Deep Dives & Deep Stops

- Why we are here, where we are going
  - Bringing Dive Physics, Physiology, and Practice into Focus
    - A closer look at the recreational dive mantra: you can ascend anytime from anywhere
    - Exploring the Deep Stop Discussion
    - Some Practical Guidance on deep diving with a 7mm wetsuit
    - Gas tissue terms and definitions
  - NAUI Master Scuba Diver Candidate Presentation
  - Addendum
    - Dive Gas Laws

Why This Matters

- Beyond AGE, most recreational dive DCS incidents are neurological (spinal cord, brain).
- Majority incidents occur after diver has spent time beyond 80 ft.
- Key diver questions:
  - **Does adding a deep stop reduce bubble risk?**
  - **Is it safe to dive to 100 ft in a 7mm wetsuit**

Decompression Basics Refresher

- Henry’s Law: gas dissolves under pressure.
- Fast vs. slow tissues: on-gassing/off-gassing rates differ.
- Supersaturation = bubble risk.

Confusion vs Clarity

- What is the official dive agency guidance on the 12-15 ft safety stop?
  - PADI
    - Do it unless the dive is shallow/easy
    - Required below 100 ft or if NDL is hit
  - SDI
    - Do it whenever you can, it's part of the ascent,
    - Formally, it's '*recommended*'.
  - NAUI
    - Do it whenever you can, it's part of the ascent,
    - Formally, it's '*recommended*'.

The Myth of No-Decompression Ascent

- No-Decompression Limit (NDL) $\neq$ Free Ascent Safety.
- Gas loading at 80–100 ft stresses fast tissues.
- Rapid ascent may trigger bubble growth and DCS symptoms.
- Gas consumption at depth shortens available reaction time.
- Even the emergency ascent **must** be slow, controlled, and deliberate.

A Few Definitions

- **Stress**: high gas tension approaching or exceeding safe gradients relative to ambient pressure, e.g., the tissue is challenged by a high level of dissolved inert gas. The higher the tissue tension, the less margin remains before supersaturation occurs on ascent
- **Tension**: or gas tension is the partial pressure of a dissolved gas in a tissue or fluid. It may be more convenient to think of tension as how “compressed” or “packed” the gas molecules are in that tissue. Tension is expressed in ATA (atmospheres absolute), the same units as ambient pressure. On ascent, if tissue tension > ambient pressure, the tissue is supersaturated → risk of gas coming out of solution (bubble formation).
- **Supersaturated**: A tissue is supersaturated when its gas tension (dissolved gas pressure) is greater than the surrounding ambient pressure, e.g., the tissue is holding more dissolved gas than the current pressure should allow.
- **Gradient**: is defined as the difference between tissue gas tension and ambient pressure, e.g., Tissue Gas tension less the Ambient pressure

A Recap

- **Stress** (informal use): tissues carrying high gas load, reducing margin before gradient gets risky.
- **Tension**: the dissolved gas pressure inside tissues.
- **Supersaturation**: condition when tension > ambient.
- **Gradient**: the magnitude of that difference.

Silent Bubbles & Neurological Risk

- Microbubbles form even inside NDL dive limits.
- Neurological tissues (spinal cord, brain) especially vulnerable.
- Bubbles *can* grow during ascent, not depth (re: gradient).
- Mitigation:
  - ✓ Slow, controlled ascent rate (<30 ft/min).
  - ✓ Brief pause near half depth (optional, brief, and only if gas permits).
  - ✓ Extended the 3 min safety stop to 5+ min at 12-15 ft.

The Deep Stop Argument

- Likely not needed for recreational dives.
  - There is no empirical physiological data that suggests the recreational, non-technical, no-deco dive benefit from a stop at 60 feet after a brief stay at 120 feet.
  - Watch the NDL time on your dive computer
    - If you don’t have a dive computer, get one
    - If your NDL time has ticked down to single digits, then consider a deep stop
    - Otherwise, consider a slower than normal ascent and a longer safety stop at 12-15 feet
- What does physics and physiology tell us?

Why Deep Stops Came About

- **Originated in technical/military dives**, where divers spent long bottom times, accumulating significant load in slower tissues.
- **Idea**: stop deeper to control bubble growth in fast tissues before surfacing.
  - Fast tissues coming from time at 130 feet are likely supersaturated at 60 ft, but slow tissues are likely still on-gassing
- **Evidence**: Some studies (e.g., Marroni, Bennett, DAN Europe) showed fewer venous bubbles with deep stops — but these were decompression dives, not recreational no-stop dives.

