Scuba Regulator Freezing Chilling Facts & Risks Associated with Cold Water Diving

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1.0 Acronyms

ATA: Atmospheres Absolute
ACTM : Actual Cubic Feet per Minute
ALPM: Actual Liters Per Minute
Bar: One Bar Equals 14.5 psig
DOD: Department of Defense
KMDSI: Kirby Morgan Diving Systems International
MBR: Millibar, Pressure Measurement 68.9 mbr = 1 psig
MOD: Ministry of Defense
PSIG: Pounds per Square Inch
RMV: Respiratory Minute Volume. The amount of air ventilated in one minute, also known as respiratory work rate.
FSW: Feet of Sea Water
MSW: Meters of Sea Water
SLP: Standard Liters per Minute
EU: European Union
NEDU: Navy Experimental Diving Unit

2.0 Background: Over the past 35 - 40 years as self-contained underwater breathing equipment has evolved, and grown, SCUBA regulator breathing performance has improved four fold resulting in demand regulators that can flow more air allowing greater breathing rates. However much of the knowledge and situational awareness of diving in cold water appears to have been forgotten, lost, or just plain ignored which has undoubtedly resulted in many accidents. The effects of cold water on the divers equipment as well as the effects and importance of the refrigeration effect of expanding gas from a compressed air/gas cylinders (tanks) has been largely ignored or grossly overlooked by many in the diving communities and in fact, over the past 13 years, the data collected since our initial testing (the year 2000) has not only been largely ignored, but downright rejected by some in the diving community. So once again, we will attempt to put out information in the hope it may help those that take the time to read and understand this information. In addition, we hope this information will help equipment manufacturers, test facilities and those influencing future equipment standards.

This paper was written in an effort to inform anyone that dives in cold water using open circuit SCUBA about the potential hazards of regulator freezing and cold related issues. Much of the information herein was derived from testing open circuit SCUBA demand regulators under controlled conditions using scientific test equipment and procedures. This information is also intended to explain and inform about the test techniques, procedures, and equipment used when testing open circuit SCUBA regulators. We have also included information and knowledge shared by many experienced cold water divers over the last 50 years.

2.1 Dive Lab Cold Water Testing Background: Over the past 15 years Dive Lab has been conducting cold water testing on regulators and components used for open and closed circuit SCUBA diving as well as umbilical supplied helmet and full face mask diving. Much of this testing was / is in support of Dive Lab and Kirby Morgan specialty equipment, as well as for companies and agencies that have contracted Dive Lab's testing and development services. Many of the basic procedures used by Dive Lab are from procedures used by the US Navy, European CE test requirements, and methods employed by ANSTI Test Systems Ltd. Besides these procedures, Dive Lab has also developed procedures and techniques that we feel fill in the blanks. Research and testing at Dive Lab suggests that equipment manufactures as well as well as agencies that dictate the use of equipment for diving in cold water including military test facilities should carefully evaluate their understanding of how and why SCUBA regulators form ice and the circumstances and conditions that allow ice to form and regulators to freeze and perhaps adopt a more realistic approach to diving procedures, practices, as well as equipment evaluation and testing. In addition, training agencies that teach cold water may need to revisit what is being taught in regards to the mechanics of cold water diving. We (I) recommend those that dictate industry cold water test standards and / or military cold water standards should evaluate the information herein. If you want more information we will be happy to supply any data we have collected. For SCUBA divers that routinely dive in waters colder than 40°F (4.4°C), the potential for regulator freezing is a significant possibility that the diver needs to be aware. Most seasoned cold water divers acquired their experience the hard way and all have stories of regulator freezing. The basic root cause of regulator freezing is not often taught properly because many do not have an accurate understanding of the mechanical cause of regulator freezing and ice development inside SCUBA regulators. If you don't understand the cause of how and why ice can form, and exactly how regulator freezing happens, it's hard to prevent it.

2.2 Regulator Freeze: The basic definition of regulator freezing is the condition where the second stage demand valve starts free flowing air due to ice formation around the inlet valve mechanism that keeps the inlet valve from closing after inhalation. This is pretty close, but there is a little more to it than that, as you will soon learn. It is not all gloom and doom; if you dive in cold water and keep your breathing rate at low to moderate breathing rates and keep the HP cylinder pressure under 3000 psig, you will minimize the potential for second stage freezing.

2.3 Free ice Formation: Besides having the well-known free flowing regulator event from second stage icing, there is another not so known or thought about threat, "Free Ice Formation". Free ice formation is where ice forms and builds up inside the second stage but does not cause the regulator to free flow, and the diver will not even be aware that the ice is there. Free ice buildup inside the second stage can pose a significant inhalation hazard because the ice can break loose in the form of a sliver or chunk, and can be inhaled. This is especially true with regulators that are advertised by their manufactures as having ice-shearing capability. Some of these regulators are advertised to have ice shearing capability and have parts and components that are Teflon® coated, which allows for the ice to slip away and helps to prevent the regulator from free flowing by clearing or breaking the ice. While this may be a helpful technique in keeping the demand valve mechanism free to move, the ice is still present in the regulator and has to go somewhere when it breaks loose. This poses the risk of inhalation and having a piece of ice whistling down your windpipe (trachea) when you take a deep breath can cause a serious coughing spell and can lead to problems especially if accompanied by a free flowing regulator.

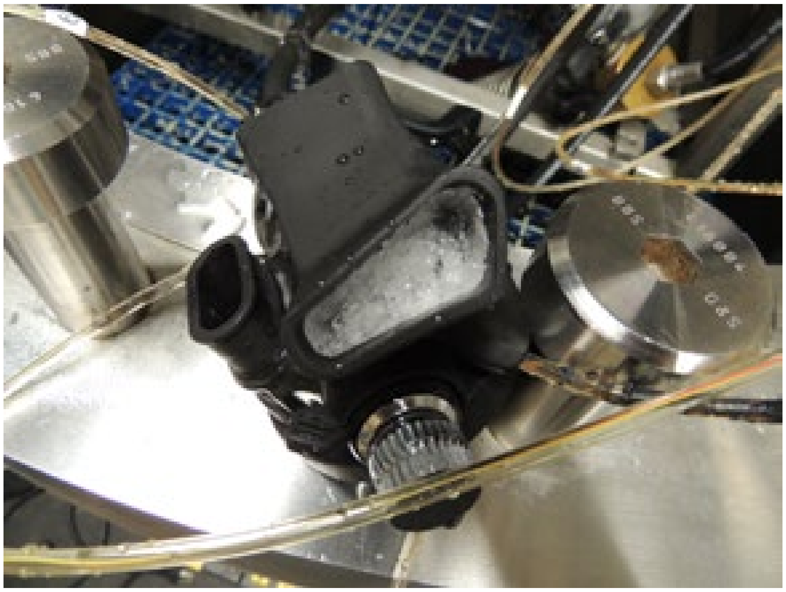


Figure 1. Exhaust ice formation due to extreme second stage free flow in water below 34°F.

Although getting into the medical aspects of what happens physiologically is outside our expertise, it is clear that inhaled chunks or slivers of ice will present a problem for the diver. The condition known as a “laryngospasm” can occur which basically causes the diver’s voice box (larynx) to close so no breathing can be done. No matter how hard the diver attempts to inhale, breathing cannot resume until the larynx relaxes and this may take minutes. The diver does not know and cannot identify why he / she cannot breathe and not being familiar with laryngospasm, the diver could believe their breathing regulator system has shut down. In any case seconds count, and whether the diver survives or not, there is no evidence remaining to show investigators what actually happened. The subject of the laryngospasm is fascinating and there is much information on the subject available on line.

2.4 Mechanical Effects of Ice: With most second stage SCUBA regulators, as ice forms and builds on internal second stage components such as the lever, main tube, and inlet valve, the minor free play adjustment (Gap tolerance) between the lever and fulcrum point is reduced and eventually eliminated by the ice that forms, preventing the inlet valve from fully closing during the exhalation phase of breathing. Once the valve starts free flowing, the second stage components get even colder due the refrigeration effect of the continuous flow, creating more ice and an even greater free flow. With some regulators the air flow, and cold air is so great, that the exhaust flapper valve and water around the valve freezes, reducing exhaust flow, and increasing exhalation effort and at the same time showing some really high positive pressure numbers and in many cases in excess of 40-50 mbr (>0.5 psi)! That is very high and it is really hard for the diver to exhale air

Figure 2. Regulator that experienced free flow after ice formation

through the regulator. This can be very dangerous because if the diver cannot exhale, the diver cannot inhale, forcing the diver to loosen the grip on the mouthpiece and exhale around the mouth piece before being able to inhale. This entire experience can happen really fast and be very confusing, and it is extremely dangerous, even for the most experienced divers, it can even prove to be fatal. With some regulators, once the regulator starts free-flowing the flow quickly escalates into a full blown free flow, delivering air to the diver at temperatures cold enough to freeze mouth tissue in a very short time. The deeper the diver is, the faster the air will be lost and in many cold water fatality cases, by the time the diver's body is recovered not only is there no air left in the cylinder, but the regulator has since warmed up and melted the ice. The official report is usually drowning and no one can figure out how such an experienced diver could have run out of air.

Figure 3. Extreme ice formation.

2.5 Regulator Freezing in 50°F (10°C) Water: So how does ice form in the second stage if you are not diving in water much colder than 50°F (10°C)? Simple! When the high pressure air passes through the first stage regulator, the rapid drop from high pressure to low pressure causes a dramatic temperature drop. This pressure drop is basically how your refrigerator and air conditioner work, the temperature drop is fairly linear, the higher HP pressure the greater the drop in pressure and the colder the air gets at the second stage. Now increase the flow and it gets even colder. If you can keep your breathing rate at the low to moderate breathing rates (15 - 30 lpm flow) the risk of ice formation is less and you will minimize the potential for second stage freezing. <u>See: Table 4 page 16</u>. The temperature / breathing tables show how extreme the cooling can get.

3.0 Primary Factors: The primary factors that influence second stage ice formation.

- Cylinder Pressure
- Breathing /Flow Rate
- Water Temperature
- Time
- Regulator design

3.1 First and Second Factors: The first and second factors are closely interrelated and if the HP cylinder pressure is 2500 psig or higher, and the flow is great enough, (50 - 62.5 lpm), ice will often form inside most second stage demand regulators even in water of 45 - 50°F (7.2 - 10°C). Once the water temperature drops below 40°F (4.4°C) the possibility of developing ice in the second stage becomes a significant probability, and something the diver needs to be thinking about especially before doing heavy breathing, filling a BC, or anything that requires a moderate or substantial flow of air. Even in 45 - 50°F (7.2 - 10°C) water, with most regulators if the diver was to aggressively purge the demand regulator for just 5 - 10 seconds to fill a small lift bag, the temperature drop can be enough to form ice in a demand regulator valve and start a free flow event. For this reason the number one rule in cold water diving is "Never free flow the regulator!"

