ROTARY DRILLING

DIVING AND EQUIPMENT

Third Edition

UNIT V • LESSON 5

PETEX

ROTARY DRILLING SERIES
Unit V, Lesson 5

Diving and Equipment

Third Edition

Written by John Herren and Gene Lo Conte

Published by

PETROLEUM EXTENSION SERVICE
Continuing Education
The University of Texas at Austin
Austin, Texas

in cooperation with

INTERNATIONAL ASSOCIATION
OF DRILLING CONTRACTORS
Houston, Texas

2010

Library of Congress Cataloging-in-Publication Data

Herren, John, 1971-
Diving and equipment / by John Herren and Gene Lo Conte. — 3rd ed.
p. cm. — (Rotary drilling ; unit 5, lesson 5)
"Original content in cooperation with International Association of Drilling Contractors, Houston, Texas."
Second ed.: Diving and equipment / by Rusty Haggard ; edited by Nancy Janicek. Austin : Petroleum Extension Service, University of Texas at Austin, in cooperation with International Association of Drilling Contractors, 1982.
ISBN 0-88698-238-3 (alk. paper)
1. Offshore oil well drilling. 2. Deep diving. 3. Deep diving — Equipment and supplies. 4. Underwater welding and cutting. I. Lo Conte, Gene, 1969. II. Haggard, Rusty. Diving and equipment. III. International Association of Drilling Contractors. IV. Title.
TN871.3.H47 2010
622'.33819—dc22

2010020257

Disclaimer

Although all reasonable care has been taken in preparing this publication, the author, the Petroleum Extension Service (PETEX) of The University of Texas at Austin, and any other individuals and their affiliated groups involved in preparing this content assume no responsibility for the consequences of its use. Each recipient should ensure he or she is properly trained and informed about the unique policies and practices regarding application of the information contained herein. Any recommendations, descriptions, and methods in this book are presented solely for educational purposes.

First edition published 1977. Second edition 1982
Third edition 2010
Printed in the United States of America

Catalog no. 2.50520
ISBN 0-88698-238-3
978-088698-?

No state tax funds were used to publish this book.
The University of Texas at Austin is an equal opportunity employer.

Cover image: Courtesy of Epic Diving and Marine Services LLC

Editor: Debby Denehy

Graphic Designer: Debbie Caples

Contents

Figures

Tables

Foreword

Diving and Equipment, 2nd Edition, is Lesson 5 of Unit 5 of the PETEX® Rotary Drilling Series, originally developed in cooperation with the International Association of Drilling Contractors (IADC). Unit 5 is devoted to Offshore Technology. With increasing interest in offshore operations, this unit is an essential component of this comprehensive series that focuses specifically on today's drilling operations. The purpose of this lesson is to introduce nondiving personnel to the procedures and equipment used in commercial diving operations.

Additional information on offshore operations can be found in *Life Offshore*, 2nd Edition (Lesson 9), a book that showcases what life is like for workers assigned to rigs and platforms in remote locations at sea. Other lessons in Unit 5 cover rig moving, crane operations, anchor handling, marine risers, helicopter transport, vessel inspection, and weather factors. For a complete list of books in this unit and the entire Rotary Drilling Series, see the inside cover of this book or visit www.utexas.edu/ce/petex.

Preface

Commercial oilfield diving has been constantly evolving since Scottish physiologist Dr. John Scott Haldane introduced the concept of decompression tables in 1907. As exploration of offshore oil and gas has expanded geographically and continued to reach greater depths, divers have continuously searched for innovative ways to meet these needs by developing strict safety protocols and adapting everyday tools and machinery to withstand the harsh conditions of the oceans. New technologies have provided divers with more advanced life-support equipment to allow them to work at these greater depths for longer periods of time without risking their health.

Even while these technological advancements have taken place in the diving arena, divers continue to be cut from a certain mold. These men and women come from all over the world to perform in a career well suited to their personalities. They require challenge, adventure, and an unquestionable sense of accomplishment when they see a project completed. They consistently embrace the difficult tasks and are easily bored when asked to perform a task they feel is mundane. Divers are a small percentage of the offshore oilfield workforce. Many of the operations that take place under the surface of the water cannot be replicated by robotics, even with today's technology. Divers will always be required for offshore oilfields to be productive.

Because of the complexities and long history of commercial oilfield diving, an extensive amount of information on the subject is available. This text is meant to provide a general overview of the history of commercial diving, the types of tasks performed by the diver, and the tools required to complete these tasks. Hopefully, after completing this book, readers will have a better understanding of commercial diving and the environment in which divers work.

John Herren
Senior Director of Operations
EPIC Diving and Marine Services
Harvey, Louisiana

About the Authors

John Herren
Senior Director
Epic Divers and Marine Services

John Herren began his career in the commercial diving industry in 1990 after graduating from the College of Oceaneering in Los Angeles, California. He moved to the Gulf of Mexico and joined SubSea International where he worked as a tender, diver, and saturation diver in the Gulf of Mexico and West Africa.

In 1997, Herren worked as a freelance diver and Saturation Supervisor in the United States. Since 1998, he has worked for EPIC Divers and Marine where he supervised divers until he entered management in 2001. He has held positions as Operations Manager, Project Manager, and Director of Diving and is currently Senior Director of Operations.

In addition to his commercial diving credentials, Herren has been certified as a Diving Medical Technician by the National Board of Diving and Hyperbaric Medical Technology, a certified Underwater Bridge Substructure Technician, and is certified by The American Society of Nondestructive Testing in magnetic particle and ultrasonic testing methods. He has a Bachelor's degree in Business Administration from Northwood University and a Master of Business Administration from Tulane University.

Gene Lo Conte
Diving Superintendent
Epic Divers and Marine Services

Gene Lo Conte has been a leader in the commercial diving industry for over 20 years. After finishing dive school at City College in Santa Barbara, California, he began his career as a tender with SubSea International in the Gulf of Mexico.

He quickly transitioned from tender to diver and started freelancing domestically and internationally. Lo Conte's diving freelance work took him from Africa to Venezuela and included domestic work in the Gulf of Mexico and on the east and west U.S. coasts. In 1999, he joined EPIC Divers and Marine as a diver/supervisor and has been a Diving Superintendent since 2003.

In addition to his work with EPIC, Lo Conte has presented on the subject of commercial diving at oil and gas industry conferences, written articles for trade publications, and taught commercial diving at the Divers Academy in New Jersey. Lo Conte has also acted as subject-matter expert for the development of a subsea-specific Department of Transportation operator qualification program. Moreover, he has consulted with the Association of Diving Contractors International on the development of its diving supervisor certification program.

Lo Conte has a Bachelor's degree in History and Political Science from Mount St. Mary's University and an Associate's degree in Marine Technology from Santa Barbara City College.