Recreational Deep Dives Are Different

- **Bottom time is short**: with a single tank, divers don’t stay long enough at 100+ ft to load any but the slowest tissues heavily.
- **Fast tissues dominate**: these tissues can be managed effectively by a deliberate, slower ascent rate (≤30 ft/min, ideally 20–25 ft/min in last 60 ft).
- **Gas supply is limited**: better used for extending the shallow stop than for pausing deep..

A Deep Dive
into
Deep Dive Theory

Recreational Bottom Time

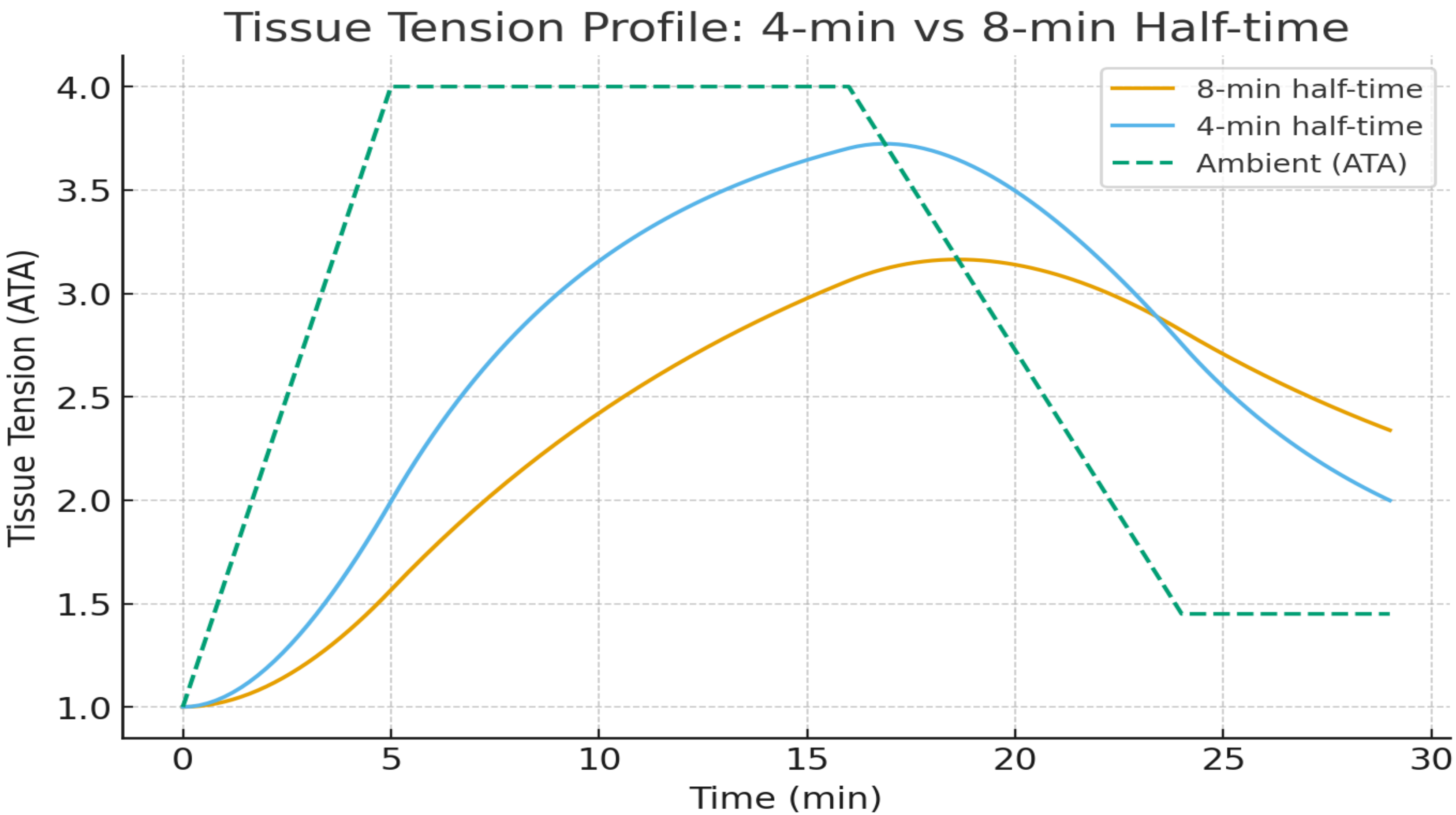
- Using modified rule of thirds (3000 PSI AL80, ~77ft^3 or 2190L)
  - 800 PSI to get to the bottom (584L air)
  - 800 PSI available at the bottom (584L air)
  - 800 PSI to get back to surface (584L air)
  - 600 PSI reserve (438L air)
- Respiratory Minute Volume or RMV
  - Average Recreational Diver : 16-18 L/min (or 25 L/min at 15 ft)
  - Nervous, anxious, or working diver : 25-26 L/ min (or 36 L/min at 15 ft)
- Bottom time at 100 feet / 30m / 4ATA
  - **Average Recreational Diver : 68 L/min or 11 minutes**
  - **Nervous, anxious, or working diver : 105 L/min or 7½ minutes**

