1980. Based on these UBAs, the U.S. Navy¹ set the goals and limits shown in Figure 1. A similar approach used by Morrison and Reimers² set the North Sea limits (NORSOK U-101³) and the European limits (EN 250⁴ and EN 14143⁵), Figure 2.

For different UBAs, these limits define the range of acceptable work of breathing from 0.23 to 1.76 kPa (J/L). This wide range makes limited physiological sense, but is based on the varying resistance characteristics of different types of UBAs (open circuit, umbilical supplied, rebreather).

We decided to devise new limits on work of breathing based on the best available physiological data.

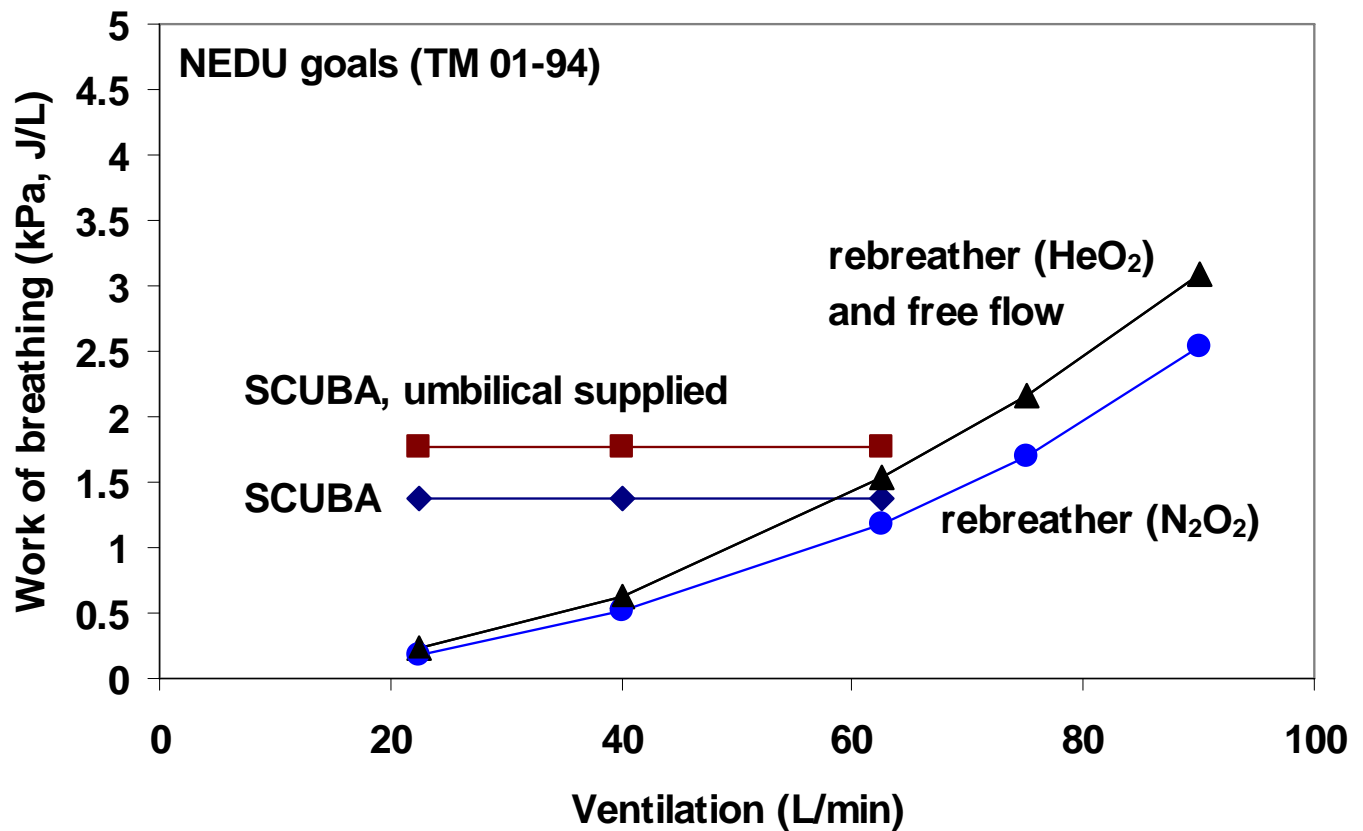


Figure 1. Performance goals for the different types of breathing apparatus as per NEDU Technical Manual 01-94¹.