Acknowledgments

The updated content for this third edition of *Diving and Equipment*, Lesson 5 in Unit V of the Rotary Drilling series of books, was graciously and expertly provided by two commercial diving experts who are actively engaged in petroleum industry diving operations. John Herren, Senior Director of Operations, and Gene Lo Conte, Diving Superintendent, both of Epic Diving and Marine Services, developed the text for this latest edition to reflect today's diving processes and considerations. They bring readers into the world of commercial divers to understand the challenges and responsibilities each diver embraces. PETEX® expresses appreciation to the authors and to Epic Diving and Marine Services for their contributions in words and images to this valuable publication.

In addition, PETEX extends thanks to Tamara Brown, President of the Divers Academy International, for her peer review of the content and support of this endeavor to provide educational content on diving fundamentals for the oil and gas industry. Thanks also go to the other individuals, companies, and organizations named within that generously granted permission to use the images featured in this edition.

PETEX also gratefully acknowledges the continued support of the International Association of Drilling Contractors (IADC), without which the original Rotary Drilling series of books would not have been created. The various units and lessons have been used by oil and gas industry personnel for decades. The series remains a staple in petroleum industry libraries, and PETEX appreciates the organization's long-standing support.

Finally, this book would not be possible without the hard work of those who helped refine the text and perform research and production functions. Thank you to Debby Denehy, Managing Editor; Debbie Caples, graphics services manager; Chris Parker, editor; E.K. Weaver, graphic artist; Sherry Rodriguez, publications assistant; and Leah Lehmann, proofreader, all of whom participated in the process of developing and publishing this book.

Units of Measurement

Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is one of only a few countries that employs the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the Système International (SI) d'Unités. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The *Rotary Drilling Series* gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is *metre*, not *meter*. (Note, however, that the unit of weight is *gram*, not *gramme*.)

To aid U.S. readers in making and understanding conversion to the SI system, we include the following table.

English-Units-to-SI-Units Conversion Factors

Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m^3)
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m^3/stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches ($in.^3$)	16.387	cubic centimetres (cm^3)
	cubic feet (ft^3)	28.3169	litres (L)
		0.0283	cubic metres (m^3)
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m^3)
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m^3)
	barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m^3/t)
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m^3/min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m^3/h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m^3/stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m^3/min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{°F - 32}{1.8}$	degrees Celsius (°C)
Thermal gradient	1°F per 60 feet	—	1°C per 33 metres
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m^3)
	pounds per cubic foot (lb/ft^3)	16.0	kilograms per cubic metre (kg/m^3)
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.75	kilowatts (kW)
Area	square inches ($in.^2$)	6.45	square centimetres (cm^2)
	square feet (ft^2)	0.0929	square metres (m^2)
	square yards (yd^2)	0.8361	square metres (m^2)
	square miles (mi^2)	2.59	square kilometres (km^2)
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

Courtesy of Brian Derby

Diving History

▼
▼
▼

In this chapter:

- Inception of the concept of diving
- Closed-circuit scuba and recreation of diver's own air supply
- The first deepwater scuba and discovery of decompression
- Causes and effects of decompression sickness
- Decompression tables and advancements in scuba equipment
- Modern closed-circuit scuba systems and saturation diving

Records of first attempts by humans to explore the great unknown depths of waters are nonexistent. The ancient sponge and pearl divers of the Mediterranean and Pacific were thought to be among the first to conduct underwater explorations, although they were probably diving to a maximum 100 feet (30 metres) and could endure the depth pressure for only 2 to 3 minutes. Their initial attempts, however, led to far greater discoveries than the treasures they hunted.

Diving as a military strategy was recorded as early as 400 B.C., but those military divers were more than likely combat swimmers. Xerxes, the King of Persia at the time, used divers to recover treasures on sunken Persian ships, and Alexander the Great put divers to military use when he destroyed the boom defenses at Tyre (Lebanon) in 333 B.C. the Greek philosopher Aristotle believed that Alexander the Great himself descended underwater in an archaic *diving bell*.

The first records of air being supplied to divers from the surface were given by the Roman historian Gaius Plinius Secundus in his book, *Naturalis Historia*. Pliny describes military divers using long tubes through which to breathe while below the surface. This tube device is similar to the modern-day snorkel, but it is impractical when used below about 10 feet (3 metres) because of the pressure differences that occur as the body descends into deeper water.

Open-circuit diving allowed divers to remain under water without rebreathing exhaled carbon monoxide.

The interest in diving increased in 1511 when the first printed drawing of a diving suit became available. This printed version was not the first documented idea for underwater systems. Italian artist and engineer Leonardo da Vinci had already sketched drawings of submarines and hand fins for swimming under water. These ideas were improved in 1524 and published in *Vallo*, a popular booklet on various aspects of military technology. The publication introduced a leather diving helmet with portholes for the eyes and a leather pipe for breathing. This early diving system was supported at the top by a floating discshaped bag. The impracticality of the design restricted its use to shallow water.

Finally, in 1680, Italian astronomer and mathematician Giovanni Borelli offered the first crude self-contained underwater breathing apparatus, or *scuba*, as it is known today. Borelli designed a large bag that covered the diver's head and contained a porthole for viewing. Air circulated from the bag through a tube outside the bag, designed to trap moisture. The air then circulated back into the bag to be *rebreathed* by the diver. Borelli believed that air passing through water could be purified and suitable for rebreathing. Of course, his belief proved false. The diver's displacement in the water was to be compensated by a crude piston-and-cylinder arrangement. Borelli's apparatus never actually worked, but his ideas were precursors of the present-day scuba systems used for business and sporting activities.

The underwater breathing designs of scientists before 1800 were impractical but not completely illogical. The missing element in their designs was a supply of breathable *compressed air*. With the advent of air compressors in the 19th century, this problem seemed to be solved. In 1825, W. H. James of England introduced the first suit to use a supply of compressed air (fig. 1). The diver's air supply was contained in an iron reservoir worn about the waist. James's design was greeted with skepticism and was never widely used.

In 1886, Frenchman Benoist Rouquayrol introduced the first design of an *open circuit*, or *demand*, *regulator*. The purpose of this design is to allow a diver to expel all used air directly into the water and avoid rebreathing exhaled carbon dioxide. The open-circuit regulator reduces the air pressure in the tanks to a diver's ambient pressure, so air can be breathed with no resistance and exhaled air can be expelled into the water. Borelli's design lacked high-pressure air tanks to deliver the air to the diver. The tanks in his design used air at 500 pounds per square inch (psi), about one-fourth of what was actually needed. The idea was later converted to a surface-supplied apparatus.