Dive Profile Tissue Loading

Two fast-tissue analysis
4 min and 8 min half-time

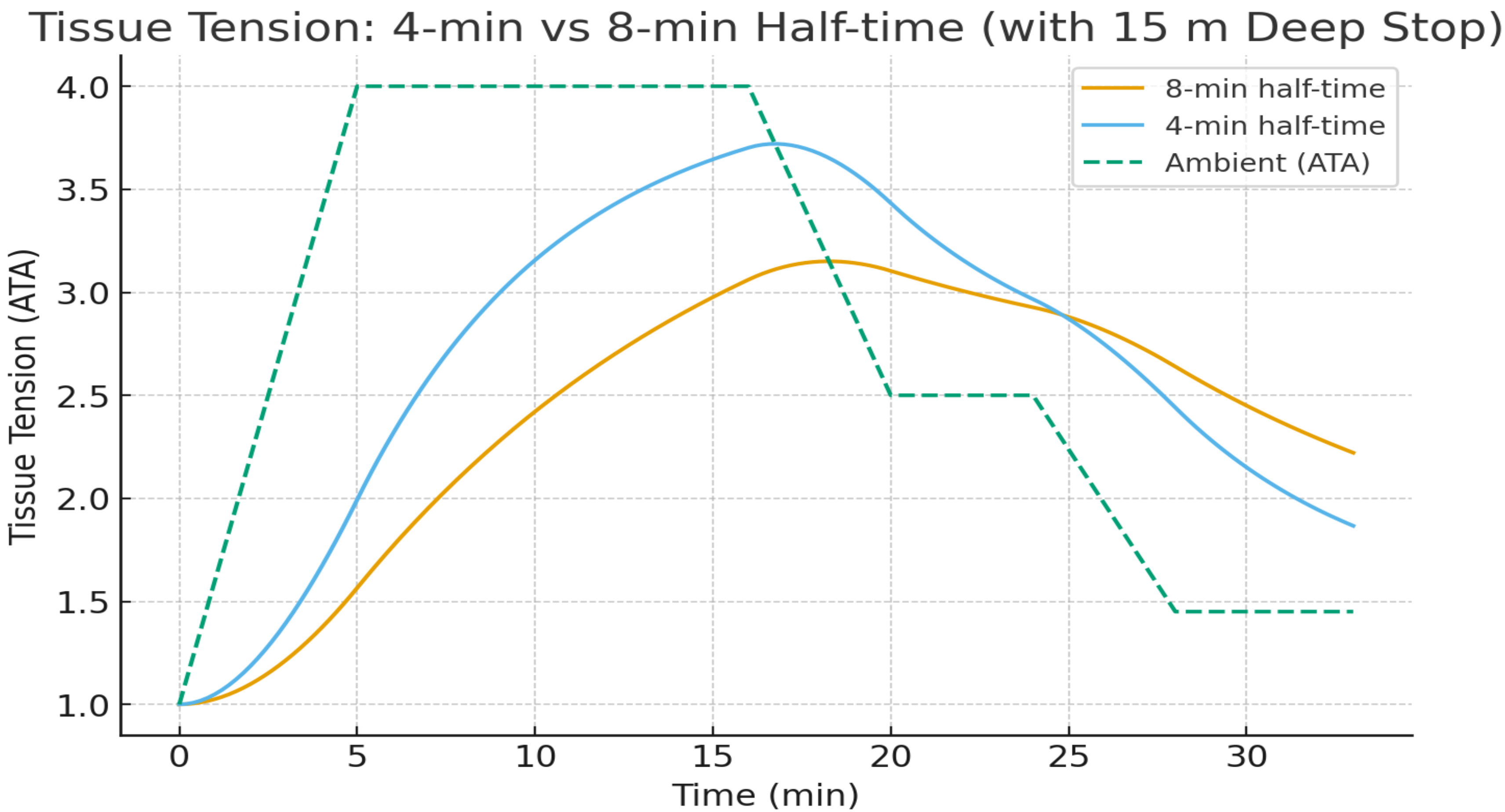
Depth (meters)	Period End	Time (min)	Tension 8-min HT (ATA)	Tension 4-min HT (ATA)
0 (0 ft)	T0 (0 min)	0	1	1
↓	T1 (5 min)	5	1.565	1.993
30 (98.4 ft)	T2 (16 min)	16	3.061	3.702
↑	T3 (24 min)	24	2.82	2.755
4.5 (15 ft)	T4 (29 min)	29	2.338	1.999