3.2 Factor Three, Water Temperature: Once the water temperature drops below 38°F there is not enough heat in the water to rewarm the cold regulator components of the second stage being chilled by the first stage and most second stage start forming ice. To understand this you need to think about how an automobile radiator works. A radiator removes the heat generated from the fuel burning engine. The hot coolant in the engine is pumped thru the radiator coils and the air that flows past the coils draws the heat away keeping the engine temperature cool and stable. A car radiator is a simple heat exchanger. If you think of the SCUBA first stage regulator as an engine that supplies air to the diver via the second stage, but in the process, supplies extreme cold air to the second stage due to the cooling effect of the air going from a high pressure to a low pressure. As the cold first stage air enters the second stage it quickly chills the second stage inlet valve components to well below freezing and as the diver exhales, the moisture in the exhaled breath instantly condenses on the cold second stage inlet components and freezes. The bottom line, it is the warmth from the surrounding water that keeps the second stage regulator components warm enough to prevent the divers moist breath from freezing and forming ice. The diver's exhaled breath even at 85 - 90°F (29 - 32°C), does not have enough heat to combat the extreme cooling effect of the incoming air once the water temperature is much below 40°F (4°C). Once the water temperature gets colder than 40°F (4°C) there is very little heat in the water to help in rewarming regulator components fast enough to keep moisture in the divers exhaled breath from freezing, especially if the diver is breathing hard. This is why the CE cold water limit is at 4°C + 0 -1°C (39.2°F) which is the point where many scuba regulators start retaining free ice, and many fail. "Rewarming is all about the thermal transfer of heat". The colder the water is the less thermal rewarming.

3.3 Factor Four, Time: This one is simple, the longer you flow gas at a high rate, the colder the regulator components will get. Keep high flow rates to as short a time as possible and the second stage components will stay warmer. As an example you could leave the surface and swim down the anchor nice and slow to say about 60 fsw, and then wrestle around with the anchor and chain to reposition better so it won't pull loose, during that time you put some air in the BC and do a little huffing and puffing while moving the anchor then the next thing you know you got a free flow going. This may have happened because you were running a cylinder that started out at 3000 psig or greater from surface which optimizes cooling, while the pressure was still above 2500 psig you put some air in your BC so you could pick up the anchor (25 lb) + the anchor-chain , another 20 lbs. The problem is your BC only has 30 lbs of lift so then you had to do a little huffing and puffing to move the anchor to a secure hook up spot on the wreck so your breathing rate got up around the 60 - 75 rmv range for 30 seconds or so and you got a free-flow. If you can't stop it quickly, it could escalate into a full blown free flow. The only way to stop it is to shut off the second stage if you have a slide valve installed. If you don't you will have to kink the hose, while struggling to get to, and breathe from your octopus. For some regulators a freeze like that can happen in water as warm as 50°F (10°C). When you are in low 40°F (10°C) or colder water, with the same scenario it can happen much faster with little or no mercy. The only difference when it happens in 50 degree water or warmer, some regulators can recover if you pull it out of your mouth and get some water in the second stage to melt the ice. Once the water gets into the 40°F range it has little rewarming capability.

3.4 Factor Five, Regulator Design: The fifth factor, regulator design, can play a significant role.

3.5 First Stage Design: As mentioned before, the first stage is basically a cold air generator, and is the birth place of all cold as far as cold air to the diver goes. "Cold is defined as the absence of heat". The air coming out of the first stage is always colder than the water, "Always". There are two things that cause first stage freezing. The least common is internal freezing due to moisture in the HP air due to poor HP filter / moisture control. Most modern HP compressor filtration / moisture separators provide air at a dew point down to at least -40°F. Internal first stage freezing can happen if the moisture separators are not maintained properly. Proper compressor maintenance and regular air samples will prevent moisture in the HP system. The second and most common cause of first stage freezing is external icing from the surrounding water freezing around the outside of the first stage. This can happen in water that is below 40 °F if flow rates and cylinder supply pressures are high. The colder the water, the less the rewarming and the greater the chance of first stage icing . Usually the most efficient first stage designs for cold water are those that have lots of surface area and mass to allow greater heat absorption from the surrounding water (Giving up the Cold) to help keep the first stage from forming ice on the exterior of the first stage. In addition by having large exposed areas with numerous large openings can be very effective in preventing first stage icing, see figure 4.

Small, lightweight first stages are nice, but for colder water they often lack the surface area and mass necessary to absorb heat fast enough from the surrounding water to rewarm the first stage components, often causing the surrounding water to freeze on, and around the exterior of the first stage. As ice forms and thickens on the exterior of the first stage, it further reduces thermal transfer ability, locking in even more cold, and in water of 35°F (1.6°C) or colder, there is not enough warmth to melt any ice that forms on the first stage in any reasonable amount of time, and the air being flowed at even 40 rmv produces enough cooling effect to prevent any ice that has formed on the first stage from melting. Once the ice has formed it may take some time to melt and disappear even after all flow has stopped, even if the first stage were left in the water. First stage freezing can be a greater problem in very cold (32°F) (0°C fresh water) because the kind of ice that forms in fresh water is harder than the ice that forms in 28°F (-2°C) salt water and can encase the piston or diaphragm sensing ports faster than in salt water. When ice forms over the sensing ports of a piston first stage or over the diaphragm on a diaphragm first stage, the first stage will lose pressure sensing and the ability to regulate the outlet pressure to the second stage. In some cases this can cause a massive free flow of the second stage due to the first stage over driving. In other cases it can result in a lower intermediate pressure resulting in inadequate 2nd stage supply pressure.

Figure 4. Note: On this first stage ice does not form around sensing area.

3.6 Insulation: Insulating the first or second stage is the wrong thing to do because it locks in cold and prevents rewarming from the surrounding water. Some SCUBA regulator manufactures cold mold layers of urethane or plastic on the outside of the first stage, which may look cool, but may be the wrong thing to do for a cold water regulator, and may inhibit the first stage from absorbing heat from the water. Environmental freeze kits on most first stage's will help to some degree, at least maybe for the duration of current CE breathing simulator tests. Freezing of first stage usually takes far more time than freezing of a second stage. Dive Lab has found that most first stages can be breathed at a rate of 62.5 rmv for at least five minutes in 35°F (1.6°C) at depths as deep as 190 fsw without freezing, however if and when the second stage starts free flowing especially a full blown free flow, the first stage will usually ice over quickly and lose all sensing capability.

Tests at Dive Lab have shown that various first stage regulators submerged in water at the same temperature, using the same HP supply, intermediate discharge pressure, and breathing flow rate will all end up with the same discharge temperature, usually within 1-2 degrees. The most significant factors influencing temperature to the second stage are the HP Supply Pressure and the Discharge Flow Rate. This is why a regulator can form ice even in 50°F (10°C) water.

3.7 Second Stage Design: As mentioned earlier, second stage freezing can happen quickly from the moisture in the diver's exhaled breath. Second stage regulators that isolate or divert the diver's exhaled breath from coming in contact with the cold inhalation components and the area where the cold inlet gas enters will usually stand the best chance of not forming ice on the valve's critical components. How well the cold inlet air components are separated or shielded from the diver's exhaled breath, as well as the thermal transfer qualities of the second stage materials can have a significant impact on free ice formation and freezing potential. Second stage regulators that have poor sealing exhaust valves will form ice quickly. Bottom line! "All" second stage regulators can develop ice when the incoming second stage air inlet temperature averages 25°F (-4°C) or colder and for this to happen the water does not have to be any colder than 50°F (10°C). Whether or not the ice that develops causes a free flowing regulator is another story. Regardless, any ice in the regulator may presents an inhalation hazard.

3.8 Metal or Plastic Second Stage? Both metal and plastic second stages get just as cold. The only difference is how fast they get cold. How fast is based on the thermal transfer capacity of the materials used. Second stages made of metal will transfer heat faster than plastic, therefore a metal body will get cold quicker. However, metal will also warm quicker, especially at the spot where the air enters the demand valve. Plastic second stages transfer heat slower than metal second stages and in many cases the plastic will insulate any metal air inlet components, requiring longer time to transfer heat. In the big scheme of things the difference from metal to plastic can be compensated for thru design considerations. Insulating a second stage only makes the icing worse because the second stage cannot get warmed by the water, or if you want to think of it in another way, "Give up the Cold".

Figure 5. Ice formation on air supply line to second stage regulator

4.0 Cold Hard Numbers: The mechanics of regulator freezing are simple, with each breath the diver takes there is a sudden pressure drop from high pressure to low pressure. If the diver is in really cold water say, around 32 - 35°F (0-2°C), breathing at the heavy rate of 62.5 lpm from cylinders charged to 3000 psig (206 bar), the air coming out of the first stage at the end of each breath will be in the range of between -16°F to -18°F . Think about it! Water freezes at 32°F, -16°F is 48 degrees below the freezing point of water and as air from the first stage at -16°F flows through a standard 28"to 32" long hose to the second stage, the air has only warmed up to 12°F which is still 20 degrees below freezing! The inlet valve components inside the second stage are at a temperature of 12°F or maybe slightly colder, which is more than cold enough to freeze the diver's exhaled breath in the second stage after each exhalation, quickly layering ice. Now, think about higher cylinder pressures, say in the range of 3500-4000 psig (241-276 bar), the freeze potential gets much greater. In 32 - 35°F (0-2°C) degree water at 3000 psig (206 bar) if the purge valve of the second stage was depressed for just three to five seconds, the air will get down below -25°F (-31°C) at the first stage, and -5°F (-20°C) at the inlet to the second stage. This is why a second stage can freeze so fast. If and when a free flow starts in cold water with a supply pressure in excess of 2500 psig, the air the diver will be exposed could be well below -15°F (-9°C). These are cold hard numbers. See: Table 4, page 16.