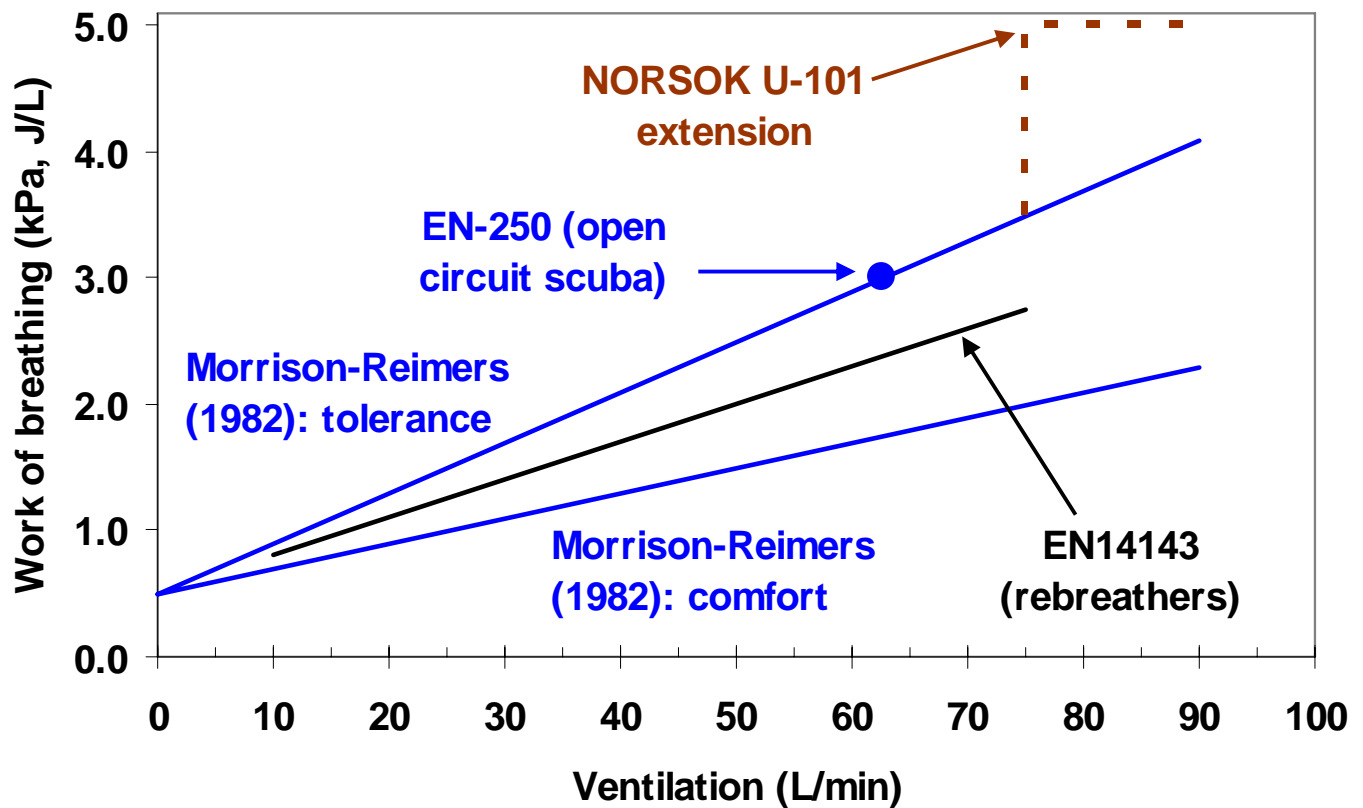


Figure 2. Limits on resistive effort proposed by Morrison and Reimers² and as implemented in the NORSOK 101³, EN-250⁴ (open circuit scuba) and EN 14143⁵ (rebreathers).

METHODS:

Physiological data on acceptable breathing resistance were obtained from experimental work with divers^{6,7}.