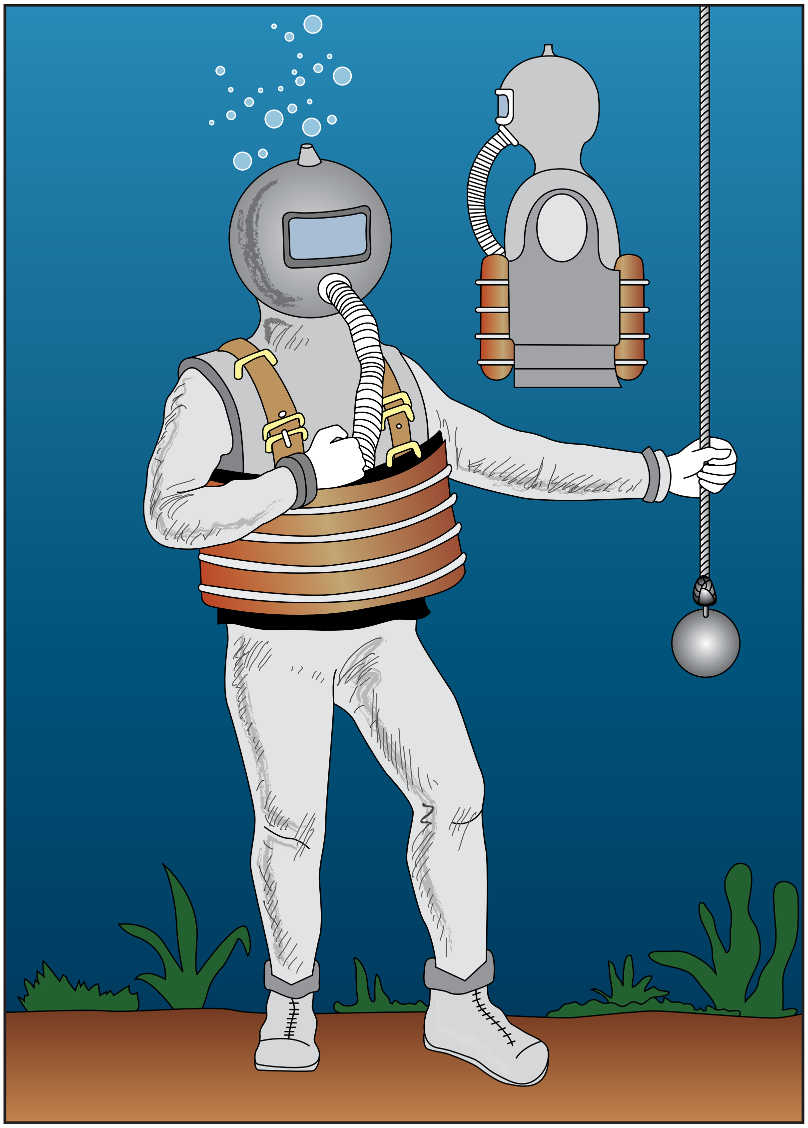


Figure 1. The first design of compressed air tanks was introduced by W.H. James of England in 1825. Although the tanks were never widely used, they helped advance the concept of diving.

In 1873, H. A. Fleuss of England used a solution of caustic potash to remove the carbon dioxide from the diver's exhaled air. This step purified the used air and made it suitable for rebreathing. Fleuss's system was the first *closed-circuit* scuba in existence.

With the development of a closed-circuit air supply, divers could successfully descend great depths.

After divers were equipped with closed-circuit scuba and could recreate their own air supply, they were able to descend to considerable depths. However, the effects of deep dives were unknown. Pressure differences caused physiological problems that had never before been encountered, and only through trial and error were the problems defined.

In the late 19th century, J. S. Lambert, a well-known English diver, accomplished great diving feats but suffered physiological consequences. In 1880, using a crude oxygen rebreathing apparatus, Lambert descended down a flooded tunnel under the Severn River to locate the reason for the flooding. He discovered that a crow bar was needed to pry open a door so the tunnel could be pumped out. He returned to the surface for the tool, descended again into the black unknown waters, and completed the job. Three years later the tunnel flooded again. Using the same closed-circuit scuba equipment, Lambert again descended. This time, his prolonged breathing of air under pressure caused him to suffer either oxygen or carbon dioxide poisoning. Within two days he was well enough to return to the flooded tunnel and complete the job.

Prolonged breathing under water causes decompression sickness, otherwise known as the bends.

In 1885, Lambert went down 162 feet (49 metres) through three decks of a wrecked ship and recovered nearly one-half million dollars worth of gold in the fireproof room storing valuables in the wreck. Without decompression tables, the limits on diving time and depth were unknown, and Lambert's profitable dive gave him a severe case of *decompression sickness*, forcing him into retirement.

Decompression sickness, or the *bends*, is a highly painful condition resulting from the formation of gas bubbles in the blood or tissues of a diver during ascent. Failure to rid tissues of the inert gas can cause a diver to feel weak, numb, or nauseated, pain in the joints, and can even lead to blindness and paralysis. To avoid decompression sickness, a diver must undergo *decompression*, a process that gradually lowers pressures and allows the inert gases to dissipate from the tissues and blood. A *decompression table* is used as a guide to reduce the pressure on a diver safely to atmospheric after a dive. This table provides a profile of ascent rates and breathing mixtures. It shows depths, bottom times, decompression stops, and total decompression times.

Decompression tables did not exist until the 20th century. In 1907, Dr. J. S. Haldane first attempted to put the problem of pressure differentials on a sound mathematical and physiological plane. Haldane believed that as long as a diver went no deeper than 33 feet (10 metres), he or she could surface directly with no decompression. However, if a diver remained at 33 feet (10 metres) for 24 hours, he or she would have to decompress.

Haldane was correct in his theory that it was the ascent from greater depths with the increased pressures that could cause severe physiological problems. In his calculations of decompression, he used the one atmosphere of pressure (14.7 psi) gained by diving 33 feet (10 metres). Haldane's theory was that, as long as the diver's atmosphere was no greater than twice the surface pressure, he or she could ascend without decompressing. Experiments with longer and deeper dives proved his theory to be inaccurate for some depths, but modifications and modern computers have given us the present tables of decompression that are so important to diving operations today.

Advances in equipment design and in understanding the mechanics of breathing air under water naturally led to improvements in the type of air best suited for a breathing medium. By 1900, the fact that air (80% nitrogen, 20% oxygen) was not safe for breathing under high pressures had been established. High concentrations of oxygen were known to be toxic, and prolonged breathing of nitrogen at increased pressures was known to cause a narcotic reaction. These detrimental underwater side effects necessitated a breathing medium of reduced concentrations of nitrogen and oxygen when pressures increased. This need led to the concept of partial pressures and the idea of substituting another inert and less dangerous gas for nitrogen. Helium proved to be the inert gas that served as the best substitute, and it is still used today to dilute the oxygen content of breathing mixes.