4.1 Back to Primary Factors: Let's remove the regulator design factor, and only look at water temperature, pressure, and flow. These three factors are closely linked and a change in any one will directly affect the others. As mentioned earlier, at high flow rates, and high supply pressures, especially in deep water, regulator icing will take place with some regulators even in water as warm as 50°F (10°C). In waters of 50°F (10°C) or colder and a cylinder pressure of 2500 psig (172 bar) and flow rates (breathing at a rate of 50 rmv) or greater, the temperature of the air entering the second stage can be well below freezing and the higher the cylinder pressure, the colder the air. Using cylinder pressures greater than 3500 psig (241 bar) can cause extremely low temperatures at first and second stage.

Note: Table 5 shows a diver breathing at a depth of 165 fsw (50 msw) in 33°F(0.6°C) water using an HP supply pressure of 2500 psig. Note how the supply pressure affects the temperature of the first and second stage.

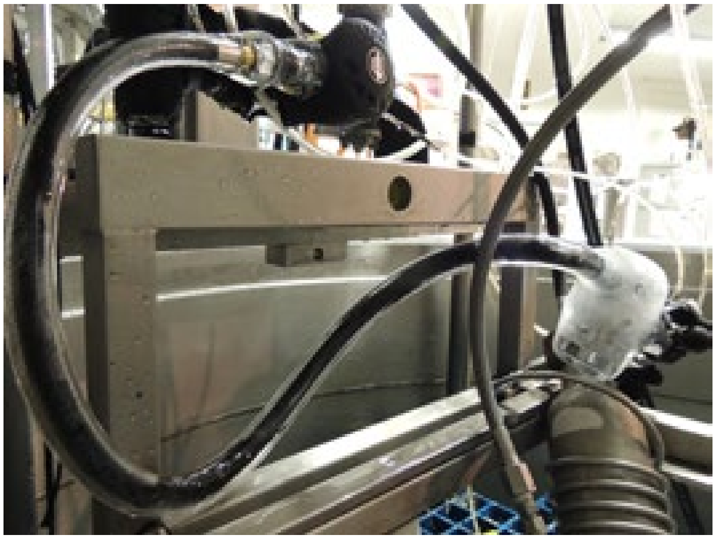


Figure 6. View of first and second stage from previous figure.

As soon as you start diving in waters colder than 40°F (4.4°C), the possibility of forming ice in the second stage becomes much greater especially if the breathing rates exceed 50 lpm. If, or when a free flow starts, in many cases it will only increase in intensity until the regulator is dumping a serious amount of air, raising the exhalation pressure / effort, and making it very difficult to breathe. The deeper the diver's depth, the more air will be flowed and the colder everything gets. If diving at a depth of 100 fsw (30 msw) or deeper, the diver will have a serious problem because the volume of air that is flowing makes breathing very difficult, and in very short order you are out of air.

5.0 US Navy Cold Water Testing: For the past 30 years or so, the US Navy unmanned cold water test procedures have been used as the benchmark for cold water testing by many of the World's Militaries as well as major equipment manufactures. Testing of open circuit SCUBA by the US Navy is done in accordance with (IAW) the Navy Experimental Diving Units "Unmanned Test Procedures" "last revised in 1994". The Navy test procedures are not an official standard for anyone other than the US Navy and / or other agencies within the / US Department of Defense (DOD) that elect to use it. Navy testing of SCUBA regulators has changed very little over the past 25 years.

6.0 European CE Cold Water Testing Background: In the late 1980's, breathing simulator testing done by the US Navy and the development of test methods and procedures, for the new European CE open circuit standard EN 250 which came out in 1993. The new CE EN250 standard raised the bar, or at least pushed the bar to a much higher level for open circuit SCUBA testing. The EU EN250 1993 standard covered not only breathing performance and cold water testing, but also proof, pressure, mechanical, hot and cold storage testing, CO2 wash out tests. The standard also delineated requirements for failure modes effects analysis (FMECA), and many other items and issues relating to manufacturing and quality assurance documentation. When the standard came out in 1993 it took many equipment manufactures by surprise because the standard identified issues with a lot of equipment that had been sold for years. Testing to the CE standard EN250 1993 influenced and pushed manufactures resulting in major improvements in open circuit SCUBA regulator performance.

7.0 Breathing Simulation History: The early breathing simulation testing done by the US Navy was the catalyst that kicked off the modern simulation testing in the late 1970's. The early Reimers breathing simulator systems built by Stephen Reimers started the basic breathing simulator testing. The Reimers machine was also bought by the Ministry of Defense in the UK and by some private equipment manufactures like Kirby Morgan Diving Systems. The basic Reimers breathing machine helped bring about the European standards in the early 1990's, but it was the introduction of a complete turnkey breathing simulator systems made by ANSTI Test Systems Ltd in the UK that ushered in the modern, ultra accurate, breathing simulator testing that is in place today. The wide spread use of the computerized ANSTI breathing simulator systems made it possible for faster, easier testing, with a level of accuracy far greater than anything done before. Prior to the ANSTI systems, the only ones that could test diving equipment were the military. The ANSTI systems changed all that. The ANSTI systems were designed from the ground up for testing diving equipment in cold water, warm water, and anything in between. The system includes precise humidity and exhalation temperature control as well as environmental water temperature control from 0-50°C, the ability to do breath by breath Co2 analysis and closed circuit rebreather set point control and scrubber endurance testing. The test systems built by ANSTI today represent the absolute state of the art.

7.1 Navy Cold Water Test Specifics: Overall both the Navy test protocol and the EU CE standards EN250 have made equipment much safer but both are in need of revision. Very little has changed with the US Navy testing over the past 25 years and the same with the European CE standard EN250. Neither the EN250 standard nor the US Navy unmanned test procedures use any kind of real world human type diving scenario as the basis for testing, especially cold water testing. We at Dive Lab as well as others believe this is where both the Navy and EU testing could easily make significant improvements. The Navy rational for cold water testing has been to test regulators primarily at a depth of 190 fsw (58 msw) in water 28 - 29°F (-2.2-1.6°C) at the severe breathing rate of 62.5 rmv for a minimum of 30 minutes. That test would be pretty much impossible for any regulator to pass using the free flow pass or fail criteria, except for the fact that the US Navy only uses an HP supply pressure to the first stage of 1500 psig (103 bar). By only using a 1500 psig the average second stage inlet temperature is around 7°F (-13°C) as compared to an average of -13°F (-25°C) if 3000 psig was used. This difference is significant. See: Table 6, page 18. Even at that, 30 minutes breathing 62.5 rmv is a torture test but it does not equate to anything a human might or could do.

The Navy cold test pass /fail criteria like the EU EN250 test criteria centers around whether the regulator fails to meet minimum breathing performance requirements and whether or not a free flow starts. The Navy knows from years of testing that that very few regulators have, or can pass this test because "ALL" second stage regulators will form ice in the second stage under the extreme test conditions. Whether or not the ice causes the regulator to free flow or go outside the performance boundaries is another story. If the breathing test conditions are being maintained properly it is "impossible" for the second stage to "not have" lots of ice inside.

The current Navy cold water testing could be improved by using an extremely aggressive human like test scenario that starts at the surface and ends at the surface and simulates or at least emulates what a real super fit diver might be capable of doing.

7.2 CE Cold Test Verses US Navy Cold Water Test: Very little has changed with the CE standard in the past 25 years. The cold testing called out in the European SCUBA standard EN250:2000 has SCUBA regulators being tested in water 4°C (39°F) or colder, as stated by the manufacturers limit. Regulators are tested twice, once in the face forward position, and once in the face down position. The test starts at 165 fsw (50 msw) and the regulator is breathed at 62.5 rmv for five minutes. To pass, the regulator must remain within the resistive effort limits and must not free flow. Like the US Navy test the formation of ice is of no significance as long as the ice does degrade the breathing performance preventing minimum performance requirements to be met and / or it does not free flow. With EN-250, the cold water test actually starts at 165 fsw (50 msw) not at the surface. Unlike the Navy test, the CE test uses an air supply starting at the highest pressure the regulator is rated for and uses a minimum floodable volume in liters of 14 +1- 0 – . Unlike the Navy test where they maintain a constant 1500 psig, the CE test starts at 165 fsw at the maximum rated supply pressure and the system is breathed for five minutes at 62.5 rmv using an exhalation temperature of 28 + - 2°C (82.4 + - 3.6°F) and an exhalation relative humidity of no less than 90%.

In our opinion using an actual dive scenario as the basis for cold water testing would provide the most accurate overall assessment of the regulators suitability. At least three regulators should be tested, and each of those should be tested at least twice. However, before performance testing is performed, all tests that could possibly cause damage or degrade the performance i.e. hot cold storage tests, detergent exposure, proof pressure should be accomplished first to stress the product. Additionally, all test standards should have a list of tests in the order that they should be performed and / or exemption from sequence if not applicable. At Dive Lab when we perform CE tests we conduct the hot and cold storage, proof pressure, and mechanical tests before any final breathing performance tests so that if any of the tests damages or degrades the product, it will hopefully be apparent before final human test dives.

8.0 Proposed Cold Water Testing: Dive Lab recommends using a simple cold water test scenario when testing regulators. The breathing simulator should first be stabilized with an inhalation temperature of 80 - 90°F and a relative humidity of

Figure 7. Extreme First Stage icing event.

88 - 95%. The scenario is focused around the concept of a rescue diver making a dive to a pre-determined depth to render aid to another diver. In the scenario the water is 32°F (0°C) or at a temperature specified for the test or standard, and that temperature will become the temperature limit for the regulator. The test simulates a diver leaving the surface breathing at the realistic rate of rate of 50 rmv (heavy work). The diver descends to the pre-determined test depth at a rate of 75 - 90 feet per minute (or as specified) and upon arrival at the test depth the breathing rate is increased to 62.5 rmv and the equipment breathed for five minutes. After the five minute test, the breathing rate is shifted back to a lower rate of between 25 - 50 rmv (or as specified) and the equipment is surfaced at a rate of 30 fpm (9 mpm) at which point the breathing machine is shut off, and the regulator checked for free flow condition and ice. A very minor free flow that does not have a significant impact on breathing performance is acceptable providing the resistive effort is within limits and, when the breathing machine stopped, the exhaust pressure from the free flow is no more than a minor hiss or bubbling, and the exhaust valve is clear and not obstructed by ice. This, we feel would better represent real world testing. Parts of the test could be changed such as the breathing rate, water temperature or time. Regardless, with this type of testing at these cold water temperatures, "All" regulators will form ice in the second stage. While ice formation is not desirable, formation is inevitable under these extreme test conditions and must be considered. Depending on the temperatures, the above test can prove to be very difficult and many SCUBA regulators will fail using the current test criteria. The test is relatively simple, it is straight forward, and it explains what needs to be done. This scenario test can be tailored by the Navy and CE to allow for some realistic testing that is clearly spelled out both in rational and procedure.