Dive Profile Tissue Loading



Dive Profile Tissue Loading

adding 5 minute deep stop at 15 meters



Dive Profile Tissue Loading

Key Takeaways

- A deep stop at the half-depth point would provide a marginal amount of off-gassing to occur
  - It might be effective, but not needed
  - Without the deep-stop, diver arrives at the 15 ft safety stop with a +1 to +1.5 ATA gradient for the two tissues. Both are well below the Workman 1.58 max
- A quick ascent to the surface at the end of the deep dive would be dangerous
  - Tissue tensions are +2.25 and +2.75, well above even the earlier Haldane max gradient of 2.0

Where the Gas Should Be Spent

- A diver has **limited** "safety gas budget."
- The **best return on that gas** is:
  - Slow ascent through the 60–30 ft zone.
  - An extended safety stop at 12–15 ft or 1.4 ATA (5 min or longer if gas allows).
- An extended stop at 12-15 feet after a slow ascent is where the **largest gradient reduction** occurs, and where most tissues can off-gas safely and efficiently.

Leadership Framing

- Instead of saying *deep stops don't work*, we frame it as:
  - "*For recreational deep dives, the need for a deep stop isn't demonstrated. You don't have the gas load in slow tissues that would make it critical*."
  - "*What really makes a difference is slowing your ascent and saving gas to extend time at the shallower safety stop — that's where gas comes out most safely*."

Deep Stop Summary

- *Recreational divers get the most safety benefit by*
  - *ascending **slower** than 30 ft/min and*
  - ***extending** the shallow safety stop.*
- *Deep stops are not typically necessary unless long exposures load slow tissues.*
- *A deep stop just for the sake of off-gassing may actually see some tissues still on-gassing*

A Case Study

on a slightly different topic

Fatal Buoyancy Failure

- Incident Summary
  - Location: Lake Ray Roberts, Texas (2008)
  - Diver: 31-year-old male
  - Location: Lake Ray Roberts, North Texas
  - Date: July 2008 (holiday weekend)
  - Reported cause: BC corrugated inflator hose/tube ruptured
    - diver lost buoyancy control
  - Diver was reportedly carrying ~60 lb of lead weight:
    - full tank at start of dive
    - the vest weight and,
    - additional 18 lbs. of weight in belt and pockets
  - Air supply: still had ~1200 psi at time of incident

A Case Study

- What we know – what we don’t
  - Hose/tube rupture caused sudden loss of buoyancy → diver could not offset excess weight.
  - Overweighting compounded risk: diver was unable to swim up effectively.
  - Panicking did not help matters

Does this teach us anything

- Wetsuit Buoyancy Loss with Depth in cold water
  - 7 mm wetsuit compresses significantly with depth.
    - Surface: high buoyancy → requires extra lead.
    - At 110 ft: most buoyancy lost → diver relies heavily on BCD.
- Failure of BCD bladder at depth creates severe negative buoyancy.
  - Combination of depth + wetsuit compression = sharp edge of safe diving if things go wrong.

Uncontrolled Ascent Risk from 110 ft

- If BCD fails, dropping weights may trigger runaway ascent.
  - Controlled ascent: slow gradient = gas tension managed.
  - Uncontrolled ascent: steep gradient = neurological bubble risk.
- Blowing bubbles protects lungs (AGE)
  - Does nothing to mitigate bubble formations in neurological tissues
- Fast tissue insult → spinal cord, brain most vulnerable.