In 1943, Jacques Cousteau of France introduced the *AquaLung*, a scuba system that proved to be extremely popular because of its supply of compressed air in cylinders and its demand regulator, an invention first conceived by Rouquayrol of France 77 years before. The AquaLung cylinders held pressure at 2,000 psi, compared to Rouquayrol's cylinders at 500 psi. The higher pressure enabled a much longer *bottom time*, or working time, for the diver.

Higher pressure compressed air allows divers to descend deeper and remain under water for longer periods of time.

World War II brought about rapid advances in the closed-circuit (rebreathable air) scuba system. The Italian Navy demonstrated the military advantage of the system by successfully destroying a British tanker in Gibraltar in 1941. This event and other successful operations involving scuba divers encouraged the United States Navy to take an increased interest in scuba systems that could be used for military purposes.

In the early 1960s, the world became interested in creating living and working habitats underwater (fig. 2). During this decade, many important underwater experiments were carried out by nations all over the world. Programs like SeaLab and Conshelf tested the new concept of *saturation diving*, a method of completely saturating a diver's tissues with inert gas. Once saturated, the diver's length of time on bottom is relative only to his or her depth. If the diver descends no deeper, he or she can remain at the saturated pressure for several days, provided the proper saturation equipment is available. Of course, lengthy decompression times are required for saturation diving, but the technique allows many underwater tasks to be completed without the intervening decompression times that are associated with other diving methods.

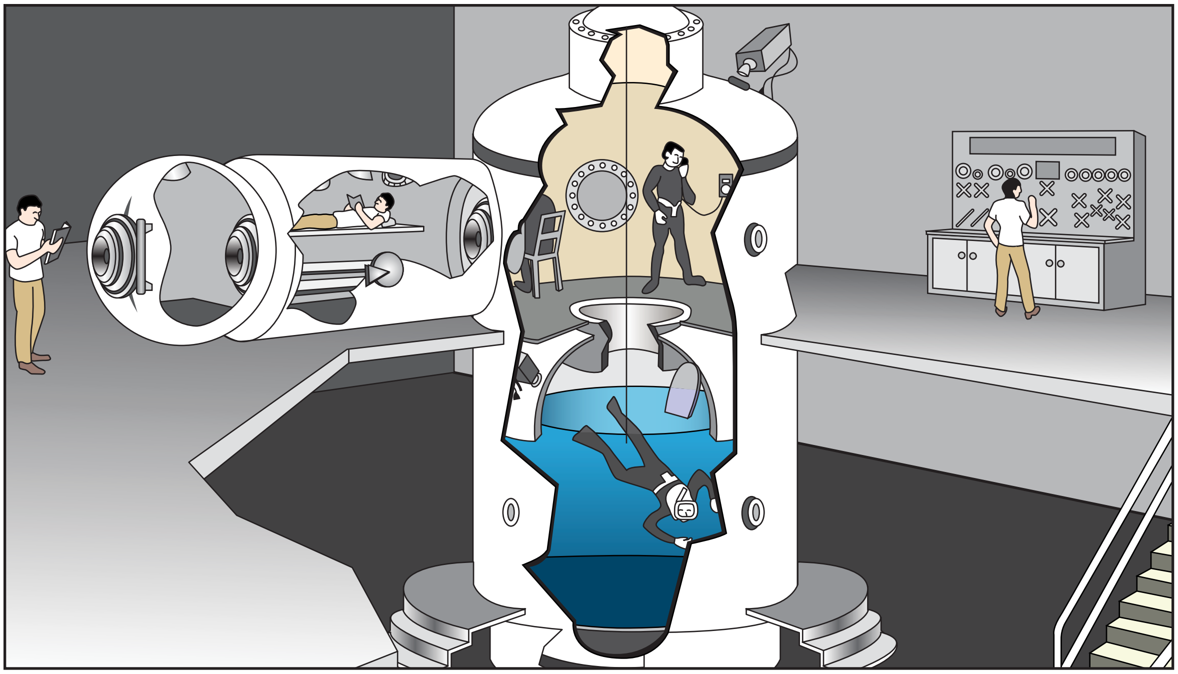


Figure 2. Futuristic underwater workstations such as this one were conceptualized in the 1960s and 1970s.

The success of these and other programs created a worldwide interest in many areas related to the study of humans under water. Endeavors in this area resulted in complex diving systems, underwater vehicles, and new designs for life-support systems. Today, diving has many uses and has evolved into a big business. Recreational enthusiasts have brought the demand regulator and scuba diving to the forefront as a sport, and the advancing state of offshore technology is putting new demands on diving and bottom times. Work in the offshore oil and gas industry has led to new concepts in underwater construction inspection and deep-diving systems.

To summarize—

- Records of diving as a military strategy began as early as 400 B.C. Air supplied to divers from the surface was first explored in ancient Rome.
- In the late 1600s, Giovanni Borelli designed the first self-contained underwater breathing apparatus.
- Scientists discovered the theory of compressed air in the 1800s. From this, open-circuit diving came about, allowing a diver to avoid rebreathing carbon dioxide.
- J.S. Lambert performed the first deepwater dive in 1880. Diving time and depth were unknown, and Lambert grew ill from decompression sickness. Decompression tables were invented to show depths, bottom times, decompression stops, and total decompression time.
- Advancements made in World War II convinced the U.S. Navy to adopt scuba systems.
- Saturation diving was invented to enable divers to remain under water without intercessory decompression times. A diver's length of time under water is relative only to depth.

Underwater Physics

In this chapter:

- The tendency to rise and float
- Heat loss and hazardous situations
- Liquid, gas, and pressure measurement
- Air supply in relation to depth
- Dalton's law of partial pressure
- Light exposed in an underwater environment
- Sound travel under water

As people walk through their environments every day, they rarely think of the mixture of gases they inhale and exhale or the pressure being exerted on each square inch of their bodies. Only when they are taken out of their safe physical surroundings do people become aware of the environment's life-sustaining qualities. When exposed to an underwater environment, people must understand the changes in physical properties and how to adapt to them to survive.

Buoyancy

Upon entering the underwater world, one of the most immediately noticeable differences is the tendency to rise or float. This elemental water force is known as *buoyancy* and is expressed in Archimedes' principle. This principle states that "a body submerged in a liquid is buoyed up by a force equal to the weight of the water it displaces." Because the densities of water and the human body are almost the same, the human body displaces almost its exact weight when submerged.

Buoyancy is the tendency to rise and float.

This weightless condition under water can be a problem. Without an effective counterweight, a diver in a weightless condition might find it difficult to stay at a desired depth. Weighted diving belts are worn to compensate for this loss of weight. The equipment gives divers negative buoyancy, enabling them to remain stationary at any desired level between the surface and ocean bottom.