By not using simple human type scenarios as the basis for formulating test procedures and guidelines, the equipment may not be tested to a measurable benchmark of what the equipment should be able to do based on what a super fit diver could do, especially as it applies to cold water performance testing. Cold water unmanned breathing performance testing needs to be reasonably comparable to what a "Super Fit" upper 10% user might be capable of doing. This means using a scenario that a Super Diver might be capable of doing. It is doubtful that even a super fit human diver would be capable of breathing at 62.5 rmv for five minutes at a depth of 165 fsw (50 msw) in water as cold as 33°F because the actual inhalation temperatures would be well below freezing. See Table 3, page 15.

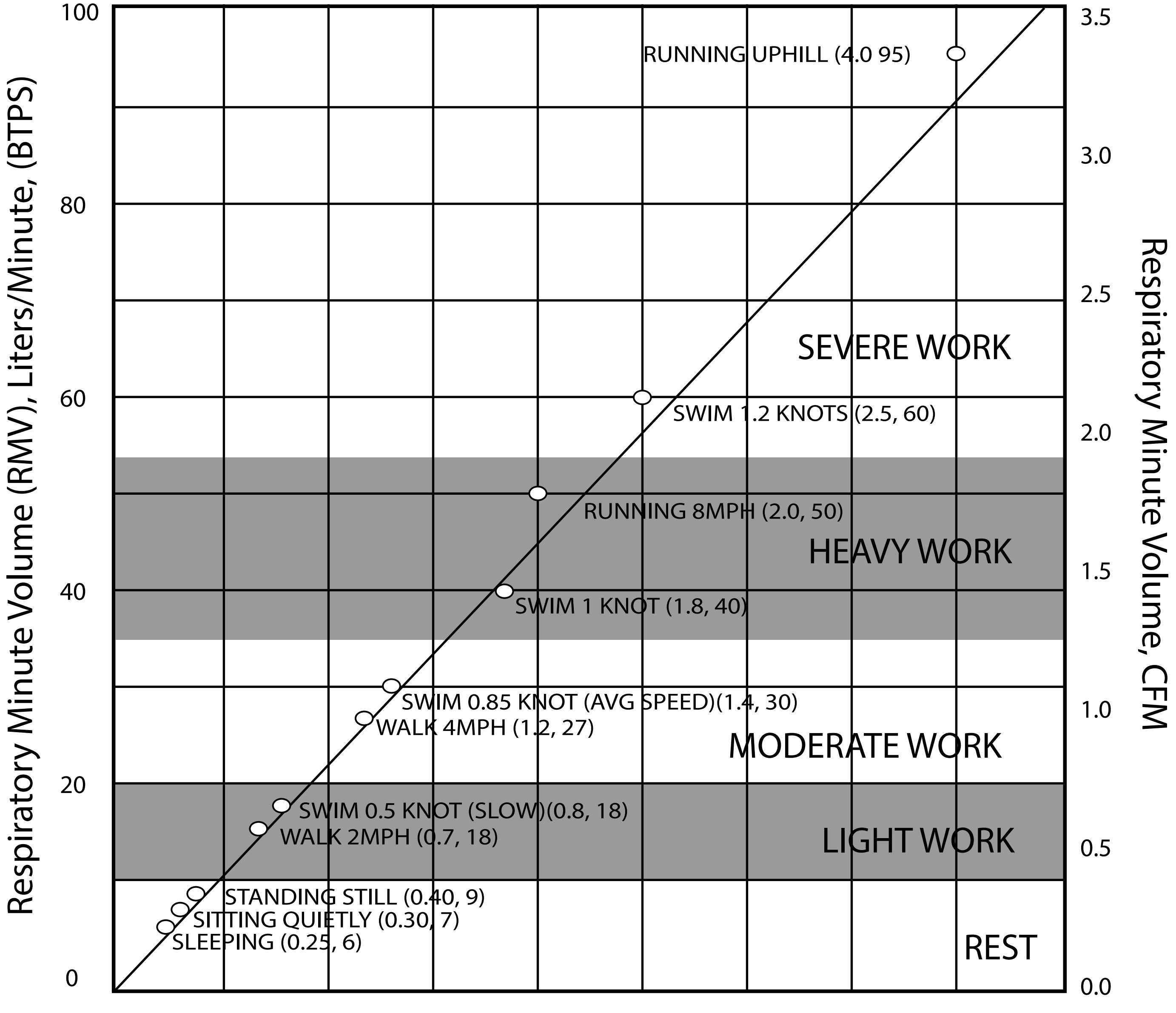
8.1 Verifying Test Methods and Procedures: Quite often when standards are written, the actual tests within the standards have not been fully tested or proven before being implemented. Once a standard has been written it becomes very difficult to change or modify, because of all the different interpretations and bureaucracy of the individual countries involved as well as the personalities and egos of those involved. This is can be very frustrating, especially for manufactures, and others that do not belong to the EU and have absolutely no say in how these standards are written. Quite often manufactures, test facilities and the notified bodies are forced to test to standards that they know are not correct, are inadequate, or could be done in a much more simple manner with greater accuracy. Because standards are often directed, mandated, or at the very least, influenced by governments, changes tend to come very slow if they come at all. The EU Notified Bodies as well as the testing facilities should have greater input in the standards they are required to test to. EN250 could be vastly improved if there was some sort of mechanism in place that allows the test facilities and notified bodies greater input and influence in the standards. Notified bodies and test facilities should have a more active role in the standards because they are the ones that actually perform and witness the testing. The test facilities and the notified bodies as well as manufacturers of equipment should be taking the lead in influencing changes to things they find are inadequate or incorrect. The notified bodies and the test facilities see firsthand the problems with some of the tests and procedures. If you look at the changes that have been made to EN250 since its inception in 1993, you will see that there have been very few significant changes, especially in procedural clarification. All this being said, EN250 has helped make diving much safer and has forced an overall improvement in equipment. But there is major room for improvement.

8.2 Pre Cold Water Proposed Ambient Testing: Before cold water testing of a particular regulator is done, it is recommended that a quick 50°F (10°C) ambient water pre-test be done. The pre-test was developed by ANSTI Test Systems Ltd and was designed and intended to weed out SCUBA regulators that develop ice and freeze at 50°F (10°C) water temperatures. Basically this test is intended to identify wet breathing regulators that get wet on their own thru leakage of the exhaust valve. Typically with this test you do not heat the exhalation air or humidify it from the breathing simulator because you do not want to introduce any moisture into the second stage. With this test, the regulator is breathed at 25 rmv or less to a depth of 165 fsw (50 msw) and then breathed at 62.5 rmv at 165' for five minutes using a constant supply pressure of 3000 psig. This is an extremely tough test for most regulators to pass because at the extreme breathing rate of 62.5 rmv, using a supply pressure of 3000 psig the first stage discharge temperature will hover around -7°F (-21°C) and the inhalation temperature will average around 17°F (-27°C). This is "COLD", and because the second stage temperature is well below freezing, if the second stage exhaust valve leaks at all, or if any water comes in from anywhere, water will freeze often resulting in a free flow and failure. This test can save the manufacture time and money in testing because if the regulator fails this test it is a sure bet it can never pass the CE cold 39°F (4°C) cold test.

8.3 Proposed Cold Water Testing: Before cold water testing is done, Dive Lab recommends the ANSTI Ambient water test. After successful ambient testing, Dive Lab recommends using a simple cold water test scenario when testing regulators. The breathing simulator will be stabilized with an inhalation temperature of 85 - 90°F and a relative humidity of 87 - 95% The scenario is centered around the concept of rescue diver's making a dive to a pre-determined depth to render aid to another diver. In the scenario the water is at a temperature specified for the test or standard, and that temperature will become the temperature limit. The test simulates a diver leaving the surface breathing at the realistic rate of rate of 50 rmv (heavy work). The air required for testing to 165 fsw (50 msw) would be a minimum of 130 scf (3680 slt) and for testing to 190 would be a minimum of 190 scf (5379 slt) The final volume for testing can also be determined according to the test procedure. The diver descends to the predetermined test depth at a rate of 75 - 90 feet per minute or as specified, and upon arrival at the test depth the breathing rate is increased to 62.5 rmv and the equipment breathed for five minutes. After the five minute test, the breathing rate is shifted back to a lower rate of between 25 - 50 rmv and the equipment surfaced at a rate of 30 fpm (9 mpm) at which point the breathing machine is shut off, and the regulator checked for free flow condition and ice. A very minor free flow that does not have a significant impact on breathing performance is acceptable providing the resistive effort is within limits and when the breathing machine is stopped the leak from the free flow is no more than a minor hiss or bubbling, and the exhaust valve is clear and not obstructed by ice. This, we feel would better represent real world testing. Parts of the test could be changed such as the breathing rate water temperature or time. Regardless, with this type of testing at cold water temperatures, "All" regulators will form ice in the second stage. While ice formation is certainly not desirable, formation is inevitable under these extreme test conditions. Navy and EU testing has always used the free flow as pass or fail criteria because some regulators continue to perform even with heavy ice formation inside the second stage. The above test is very difficult and many if not most SCUBA regulators will fail.