What Next

- Is deep, cold-water lake diving safe in a 7mm wetsuit?
  - Maybe
  - Risks are certainly higher
  - Equipment checks and servicing can mitigate failures
  - Planning and practicing can mitigate panic
  - Dive agencies do not teach or addresses the issue
  - Diver is responsible
    - know your limits
    - test your capabilities

Final Points

- **Deep Stops research** shows us why rapid pressure changes are dangerous even within NDL.
- **7 mm wetsuit research** shows how easily a diver can be forced into such a rapid ascent if buoyancy systems fail at depth.

Final Points

- Together, the message is:
  - *The physics and physiology don’t care about agency limits.*
  - *A “no-deco” label won’t protect you from a bad ascent.*
  - *Diving smart means preventing uncontrolled ascents before they start.*

Final Points

- **The Leadership Reality Check**
  - **Recreational ≠ Always Immediate Exit:**
    - True “no-overhead” diving applies in physical terms (no cave/ice/ship overhead), but
    - *physiological overhead* begins at depth when gas loading is high.
  - **Instructor Responsibility:**
    - Deep Diver specialties often spend too much time on narcosis anecdotes and not enough on ascent discipline.
    - As we move into being the better dive buddy, we need to practice and reinforce:
      - Controlled ascent
      - Gas planning (rule of thirds, rock-bottom minimums)
      - Safety stop discipline (extend when possible)

Addendum

- Gas Laws (standard)
- Gas Laws (the rest of the story)
- Gas Laws (the necessary)

Gas Laws

Gas Law	Formula (Absolute Units)	Diving Meaning	Notes
Boyle's Law	$V \propto 1/P$ or (but not) $P_1 \cdot V_1 = P_2 \cdot V_2$	~~At constant temperature~~, gas volume changes inversely ~~with absolute~~ pressure. • Lung expansion, buoyancy, air consumption.	Boyle's law is stated in terms of relative pressure, more weight yields less volume
Dalton's Law	$P_{total} = \Sigma P_{gas}$	Total absolute pressure equals sum of partial pressures. • O_2 toxicity, narcosis, MOD calculations.	Partial pressure = fraction × absolute pressure.
Charles's Law	$V \propto Ta$ or (but not) $\frac{V_1}{T_1} = \frac{V_2}{T_2}$	At constant absolute pressure, volume changes with absolute temperature. • Tank cooling after fill.	Temperature in Kelvin (K = °C + 273.15).
Henry's Law	$C \propto P_{gas}$	At constant temperature, amount of gas dissolved in liquid is proportional to partial pressure. • Decompression theory, ascent control.	Partial pressure from absolute pressure × gas fraction.
Gay-Lussac's Law	$P \propto T_a$ or (but not) $\frac{P_1}{T_1} = \frac{P_2}{T_2}$	At constant volume, gas pressure changes with absolute temperature. • Tank heating/cooling, burst disk safety.	Temperature in Kelvin.

Gas Laws
(the rest of the story)

- Archimedes' Law (circa 250 BC) the buoyant force of a submerged object is equal to the weight of the displaced fluid.
- Boyle's Gas Law (1662) pressure and volume of a gas vary inversely
  - the mercurial thermometer was not invented until some 50 years later
- Charles' Gas Law (1787, 1802) at constant pressure, a volume of gas is directly proportional to its temperature (e.g., gas expands when heated)
- Dalton's Gas Law (1801) the total pressure of a gas mixture equals the sum of the partial pressures of each component gas
- Gay-Lussac's Gas Law (1802) at constant volume, the pressure a of gas is directly proportional to its temperature (e.g., pressure increases when heated)
- Henry's Gas Law (1803) at equilibrium, the amount of a given gas dissolved in water is directly proportional to the partial pressure of that gas above the water.
  - a tissue's inert-gas *tension* tends toward the inspired partial pressure of that gas
- The Ideal Gas Law (1834) : $pV = nRT$
  - *p: pressure of the gas (absolute)*
  - *V: volume of the gas*
  - *n: amount of substance (moles of gas)*
  - *R: the universal gas constant*
  - *T: absolute temperature (kelvin K)*

Gas Laws
(deriving the scuba version of Boyle's Law)

- Given pV=nRT
- When dealing with a gas, we can assume n and R are constant. Through substitution, we can rewrite the Ideal Gas Law as:
  - $\frac{P_g V_g}{T_g} = c$
- When dealing with a gas at a constant temperature, we can assume n, R and T are constant
  - $P_g V_g = c$
- When comparing to equal amounts of same gas (same # of moles) at same temperature, we can write:
  - $P_1 V_1 = c$, and $P_2 V_2 = c$, → $P_1 V_1 = c = P_2 V_2$
  - $\boldsymbol{P_1 V_1 = P_2 V_2}$