A diver must be extremely cautious when working with positive buoyancy because of the danger of blowing up (rising) to the surface uncontrollably.

Heat Loss

Most working dives take place in water temperatures between 45 degrees Fahrenheit (°F) and 60°F (fig. 3). The human body suffers rapid heat loss in these temperatures because:

- The specific heat of water is 1,000 times greater than that of air.
- The thermal conductivity of water is 25 times that of air.

The body suffers rapid heat loss in water because:
- Specific heat of water is 1,000 times that of air.
- Thermal conditioning is 25 times that of air.

Heat loss can create hazardous situations for divers. After surfacing from working in shallow depths for 16 hours, a diver's skin might turn red in a hot shower, but the diver's body, or core, temperature can remain well below the safe level of 98.6°F.

Hypothermia, the scientific term for heat loss to key organs such as the heart, brain, kidneys, and liver, is a direct result of overexposure to chilling temperatures. The body combats this heat loss by constricting the blood vessels, which slows blood circulation to the extremities. The body's natural insulation of fatty tissues also curbs heat loss to some extent. A problem for the diver is restricted blood flow. Without blood circulating through the hands, the diver begins to suffer numbness. Because the diver is working in near-zero visibility much of the time, the diver relies heavily on the sense of touch. When the diver's hands begin to experience numbness, his or her productivity and safety are greatly reduced. Divers working in cold waters usually wear standard wet suits equipped with hot water systems to protect them from the chilling underwater environment. Vigorous exercise, cold-water training, and proper diet help protect a diver who must work in cold water. A diver not prepared for such assignments is vulnerable to oxygen toxicity, nitrogen narcosis, and decompression sickness.

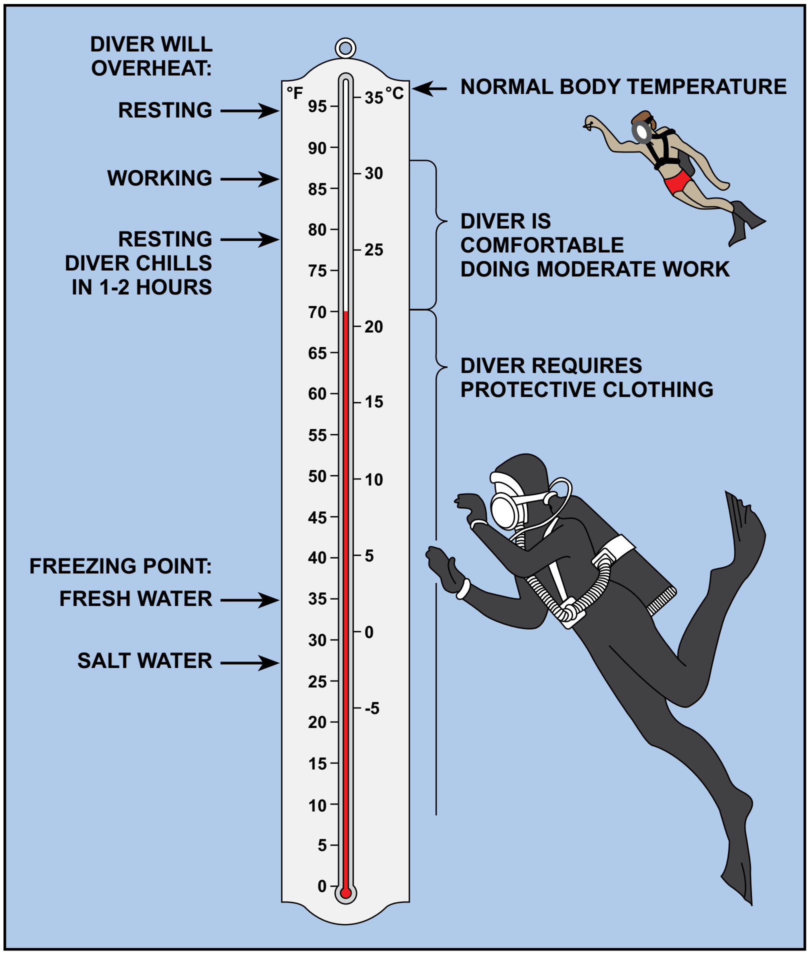


Figure 3. Working environments for a diver are usually between 45°F and 60°F. The chilling waters make protective clothing essential.

Pressure

Pressure is defined as force exerted per unit area and is usually measured in pounds per square inch (psi) or kilopascals (Kappa). A column of liquid—for example, mercury—can also be supported by pressure. In this case, pressure is measured as a certain height. Mercury is measured in millimetres to express barometric pressure. Barometric pressure is the force that is exerted on objects by the weight of the atmosphere above them, including gases. Because of the effect of gravity on the gas, the air above and around humans weighs down on us. When measured, this force is referred to as barometric or atmospheric pressure.

> Atmospheric pressure is the weight of the atmosphere, or force, exerted per square inch.

Atmospheric pressure is the pressure exerted by the weight of the atmosphere. Pressure on the human body at sea level is the same both internally and externally, so our tendency is to ignore the effects of *atmospheric pressure*. At sea level, the atmospheric pressure is 14.7 psi.

This pressure measurement is sometimes referred to as a pressure of 1 *atmosphere* (1 *atm*). A reading of 147 psi indicates a pressure of 10 atmospheres.

Gauge pressure is defined as the amount of pressure exerted by a confined, compressed gas in excess of the atmospheric (sea-level) pressure. A cylinder measured at 2,000 psi is an indication of a pressure of 2,000 psi above the sea-level pressure. Gauge pressure is expressed as pounds per square inch gauge (psig).

Absolute pressure is the true or total pressure and is the gauge pressure plus 1 atmosphere. It is expressed as pounds per square inch absolute (psia). Absolute pressure must always be used with equations involving gas laws (see section on Gas Laws).

Liquid Pressure

Water pressure is directly proportional to depth. Sea water is measured at 64 pounds per cubic foot.

The pressure of most interest to a diver is the surrounding liquid pressure, which is directly related to weight. Seawater is measured at 64 pounds per cubic foot. The *density* of a liquid is defined as the mass or weight per unit volume.

Water is practically incompressible and remains virtually the same regardless of the pressure or depth applied. As a result, the pressure of water is directly proportional to its depth. The pressure in 20 feet (6 metres) of water is double that in 10 feet (3 metres).

If a tank 33 feet (10 metres) deep is filled with seawater, the pressure exerted on 1 square foot on the bottom would equal the weight of the column above it. For example, imagine a tank of thirty-three 1-foot cubes stacked on top of each other.