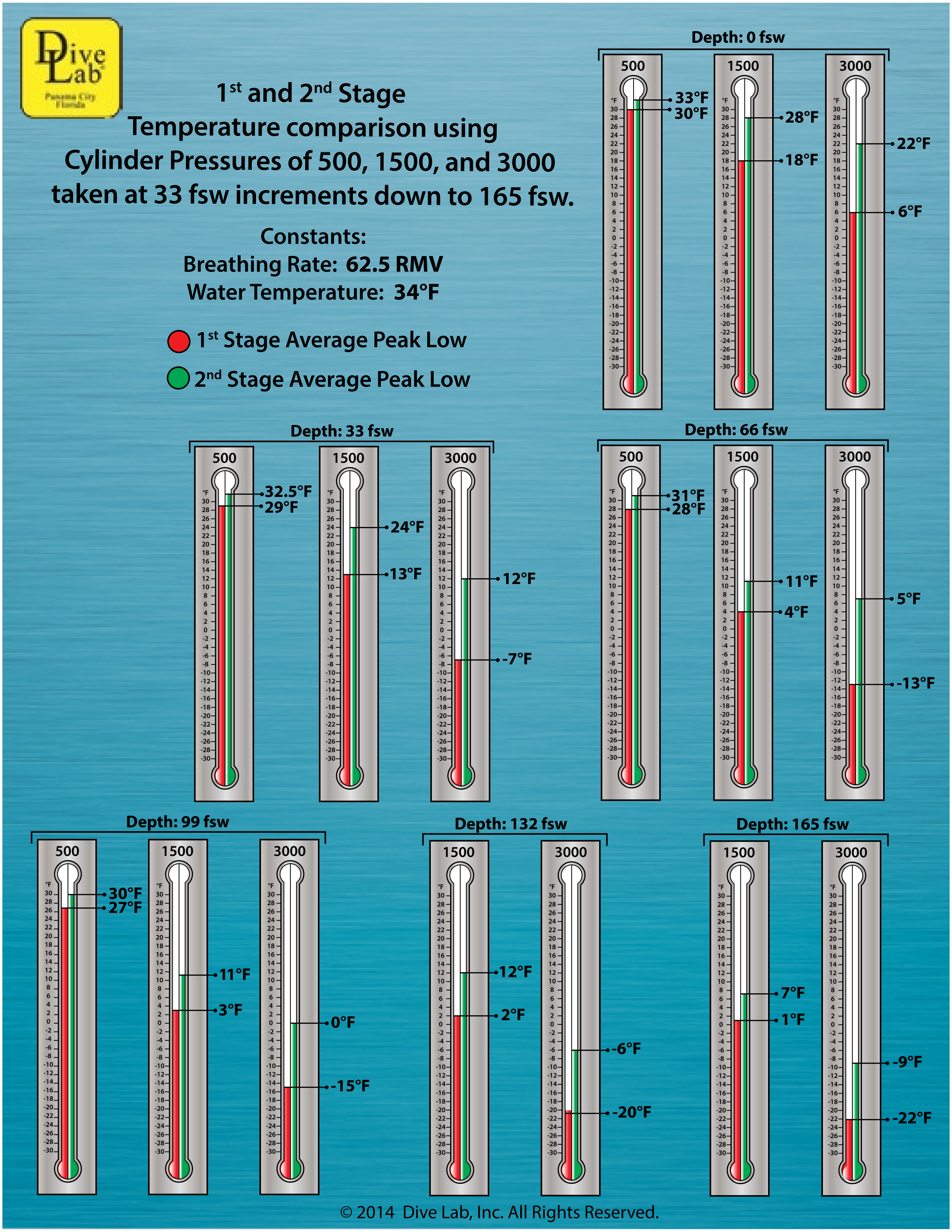
The test is relatively simple and straight forward. Test scenarios can be done at various test temperatures to determine the water temperature that the regulator can successfully pass. Once the temperature is determined it is recommend that the testing repeated at least twice with at least three regulators.

Respiration Chart



Oxygen Consumption Rates. Liters per Minute STPD

Breathing Rate Chart courtesy of the US Navy.

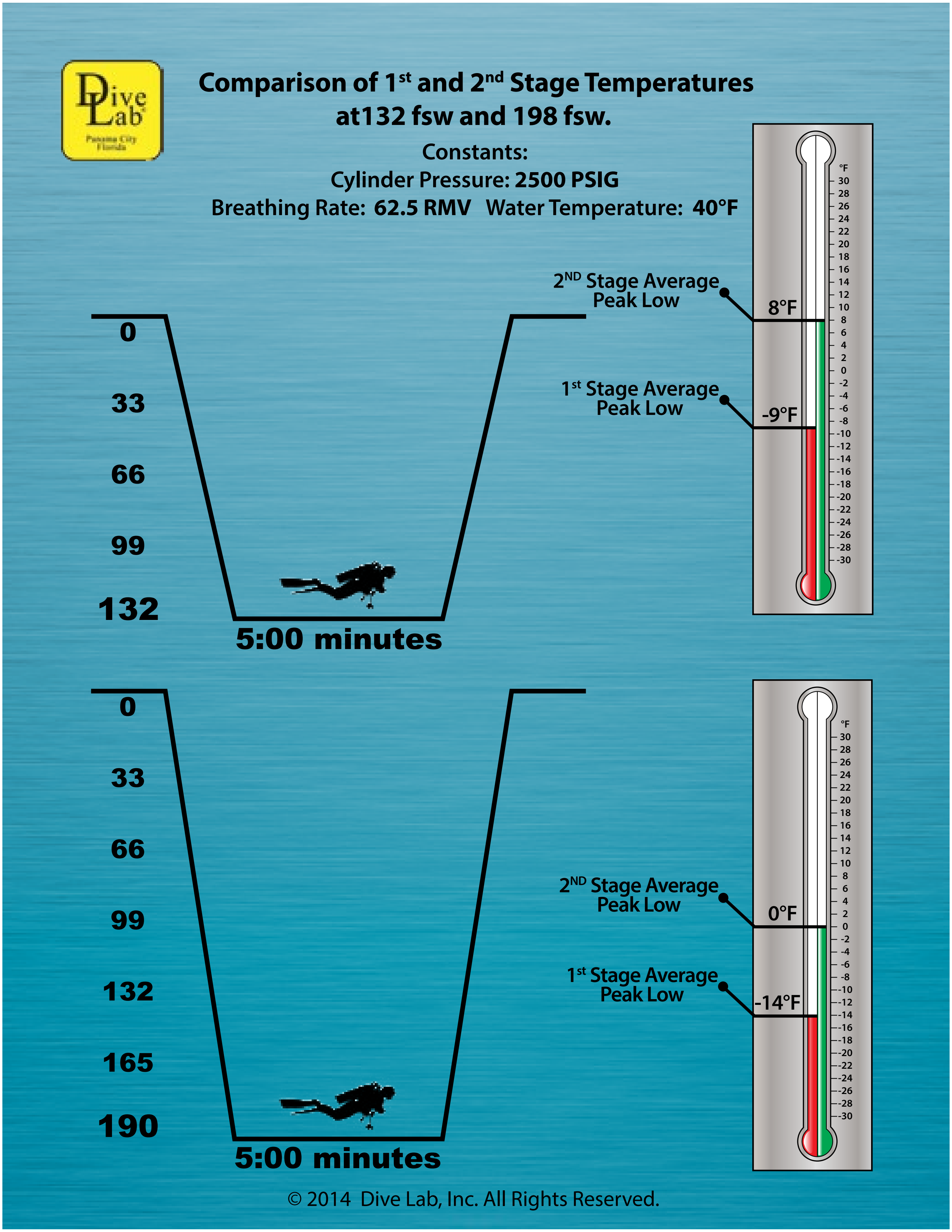


1st and 2nd Stage Temperature comparison using Cylinder Pressures of 500, 1500, and 3000 taken at 33 fsw increments down to 165 fsw.

Constants:
Breathing Rate: **62.5 RMV**
Water Temperature: **34°F**

🟥 1st Stage Average Peak Low
🟩 2nd Stage Average Peak Low

Table 1 Water temperature is at 34°F (1°C), the breathing rate is 62.5 rmv, and the HP supply pressure is varied at 500, 1500, and 3000 psig. Depth is increased in 33 fsw increments to 165 fsw (50 msw). Note how the supply pressure effects the temperature.



Comparison of 1st and 2nd Stage Temperatures at132 fsw and 198 fsw.

Constants:
Cylinder Pressure: 2500 PSIG
Breathing Rate: 62.5 RMV Water Temperature: 40°F

Table 2 Shows two basic dives in 40°F water using a constant breathing rate of 62.5 rmv and showing a comparison of the first and second stage temperatures at 132 fsw and 190 fsw. The only variable is depth.

1st and 2nd Stage Temperature Comparison at 22.5 RMV, 40 RMV, 62.5 RMV, and 75 RMV.

Constants:

Cylinder Pressure: **2500 PSIG** Water Temperature: **33°F** Max Depth: **165’**

● 1st Stage Average Peak Low ● 2nd Stage Average Peak Low

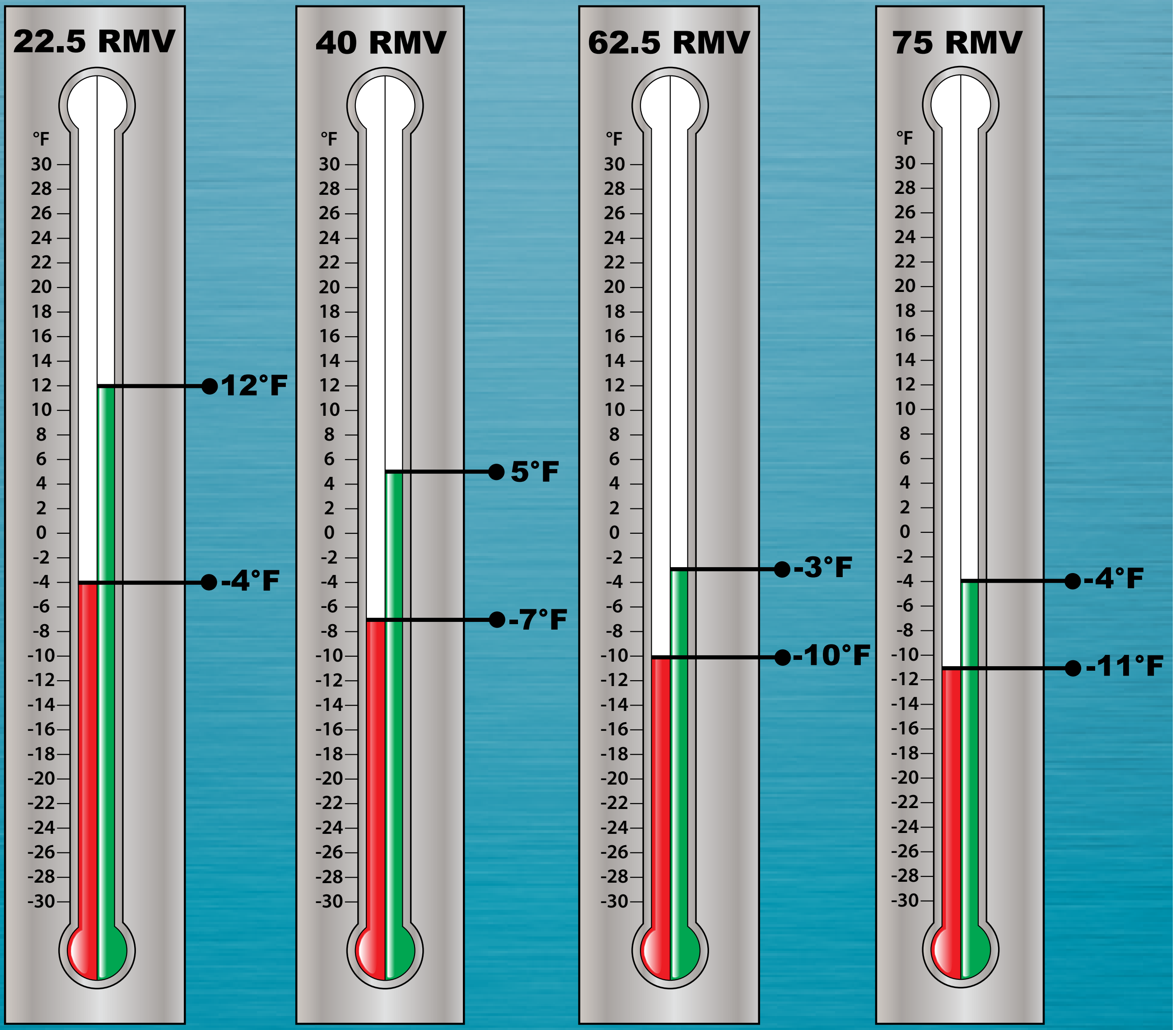


Table 3 Uses a constant water temperature of 33°F (.55°C), a constant supply pressure of 2500 psig, and a constant depth of 165 fsw. The only variable is the breathing rate.

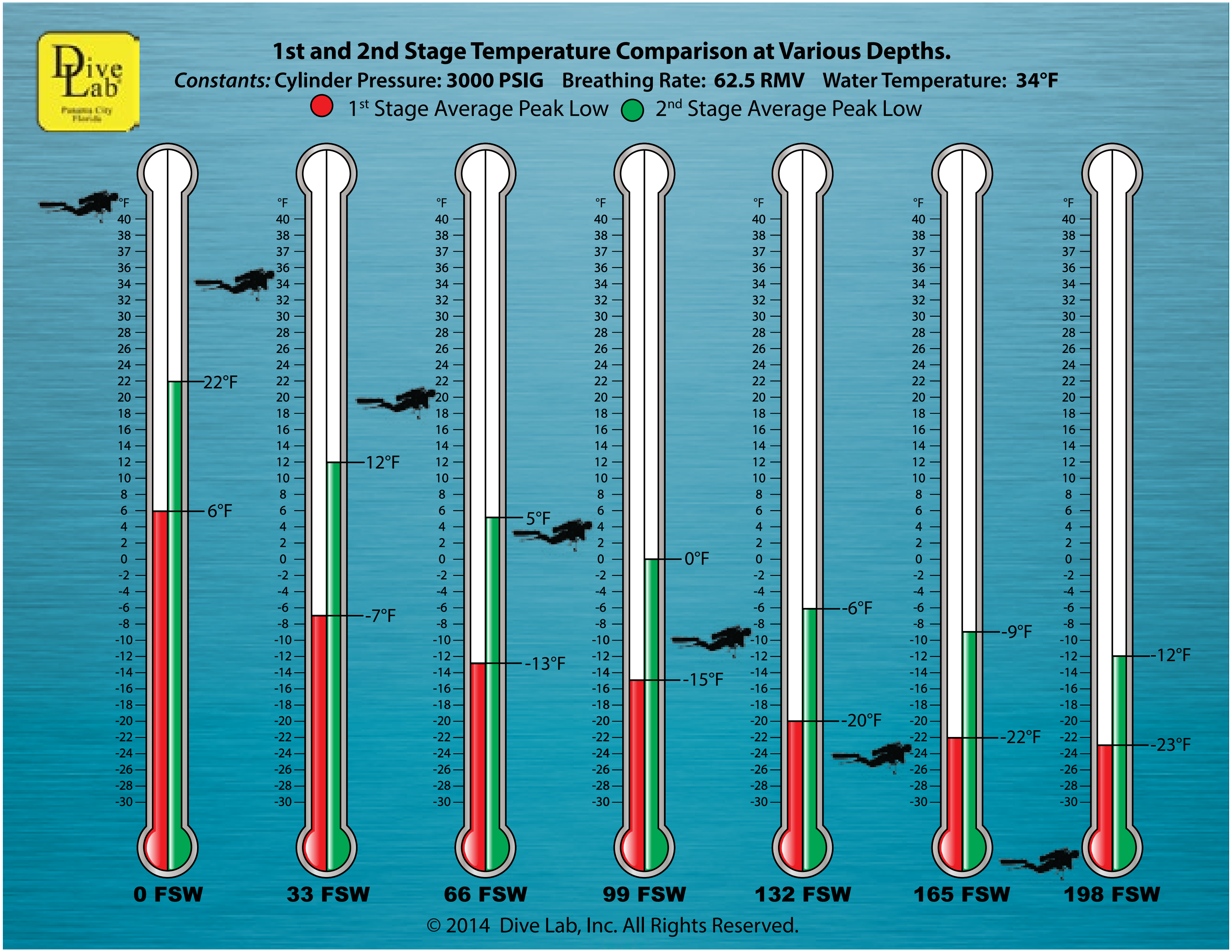


Table 4 Uses a constant water temperature of 34°F (1°C), a constant breathing rate of 62.5 rmv, and a HP supply pressure of 3000 psig (206 bar). First and second stage temperatures were taken at 33 fsw increments down to 198 fsw. This chart shows the temperature changes that occur with the increase in depth.

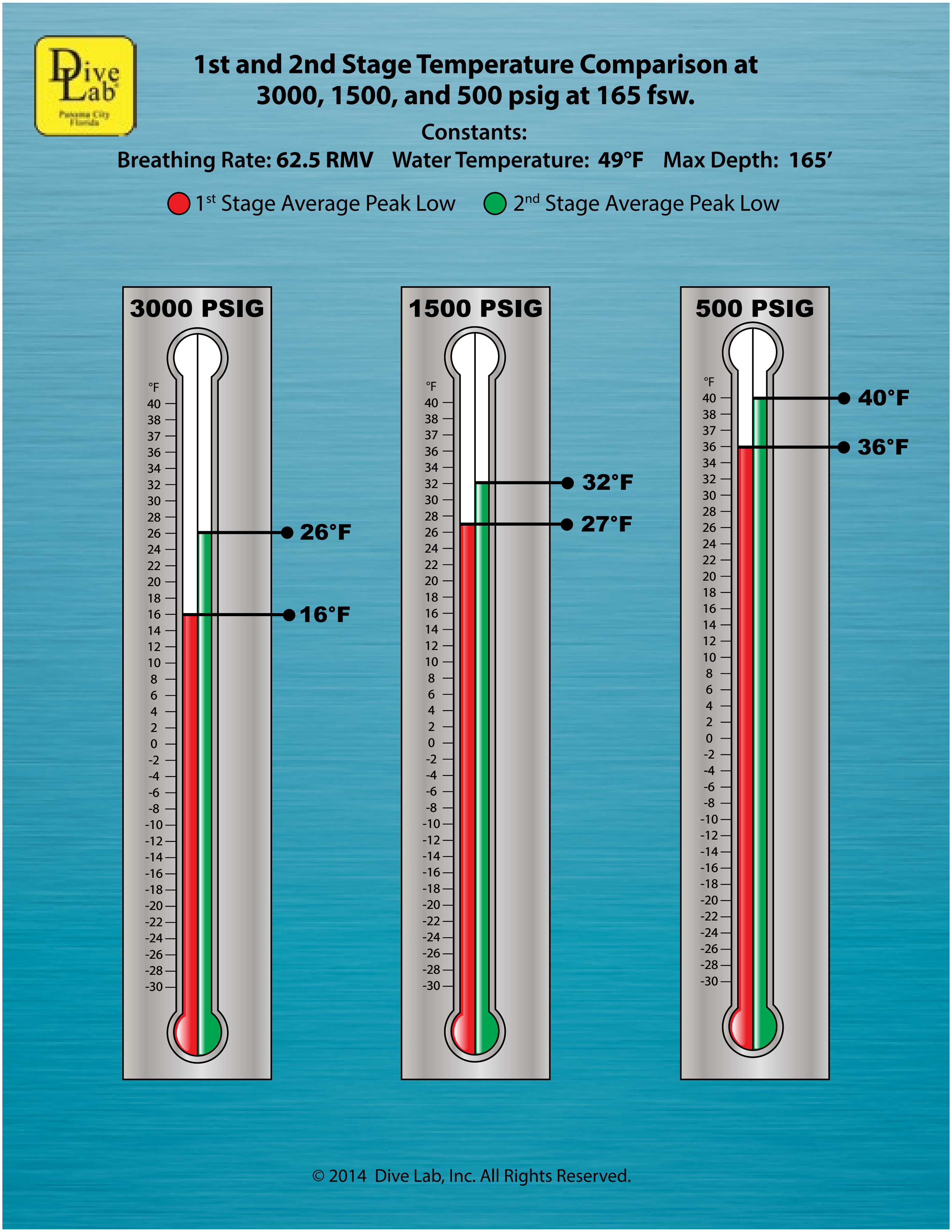


Table 5 Shows a constant water temperature of 49°F (9.4°C), a constant depth of 165 fsw, and a constant breathing rate of 62.5 rmv. Three HP supply pressures of 3000 psig (206 bar), 1500 psig (103 bar) and 500 psig (34 bar) were used.

1st and 2nd Stage Temperature Comparison at 1500 PSIG and 3000 PSIG in 190 FSW.