The resistance was deemed acceptable if high dyspnea scores and high CO₂ levels were avoided.

RESULTS:

The effort required for a diver to breathe increases with depth. However, the ability of the respiratory muscles to work does not increase with depth. Therefore, the effort allowable for the UBA has to decrease with depth.

The U.S. Navy has adopted new limits for the resistive effort. For air diving the resistive effort should not exceed:

$$3.0 - 0.021 * \text{depth (msw)}$$

or

$$3.0 - 0.0064 * \text{depth (fsw)}$$

Effort is in kPa, J/L. Figures 3 and 4 illustrate these results.

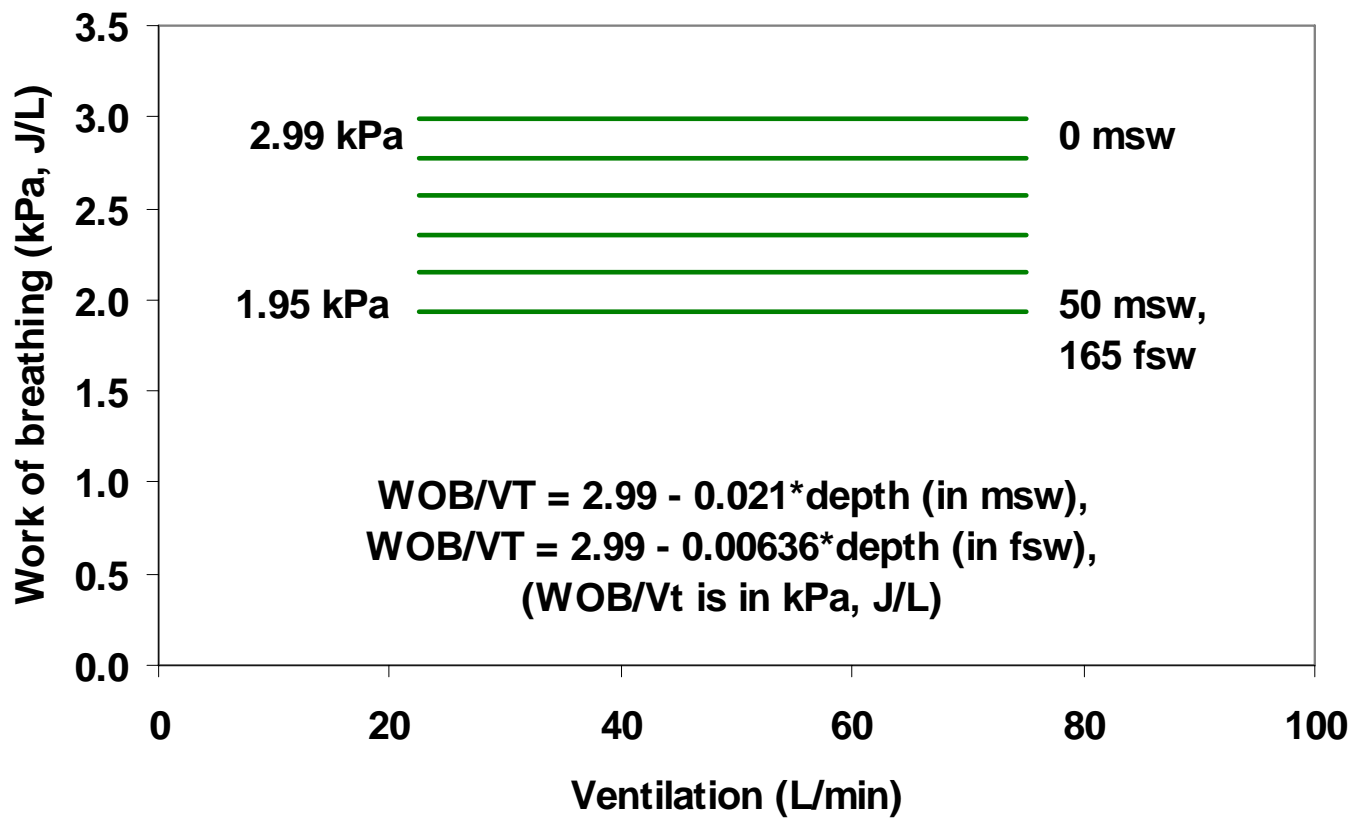


Figure 3. Physiologically based limits on resistive effort. Each line represents a different depth.