- Seawater is measured at 64 pounds per cubic foot (64 lbs/cu ft). Therefore, the total weight would be 33 × 64, or 2,112 pounds acting on 1 square foot of surface area.
- A square foot contains 144 square inches, so 1 square inch is acted on by approximately 14.7 pounds.
- At 33 feet (10 metres), the pressure is 14.7 psi, or 1 atmosphere.
- The air above the water exerts an additional atmosphere of pressure, so that the total, or absolute, pressure is 2 atmospheres absolute.
- Each additional 33 feet (10 metres) of depth adds an additional atmosphere of pressure.
- Because each foot of depth applies $^{1}/_{33}$ of 14.7 psi, pressure can be measured for any depth.
- One $^{1}/_{33}$ of 14.7 is 0.445.

- Multiplying any depth by this number gives the pressure for that depth. Adding an additional atmosphere gives the absolute reading.

Water pressure is the same at a given depth both inside and outside an open vessel. This is not true for a diver because of free air spaces such as the lungs, sinuses, and the middle ear. If these cavities trap any gas while a diver is descending or ascending, the change in pressure will cause a pressure differential that could cause severe problems.

Gas Laws

Gas Levels change as depth increases. Gas pressure is governed by three laws:
- Boyle's law
- Charles's law
- General gas law

When a person dives below the water surface, he or she must take along a portable gas supply, either in tanks mounted on the back or through an umbilical line to the surface. Demand for this air supply is subject to change with changes in depth. An understanding of the effects of this change can be furthered by a review of basic gas laws.

The three most widely used gas laws in the diving field are Boyle's laws, Charles's law, and a combination of these two laws, known as the general gas law.

Boyle's law states that "at a constant temperature, the volume of a confined gas is inversely proportional to the absolute pressure exerted upon it." That is:

$$P_1 V_1 = P_2 V_2$$

where the subscripts denote the two conditions of the gas.

Charles's law states that "at a constant pressure, the volume of a confined gas is directly proportional to its absolute temperature." Or:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

A combination of these two basic laws presents the *general gas law*, a helpful equation in computing breathing gas requirements at certain depths. The general gas law is:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

where

P_1 = initial absolute pressure
V_1 = initial volume
T_1 = initial absolute temperature
P_2 = final absolute pressure
V_2 = final volume
T_2 = final absolute temperature

To calculate the laws of pressure, it is necessary to convert pressures and temperatures to the absolute scale.

A common error when using Boyle's law, Charles's law, or the general gas law is the failure to convert pressures and temperatures to the absolute scale. For absolute temperatures, add 273° to a Celsius reading and 460° to a Fahrenheit reading. For absolute pressure, 14.7 psi is added to the gauge pressure.

Some problems encountered in diving support the usefulness of gas laws. For example, an air cylinder is charged with 2,600 psi. At the end of compression, the cylinder's temperature is 130°F. What is the pressure when the cylinder reaches a temperature of 70°F?

Because the volumes remain the same, or $V_1 = V_2$, then according to the general gas law we find:

$$P_1 T_2 = P_2 T_1$$

$$(2{,}600 + 14.7) \times (70 + 460) = P_2 \times (130 + 460)$$

$$P_2 = 2{,}349 \text{ psi} - 14.7$$

$$P_2 = 2{,}334 \text{ psi}$$

As another example, if a scuba cylinder delivers 60 cubic feet of air on the surface, how much will it deliver at 100 feet (30 metres)? (Use table 1 for depth-pressure equivalents.)

Because $T_1 = T_2$, then:

$$P_1 V_1 = P_2 V_2$$

$$14.7 \times 60 = (59.2) \times V_2$$

$$V_2 = 60 = 14.8 \text{ ft}^3$$

Table 1
Depth-Pressure Equivalents

Feet of Seawater	Atm abs	Psi abs	Mm Hg abs
Surface	1.0	14.77	60
33	2	29.4	1,520
66	3	44.1	2,280
99	4	58.8	3,040
165	6	88.2	4,560
231	8	117.6	6,080
297	10.0	147.0	7,600

In some cases, time can be substituted for volume if the diver is using about the same amount of air at the surface as he or she does when submerged. For example, how long could the diver stay at 100 feet (30 metres) while undergoing a pressure drop from 2,000 psi to 300 psi if the diver uses 25 psi for each minute while at the surface? The pressure difference is 1,700 psi, and dividing that by the 25 psi per minute used at the surface gives an answer of 16.8 minutes.

Partial Pressure and Dalton's Law

The partial pressure of gas level can become hazardous as pressure increases.

A diver uses various mixtures of gases. To make them effective, the diver must understand how these different mixtures behave as pressure changes occur. For the purpose of this discussion, air shall be considered to be 20% oxygen and 80% nitrogen. Other common mixtures of gas used in diving are helium and oxygen; nitrogen and oxygen (in different percentages than in air); and oxygen, helium, and nitrogen.

In any mixture of gases, each gas exerts its share of the total pressure. Dalton's law states that "the total pressure exerted by a mixture of gases is the sum of the pressures that would be exerted by each of the gases if it alone were present and occupied the total volume." The different pressures that make up the total pressure in a given volume are the partial pressures of the gases. The partial pressure of a gas is proportional to the number of molecules of the gas present in a specified volume at a given temperature.

If a container were filled with 100% oxygen at normal atmospheric pressure, the partial pressure of oxygen in that container would be 14.7 psi, or 1 atmosphere. The partial pressure of oxygen in this case would equal the total pressure because no other gases were present. If an equal amount of nitrogen were allowed in the volume without letting any oxygen escape and without changing the temperature, the total (absolute) pressure would be 2 atmospheres. The container would now have a mixture of 50% oxygen and 50% nitrogen. If the container were reduced to half its size without changing the temperature, the total pressure would be 4 atmospheres, with oxygen having 2 atmospheres pressure and nitrogen having 2 atmospheres pressure.

As the diver goes deeper under water's surface, the diver is being exposed to greater atmospheres of pressure, and oxygen will be 20% of the pressure if air is the breathing medium. At 15 atmospheres, about 462 feet (141 metres) under water, the partial pressure of oxygen will be 3 atmospheres, or 44.1 psi. Thus, the partial pressure of a gas at sea-level atmospheric pressure might be insignificant but can become extremely dangerous as pressure increases. Breathing 44.1 psi of oxygen causes a toxic, possibly fatal reaction, and for this reason, gases are mixed to prevent such events from occurring.

Light Properties

Water absorbs light and obscures underwater vision. Divers wear masks to magnify their view.

The physical properties of light change dramatically when exposed to an underwater environment. As light rays strike and penetrate the water's surface, the water begins to absorb different light rays (fig. 4). The red wavelength is the first to be absorbed, followed by the yellow spectrum at a slightly greater depth. At this level, the water takes on a blue tint. In bays or harbors where the water is murky or unclear, the water is often a green or brownish color. It is possible that the murky water is settled at only one particular level, and if the diver descends deeper, he or she might find the water to be once again relatively clear.