Constants:

Max Depth: **190 FSW** Breathing Rate: **62.5 RMV** Water Temperature: **32°F**

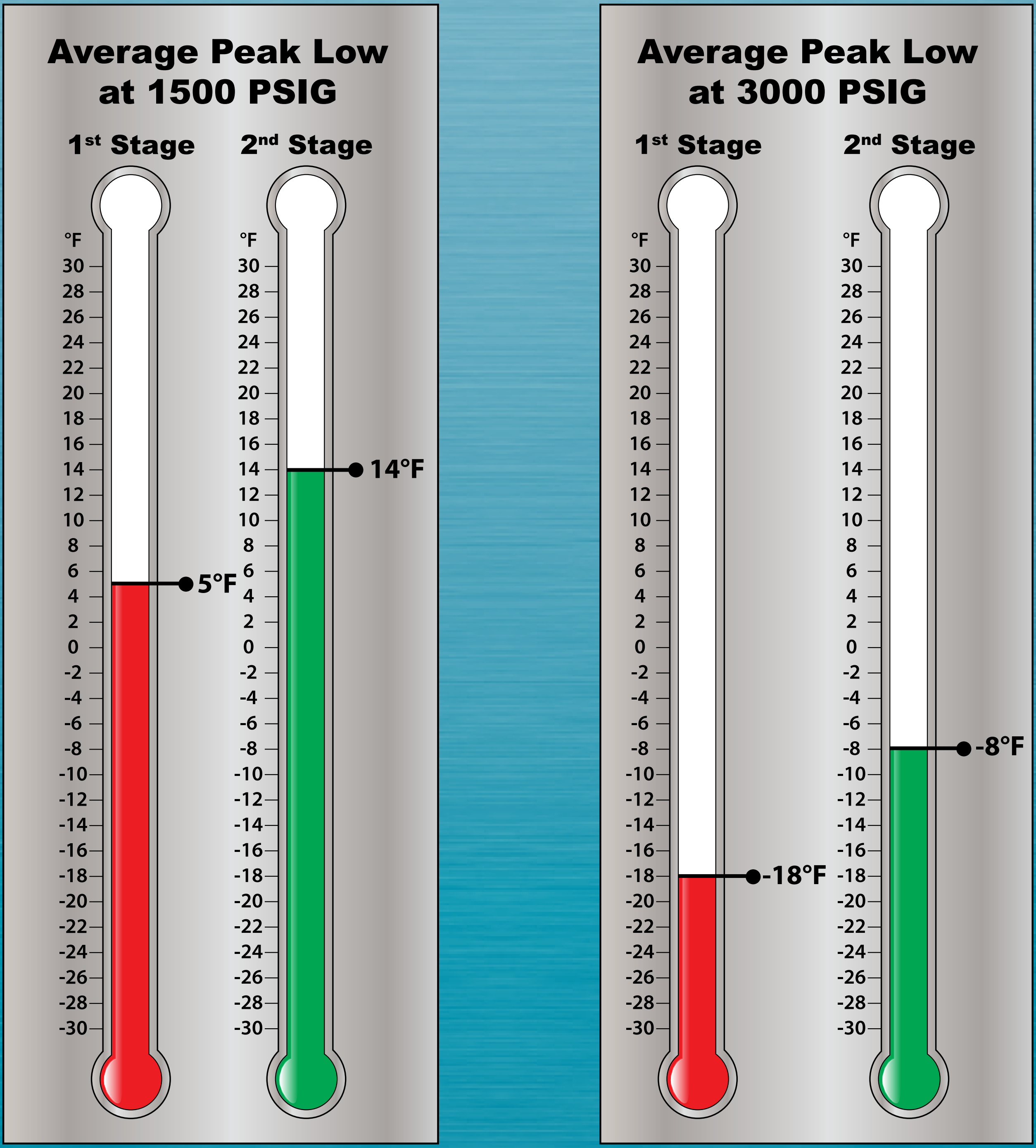


Table 6 Shows a constant water temperature of 32°F (0°C), a constant depth of 190 fsw, and a constant breathing rate of 62.5 rmv. Two HP supply pressures of 1500 psig (103 bar) and 3000 psig (206 bar) were used.

9.0 Dive Lab Recommended Cold Water Test Outline of Procedures:

Note: Actual test depths, breathing rates and times could be adjusted to meet specific test standards or requirements. The outline below is a suggestion for CE EN250 type testing as a scenario based test.

- Testing will be done to 165 fsw (50 msw), in water at the coldest temperature as dictated by the manufacture. This will become the limit.
- The first stage with air supply will be immersed in water at the required test temperature for at least 10 minutes prior to starting the test.
- The breathing simulator will be run without the test regulator attached, and or with a surrogate cold open circuit system in order to stabilize the breathing simulator exhalation temperature and humidity before the actual test regulator system is breathed on the breathing simulator.
- The regulator will be tested with the breathing simulator stabilized with a relative humidity of 87 - 95% and a breathing simulator exhalation temperature between 80 - 90°F before decent to test depth starts.

9.1 Test Guidelines:

- At the final moment just before the start of testing , the breathing machine is stopped, the second stage is attached to the "T" and the breathing gas supply shifted to the volume system for the test which may be sized dependent on the depth. This must be spelled out in the test plan.
- The breathing simulator is started, and traveled to the pre-determined test depth within 2-3 minutes while breathing at 50 rmv to simulate a rescue diver descending at approximately 75 fpm (23 meters per min) until the desired test depth is reached.
- Once at depth, the breathing rate is shifted to 62.5 rmv and the regulator breathed for a minimum of five minutes at depth.
- After the five minute breathing cycle of 62.5 at depth, the breathing rate is reduced to between 25-50 rmv and the breathing simulator system is traveled back to the surface at a rate of 30 fpm (9 meters per minute).
- Once on the surface the breathing simulator is switched off and the regulator checked for free flow. If no free flow is present, or only a very small hiss is present, it passes.
- The regulator is also checked for ice formation to insure the exhaust valve is clear and is not obstructed by ice. Presence of ice around the exhaust that does not allow the exhaust to shut is considered a failure.
- This test should be done at least twice with each test regulator. A minimum of three regulators should be tested. For the above test to 190 fsw (58 msw) it will normally require at a minimum , twin 80 cubic foot cylinders charged to 3000 psig. Other HP supply cylinders of higher pressures could be used if the manufacturer rates the regulator for higher pressure use in cold water.

9.2 For a real Navy dive, twin 80 cf cylinders would be an operational minimum requirement for military divers to actually conduct a dive to 190 fsw, spend a planned 5 minutes breathing, then make it back to the surface breathing. For the extreme test we propose using 50 and 62.5 rmv, twin 80s would the bare minimum. The "COLD REALITY", even if the water was 38°F (3.3°C) water or colder, it is doubtful that any diver would be able to maintain a breathing rate of 50 rmv down to 165 or 190 fsw (50 msw, 58 msw) and then breath at 62.5 rmv for five minutes because the "average" inhalation temperature at the second stage would be below 10°F (-12°C) degrees at all times making breathing painful and the mouth very numb. However in an effort to show worst case, this would be a reasonable test. Just like a real diver, the breathing simulator is breathing the regulator from the cylinders and as the dive progresses the cylinder pressure is continuously dropping, and the air temperature at the first and second stage is continuously increasing (warming) just like it would if a real diver were breathing. Even at that, it would take SuperMan to do it. The 190 fsw scenario that Dive Lab used, starts by leaving the surface at 50 rmv (heavy work) and travels to 190 fsw within 2.5 - 3 minutes and upon arrival at 190 fsw (58 msw) the breathing rate is increased to the severe rate of 62.5 rmv and the regulator breathed for five minutes. After the five minute breathing at 190 fsw the breathing is reduced to a breathing rate of 50 rmv or less and the chamber surfaced. Dive Lab has completed a number of different scenarios for regulator testing typically 135 fsw (41 msw), 165 fsw (50msw) and 190 fsw (58msw) these scenarios tax the equipment in a realistic manner so that the equipment's freeze potential can be evaluated in a comparable fashion. All the regulators tested at Dive Lab using the above scenario formed a significant amount of ice on the first stage and inside the second stage. The formation of ice is inevitable under these conditions.

Figure 8. Regulator fitted with thermoster probes.
*Note ice formation after 5 minutes at 62.5 lpm and 165 fsw (50 msw)

9.3 Dive Lab Testing: Dive Lab has performed numerous tests similar to the ones discussed above at depths between 132 - 198 fsw in water at 32 - 34°F with the Apeks DX-50 first and second stage as well as the Poseiden Xstream first and second. Both of these regulators have a reputation as good cold water regulators. Other makes of regulators have also been tested. All regulators tested, were fitted with rapid temperature devices (RTDs). The RTD's were fitted to the outlet fitting at the first stage, and at the inlet fitting just before the second stage. The RTDs installed in the intermediate hoses actually measure the temperature of the air in the flow path. RTDs were also installed in the interior of the second stages so that the gas entering from the inlet valve, and exiting the exhaust valve could be monitored. This is a standard set up that Dive Lab has employed many times before in other tests. In addition we often install a RTD inside the second stage at the inlet of the air going to the breathing simulator and just before the exhalation valve. Overall the most important measurements are the real time air supply temperature as the air exits the first stage going to the second stage supply hose and just before the air enters the second stage. In addition, we also measure the air temperature and humidity as the air is exhaled by the breathing simulator. In all we measured six different points using seven RTDs.

9.4 Humidity: Proper humidity is critical for accurate cold water test results. If the relative humidity is much below 87 % based on an exhalation temperature between 80-90°f, you will not be simulating what a real diver would be exhaling. As mentioned before, when breathing at 62.5 rmv @ 165 fsw and 2500 psig supply, outlet temperatures will be as cold as -10°F coming out of the first stage, and the second stage inlet valve components can get as cold -3°F during inhalation. Picture yourself breathing!, At these inlet temperatures the second stage components get "really cold", and as the warm moist exhalation gas from the breathing simulator or in the real world, the divers exhalation, enters the second stage the moisture condenses on the cold components and instantly adds a very thin layer of ice onto the cold demand valve components. If critical items like the lever are not shielded from the exhalation gas to minimize the icing, it is usually only a matter of time with most regulators until the ice interferes with the mechanics causing a free flow. We believe testing using a scenario is the most accurate way to test. If the above testing of regulators is done in 34°F (1°C) water and it can be breathed from the surface to 165 fsw or deeper, at 50 rmv, and then breathed at 62.5 rmv for five minutes followed by surfacing without the ice formation affecting the breathing performance, it is reasonably plausible to conclude it could be used safely in warmer temperatures and shallower depths. Keep in mind, the breathing simulator does not have a gag reflex like a diver, inhaling a sliver of ice is no big deal to the breathing machine but can be a "very Big Deal" for the diver. During these tests the formation of "ICE" within the second stage takes place very quickly. In the real World, ice in the second stage can pose a significant potential inhalation /choking hazard, however the US Navy and EU standards do not disqualify regulators that form ice, and as long a breathing performance remains within the requirements and the regulator does not free flow the regulator will pass. Dive Lab used the 190 foot depth because it represents the extreme of what might be done by military divers. If the same test were done at 165 fsw using the same water temperatures, it would show second stage inlet temperatures 2-3 degrees warmer overall, but ice formation in the second stage would still happen. Dive Lab has performed this same testing with water as various temperatures from 32 - 50°F, and even at the significantly warmer water of 50°F (10°C), we still developed ice in some second stage regulators during testing.