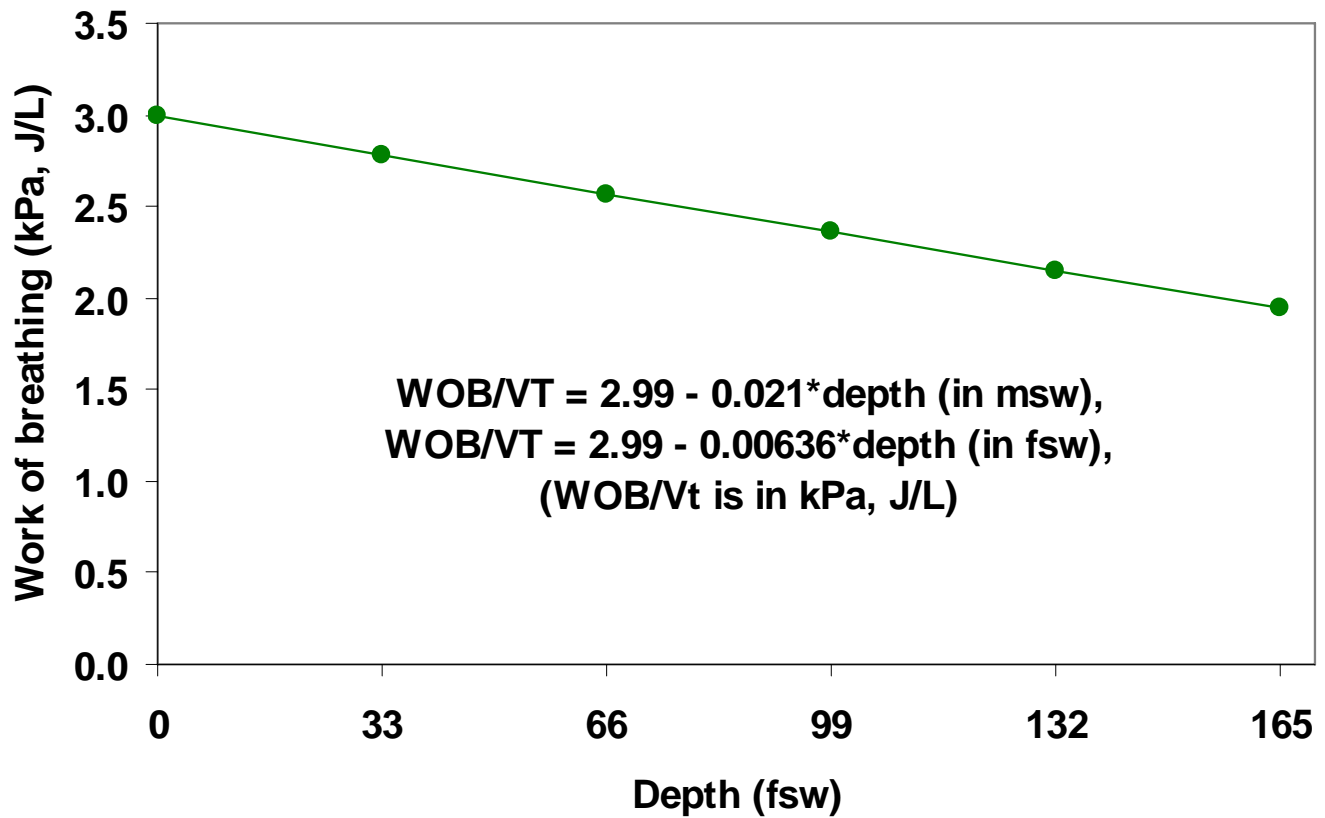


Figure 4. Physiologically based limits on resistive effort plotted against depth.

DISCUSSION:

The limits and goals for the resistive effort illustrated in Figures 1 and 2 have different characteristics. Some limits have a constant value; others change linearly with minute ventilation (\dot{V}_E) or with the square of \dot{V}_E .