Besides being absorbed, light is also diffused or scattered by the water and objects floating or living in it. Although the diffusion effect might be on a small scale, some objects become completely destroyed. Red objects appear to be black and disappear as part of the water background. A diver's field of vision is reduced considerably.

Wearing a face mask also creates changes in the properties of light. By looking through a glass face mask, a diver is observing light rays that are *refracted*, or bent, as they travel through the water into the diver's eyes. This refracting effect magnifies the diver's view. Until visual perception is adjusted, objects appear to be 1.3 times larger than their actual size. This magnification actually improves close-up underwater tasks. However, this small advantage is the only one a diver is afforded in an underwater environment.

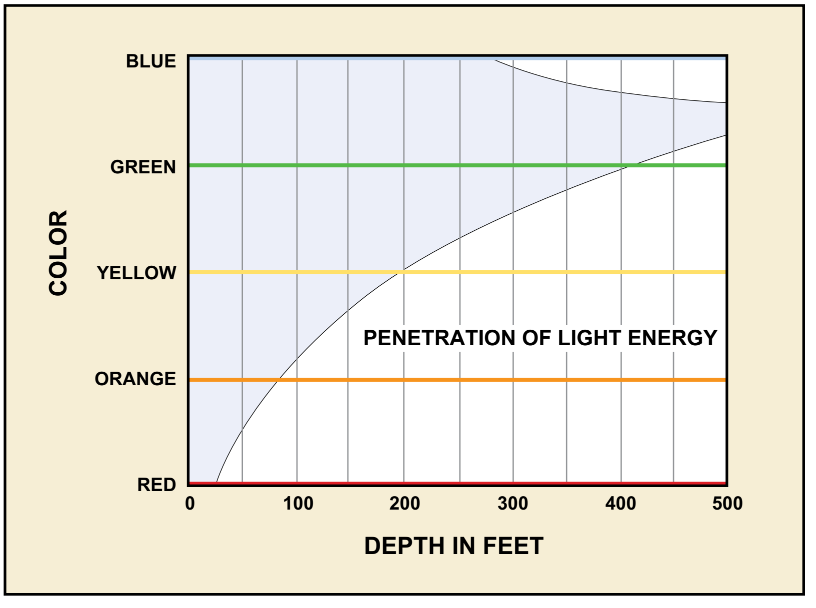


Figure 4. The absorption of light rays by water. At 200 feet, the red and orange rays have been completely absorbed.

Sound Properties

The underwater world is not the tranquil, silent world many believe it to be. Sound travels four times as fast in water as it does through air. Number, volume, and speed of the multidirectional sound sources are enough to confuse even the most veteran of divers. The speed of sound is too rapid for the ears to distinguish for its directional source. In the *viscous* medium of water, sounds cannot be distinguished as they can on the surface. Figure 5 shows the results of *intelligibility* tests run with a helium *unscrambler*, an electronic device that slows down the voice of a diver by using helium as part of the breathing mixture. According to the chart, intelligibility—the capability of being understood—drops at the rate of 50% per 200 feet (61 metres) compared to normal atmospheric levels. Because of this hearing loss, helium unscramblers and other electronic equipment are necessary for interpreting a helium-breathing diver.

> Divers use an electronic device to alter sounds under water. Sound moves four times faster than air.

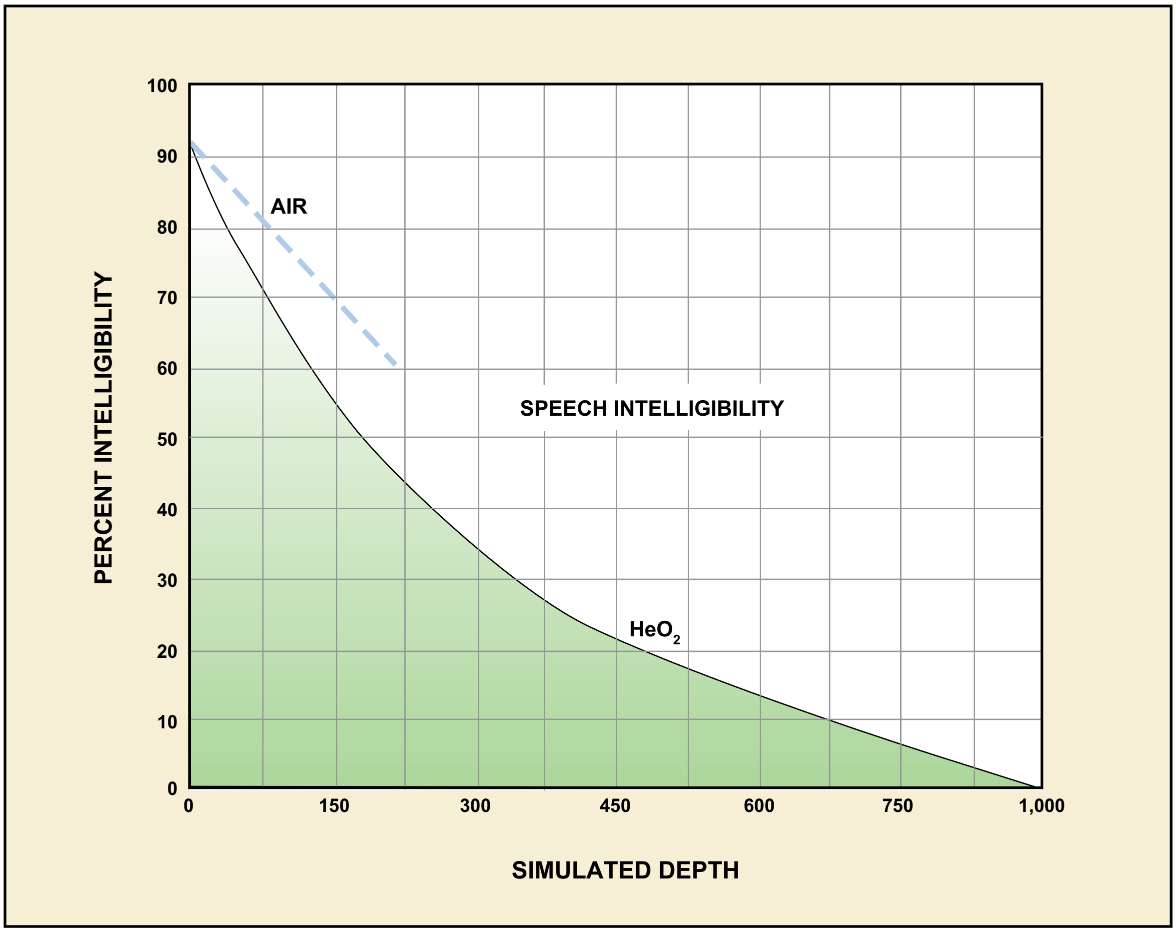


Figure 5. Intelligibility tests run with helium unscramblers. At 200 feet, almost half of the diver's conversation is unintelligible.