First stage cold water / environmental kits can delay first stage freezing and allow the first stage to operate longer in most cases, certainly at least long enough to complete the Dive Lab proposed scenario tests. Dive Lab testing has shown that a first stage design such as the Poseiden Xstream, is virtually unaffected even when tested at 190 fsw in 33 degree water at 62.5 rmv, for at least 25 minutes with a constant supply of 2500 psig. Something a human could never do. On the Poseiden first stage the ice did not form around the sensing diaphragm because the back end of the regulator is well ventilated allowing the water to re-heat the body much faster and more efficiently than any other first stage we tested. The Poseiden Xstream second stage did not free flow but did develop a significant amount of ice during the five minute test however the ice did not degrade the breathing performance. The Apeks DX-50 first and second completed testing at 190 fsw and did not free flow but also had a significant amount of ice around the second stage main tube area however the overall performance during the testing was excellent. The first stage sensing area was not affected by the formation of ice on the first stage.


Figure 9. Poseidon Regulator

10.0 Scenario 1: In this scenario we conducted breathing simulator tests on the Poseiden Xstream, and Apeks DX-50 first and second stage regulators. We set up a test that was to simulate a rescue of a SCUBA diver scenario diving to a depth of 190 fsw to assist an entangled diver. For this test we kept the water at 33 - 34°F, the exhalation temperature between 85 - 95°F, and the relative humidity 90 - 95%. Before we started the tests the breathing simulator was run for at least 20 - 30 minutes to stabilize the exhalation temperature and humidity. We started from the surface at a breathing rate of 50 rmv (heavy work) and traveled to 190 fsw in approximately 2.5 minutes at which point we shifted to the severe breathing rate of 62.5 rmv which we kept for five minutes. At the end of five minutes we surfaced the test chamber, and opened up and inspected the interior of the second stages. In each test, the second stage regulators had formed a significant amount of ice but the ice did not affect the performance or functioning of the second stage. The first also stages were covered with ice.

10.1 Apex DX-50: The Apex test at 190 fsw showed that the temperature of the air coming out of the first stage at 190 fsw, was as low as -15°F and by the end of the five minute breathing period at 190 fsw the pressure in the twin 80 cylinders had dropped to around 1200 psig and a peak low first stage temperature of +9°F resulting in an average temperature of -3°F during the 5 minute test. The second stage inlet air temperature peak low at the start of the 5 minute test was -1°F and at the end of the 5 minute test the second stage inlet temperature was +12°F resulting in and average second stage inlet temperature of +5.5°F. The second stage average exhalation temperature measured at the exhaust valve was approximately 52°F. The Poseiden Xstream was dived using the same test protocol and posted virtually identical temperatures. The Poseiden also had a significant amount of ice in the second stage.

It must be understood, we did the 190 fsw test scenarios as mentioned above, as what might be done real world by the US Navy because they might have to dive to that depth. However, in a real operation the US Navy cannot conduct open circuit SCUBA diving operations to a depth deeper than 130 feet without the commanding officers permission and if anything goes wrong, that commanding officer would have to justify why SCUBA divers were used instead of surface supplied divers. Diving below 130 fsw, especially in water colder than 50°F on open circuit SCUBA can be extremely hazardous especially if heavy work is encountered. The purpose of the 190 fsw (58 msw) by Dive Lab was to document the air temperatures at various points from the first stage thru the second stage regulator.

Surface supply has advantages, etc. See section 12.0, page 23. However, if the surface supplied diver goes on EGS some of the problems of cold water SCUBA can apply.

10.2 For the 190 fsw test we used a set of twin 80 cylinders charged to 3000 psig. In the real world if a dive to 190 fsw were to be made in the US Navy, twin 80 cubic foot cylinders charged to 3000 psig would be the minimum air supply used, however some commands are using cylinders that have a working pressure of 3500 psig, and volumes in excess of 260 CF. In these cases the freezing potential is even greater. Rapid Temperature Devices (RTDs) were installed, one at the first stage outlet, one at the inlet to the second stage, one just inside the second stage measuring the air as it flashes into the second stage, and one next to the exhaust to measure the air temperature leaving the second stage. In addition to these temperatures, we also measure the breathing machine exhalation temperature and humidity. The water temperature is measured with two RTDs.

Divers that routinely dive in waters colder than 50°F (10°C) know that if they were to try to inflate a 100 - 200 lb lift bag, or aggressively purge and free flow their regulator underwater for just a few seconds, many second stages will start free flowing and will not stop unless the air supply to the regulator is secured. Many experienced cold water SCUBA divers install shuttle type shut off valves at the inlet to each second stage regulator so if the second stage freezes, the air can be shut off to the second stage allowing them to go on the alternate second stage and abort the dive. These valves are a must for cold water diving.

Figure 10. Kirby Morgan Thermo Exchanger (TE)

11.0 Kirby Morgan Thermo Exchanger (TE): The Kirby Morgan Thermo Exchanger was developed to eliminate second stage SCUBA regulator freezing when diving in extremely cold fresh or salt water at temperatures down to 28°F (-2.2°C).

11.1 Theory of Operation: The theory of operation is based on the thermal transfer of heat from the surrounding water, which warms the air coming from the first stage regulator. The TE is a simple heat exchanger coil made of high grade stainless steel. The coil is attached to a chrome plated brass swivel block that allows for attachment of both the primary and secondary demand regulators as well as the BC inflator hose. The length of the tubing and the mass of the block is the reason why the system can warm the air from the first stage to the second stage regulator to within one to two degrees of the surrounding water. The performance of warming is based on the following technical requirements.

- Water Temperature - 28°F (-33°C)
- Breathing Rate - 62.5 lpm
- Minimum Second Stage Inlet Temperature 28°F (-2°C)
- Minimum time to 2nd stage ice formation at 62.5 rmv / 28°F (-2°C) = >10 min
- Minimum time to freeze at 62.5 rmv 32°F (0°C) = >18 min
- Mnimum time to freeze time at 38 rmv = >2.5 hours (Ice development in the second stage)
- Maximum normal working pressure 350 psig
- Normal system test pressure 500 psig

The above specification relates to extreme testing. In practical use during SCUBA operations the HP air supply pressure is constantly reducing thus reducing the temperature drop as well. In addition, even an extremely fit diver could never maintain a breathing rate of 62.5 lpm at a depth of 165 fsw for more than a couple of minutes in cold water. When using the thermo exchanger, an added benefit for the diver is the reduction in thermo drain due to extremely cold gas. The TE was primarily designed and intended to eliminate second stage regulator freezing for divers diving in extreme cold water, but also provides the diver with much warmer breathing air. The TE will not significantly reduce or degrade the breathing performance of good quality high performance SCUBA regulators that currently meet the work of breathing requirements as set forth in the European CE standard EN250:2000. It is recommended that the first stage intermediate pressure be run at the upper end limit as specified by the manufacturer to minimize any pressure drop to the second stage from the volume of the TE. For further information on performance please contact Kirby Morgan Diving Systems International www.kmdsi.com

12.0 Umbilical Supplied Equipment Freezing: Although surface supplied demand mode umbilical divers use similar demand regulators used on helmets and full face masks, these demand regulators do not pose a significant threat of developing ice and /or freezing from the divers exhaled breath because the umbilical in the water operates at low pressures and the umbilical acts as a thermal heat exchanger and warms the breathing air up to the surrounding water temperature. Even in salt water at 28°F (-2°C) the air is not cold enough to support ice formation in the second stage components even at work rates as high as 62.5 - 75 rmv. However, this does not necessarily mean surface supplied divers don't have worry about cold water. In generally, surface supplied divers stay in the water a lot longer than SCUBA divers, and in most cases have to breathe at much higher breathing rates because they are conducting working dives. Overall most surface supplied divers are supplied with air derived from low pressure compressors. Low pressure compressors can put a lot of moisture in the volume tank in a very short time depending on the atmospheric humidity. It is imperative for diving operations in cold areas to insure they have a good moisture separator / filtration system. The most significant cold problem for most umbilical supplied divers is just trying to stay warm. The next significant problem is not so much the water temperature, but rather the topside air temperature. In most cases helmet and full face masks supplied air from umbilicals do not get cold enough to develop ice because the umbilical works as a radiator (heat exchanger) and warms the incoming air up to that of the water temperature. Unlike SCUBA where if your diving is 32 - 50°F (7 - 10°C) the demand regulator incoming air arriving from the first stage can easily be in the -5 - 15°F range, where the umbilical supplied air will always be at the same temperature as the water, which in the worst case would be just below freezing but warm enough to allow the divers exhaled breath keep ice from forming.

12.1 Topside Cold: If the topside surface air temperatures are well below freezing, (around 25°F or less) excessive moisture from the volume tank in the form of water droplets can travel into the umbilical that is in the extreme cold topside environment and freeze into small "ice balls" that can then travel down the umbilical and end up in the side block and bent tube, blocking off air to the demand regulator. The blockage is not from actual formation of ice within the helmet components but rather the collection of ice from the surface supply system. The ice that was generated topside blocks passages to the regulator and side block. The ice can cause a reduction of flow, as well as a complete blockage, stopping all air flow because the down-stream flow compacts the ice.

The best way to prevent ice from developing in the surface supply system is to insure your volume tank has a good moisture separator system and the volume tank and moisture separator condensate is drained regularly to avoid moisture buildup. Air dryers in the form of electric moisture separators are available as well as desiccant type filters. Surface supplied diving using HP air will not have enough moisture to cause freezing problems with the man worn helmets or masks because most all modern HP compressors use driers that remove moisture down to a dew point of at least -40°F.

Keeping the umbilical in a heated shack and minimizing how much is exposed to the cold ambient air prevents moisture in the umbilical from turning into ice. The portion of the umbilical in use in the water is at the same temperature of the water and will not normally be cold enough to allow any water in the umbilical to freeze as long as the water you are diving in is not below 32°F (0°C). As long as the portion of umbilical topside in the air is kept above 32°F (0°C), there will be little risk of generating ice from a wet supply system. The safest bet is drain the volume tank and filters on a regular interval and run good dryers, which could be refrigerant or desiccant type .

Stay Warm.

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