The power (P) required from the muscles at a given \dot{V}_E and a resistive effort can be calculated from

$$P = \dot{V}_E * WOB/V_T / 60$$

If the WOB/V_T limit is not a constant value, the power required would have to increase disproportionately with \dot{V}_E . Therefore, the physiological limit for WOB/V_T must be a constant value.

Decision making

Figure 5 illustrates how a regulator is judged.

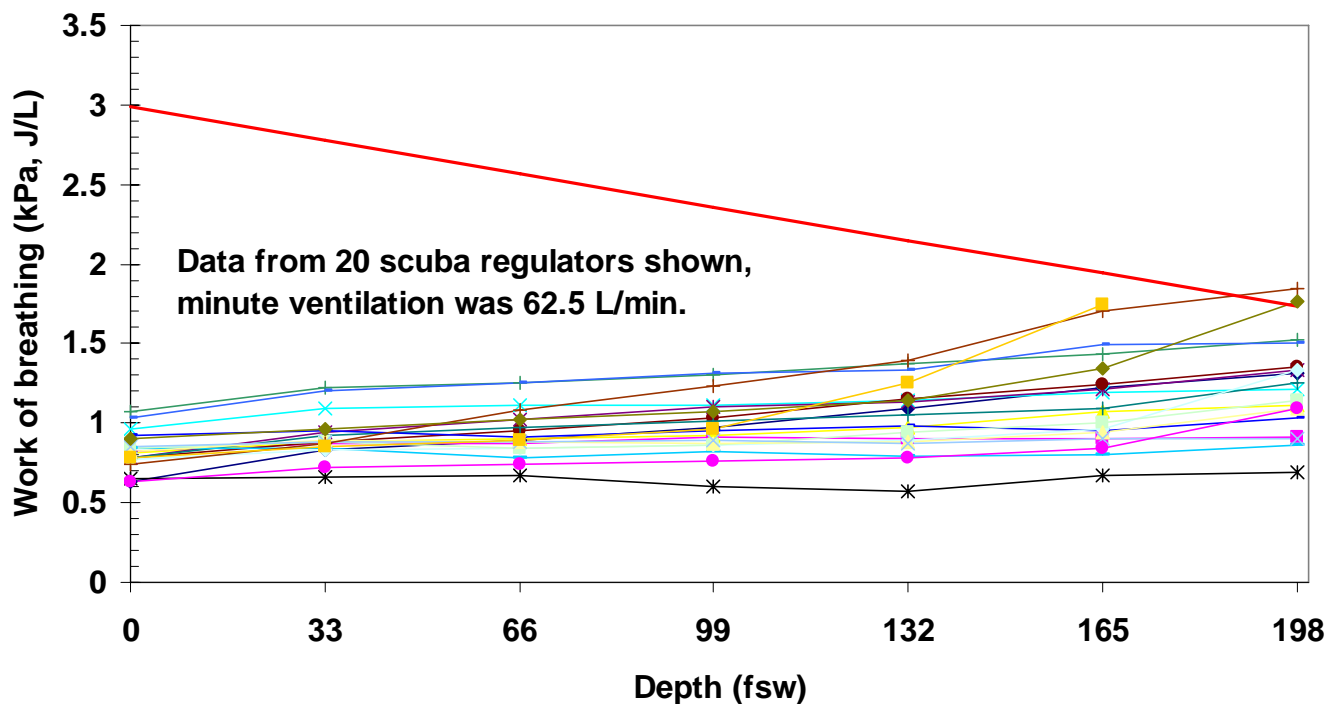


Figure 5. Illustration of decision making. The data from each regulator are plotted at the desired \dot{V}_E (here, 62.5 L/min) for every depth. The resistive effort has to be below the red line. All but three regulators would be acceptable to 198 fsw (60 msw). For clarity, the statistical analysis has been omitted.

CONCLUSION:

The new limits are based on diver physiology, not on the performance of UBAs that were available some 25 years ago.

For the first time the limits include the effect of depth.

The U.S. Navy has accepted these limits for its testing. The same limits of breathing resistance apply to all types of UBAs.

ACKNOWLEDGMENT:

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