Gas Laws

(all you need to know for recreational diving)

pV=nRT

and maybe

Henry’s Gas Law

- Memorizing the historical details of who claims credit for which law and when is nothing more than a pedagogical exercise. It may help you pass a test, but likely will not help you be a *better diver*
- Even the Ideal Gas Law exhibits a degree of pedagogery!
- If you plan on developing tissue gradient models and computer algorithms, or going into partial pressure blending, then study Dalton’s Law, otherwise save your limited cognitive shelf space for the important stuff

Fun Fact

- The Ideal Gas Law, $pV=nRT$, tells us that the pressure in a tank would drop from 3000 PSI to 0 PSI if the temperature of the gas in a tank at room temperature were dropped to absolute zero.
- Absolute 0 anything is usually an abstract concept, not attainable.
- That said, at ~77 K (well before absolute 0), the Oxygen and Nitrogen and Argon components of air are liquids, and gas laws no longer apply.
- The required scuba testing gas laws work good enough in the environment divers will be diving in (pressure & temperature)
- The gasses we use in scuba diving follow the Ideal Gas Law close enough in the environment divers will be diving in (pressure & temperature)

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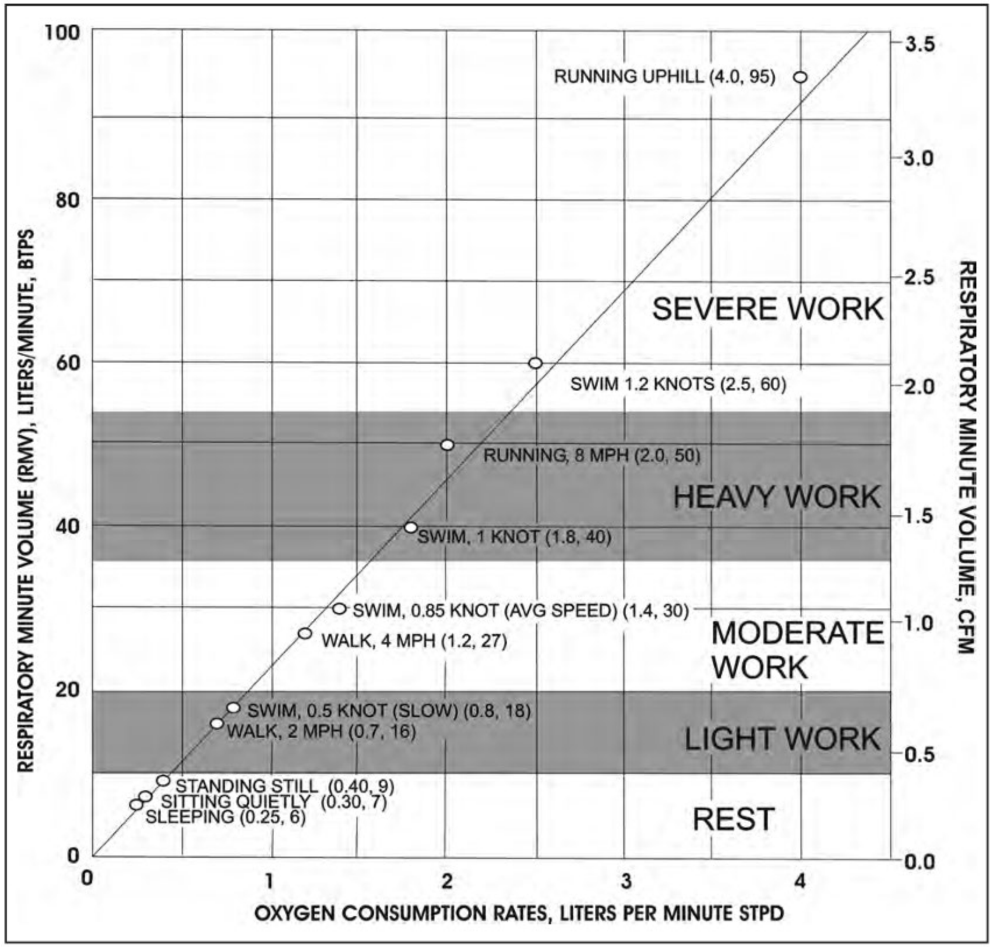

Figure 3-6. Oxygen Consumption and RMV at Different Work Rates.