To summarize—

- To survive in an underwater environment, a diver must understand its physical properties.
- Buoyancy is the tendency to rise and float. It is best described as Archimedes' principle: a body submerged in a liquid is buoyed up by a force equal to the weight of the water it displaces.
- Hypothermia can occur if a person is exposed to cold water for a long period of time. Divers wear standard wet suits to protect them from cold water.
- Pressure is measured in psi or Kappa and is defined as the force exerted per unit.
- The pressure of water is directionally proportional to depth and is the same inside and outside an open vessel.
- Gas supplies are crucial to divers. The gas levels and pressures are subject to change with depth.
- Gas pressure is defined by three laws: Boyle's law, Charles's law, and the general gas law. All three take into account initial and final volume and pressure.
- Dalton's law of partial pressure states that the different pressures that make up the total pressure in a given volume are the partial pressures of the gases.
- Under water, a diver's field of vision is significantly reduced. Water absorbs light, first by the red wavelength and second by the yellow wavelength. Divers wear protective masks to reflect light and magnify their vision.
- Sound is another physical property altered by water. Sound travels four times faster in water than in air.

Underwater Physiology

In this chapter:

- Pressure rations between diver and water
- Increased and decreased pressure in descent and ascent
- Halted breath during descent
- Helium's relationship to nitrogen narcosis
- Benefits and detriments of oxygen when diving
- Decompression symptoms and cures
- Interrupted elimination of carbon dioxide in the body
- The effect of rapid descent on the nervous system

The human body is a highly complex and sensitive system of cells, tissues, fluids, and bone that functions normally at sea-level pressure. In different environments, such as in the ocean waters, the body must make adjustments to different pressures to survive.

Subsurface Pressure

Within present diving depth capabilities, human tissues are insensitive to the increased pressures (fig. 6). However, for a diver to be relatively insensitive to pressure changes, his or her breathing gas must have access to all body cavities such as the lungs, middle ear, and sinuses. Trapped gases in these free air spaces are compressed by increasing pressure of water depth and by compliance of the cavity walls. No significant pressure differential can exist between these spaces and the outer environment, or immediate tissue damage will occur.

Courtesy of Robert Sanchez

Figure 6. Diver preparing to enter the water from a barge

Effects of Squeeze

Gas entering the middle ear or sinuses is referred to as a squeeze.

If the openings to the middle ear or the sinus spaces are closed during descent, as might happen to divers with head colds, even slight increases in pressure can cause severe pain. This pressure phenomenon is called middle ear or sinus *squeeze*, depending on the location of the pain. Squeeze is a common occurrence in diving operations. As a diver descends to levels of increasing pressure, the diver must relieve the pressure differential between these inner spaces and the outside. Swallowing is a common method of relieving this pressure. Another method is to block the nose and blow air up through the *Eustachian tubes*. Divers with head colds and sinus congestion should refrain from diving. Procedures to relieve pressure in free air spaces should begin during descent, not after pain is felt.

A reverse squeeze occurs if these same cavity spaces are closed off during ascent. For example, maximum outward pressure on the eardrum can rupture the membrane. Immediate relief is felt by the diver. Unfortunately, if the diver is not wearing a diving helmet, water might enter the ear, causing a feeling of *vertigo*, which brings a lost sense of direction and accompanying dizziness that could cause panic in an inexperienced diver. Using diving helmets usually protects a diver from water entering the middle ear.

Thoracic squeeze, or compression of the lung cavity, occurs if the breath is held during descent. The increasing pressure compresses the lungs. If this pressure is not equalized, the lungs will collapse and fill with blood and tissue fluid.

Embolism

If the breath is held during ascent, the formation of an air bubble in the bloodstream can occur. This blockage in the bloodstream is known as embolism and can create serious hazards while diving. The holding of one's breath over-expands the lungs as the diver rises to the surface. This overexpansion can cause ruptured air sacs and blood capillaries in the lungs. If these sensitive tissues are ruptured, air is forced into the pulmonary capillary bed and air bubbles are carried to the left chambers of the heart. These bubbles are then pumped into the arteries. Any bubble too large to pass through an artery lodges in the bloodstream and forms an obstruction, thus depriving other tissues of blood. The consequences of an embolism depend on the area or organ affected. Often the brain is affected and unless the diver is rapidly recompressed to release the bubble and allow blood flow to continue, death can result.

Embolism can rupture air sacs and blood capillaries in the lungs.

Courtesy of Robert Sanchez

Figure 7. While working deep under water, human tissues are sensitive to increased pressures.

Embolisms are a serious hazard to safe diving operations and can be easily avoided. Normal lung pressure is constant for routine dives because a diver is constantly breathing in and out (fig. 7). In emergency situations that require rapid ascent, a diver should breathe out at a constant and normal rate. Doing this prevents the lungs from over-expanding, thus eliminating the possibility of incurring an embolism.

Nitrogen Narcosis

The purpose of any inert, or carrier, gas is to dilute the flow of oxygen to the lungs, thereby preventing oxygen toxicity. In air and in shallow diving, nitrogen serves this purpose. However, breathing high partial pressures of nitrogen causes a narcotic, euphoric feeling. This detrimental effect, called *nitrogen narcosis*, eliminates the use of air as a usable gas for working dives below depths of about 170 feet (52 metres).

> Helium is the lightest gas known and is inert like nitrogen.

If nitrogen narcosis occurs, a feeling of drunkenness or euphoria takes place. The diver's thought processes slow down, and his or her judgment and reaction time might become impaired. The diver's working ability might also be affected, although some divers can withstand higher doses of nitrogen than others. The narcotic effect usually wears off as the diver ascends. By the time the diver reaches a more shallow depth and clearer state of mind, he or she might not remember if the assigned tasks were accomplished. Because of these limitations, another inert gas is usually substituted for nitrogen in deep dives. The most common substitute is helium.

Helium, one of the lightest gases known, is inert like nitrogen and therefore, does not react to cause chemical changes in the body as oxygen does. Instead, helium resides in the body tissues until a diver decompresses and effectively rids the tissues of helium gas. Helium has been used safely to a depth of 2,001 feet (610 metres) and is thought to be safe at even greater depths. However, divers rapidly compressing to depths greater than 600 feet (183 metres) have shown evidence of *high-pressure nervous syndrome (HPNS)*. Scientists and physicians have found some evidence tying HPNS to pressure. Research to combat this condition continues.

Breathing helium also causes rapid body heat loss. Hot-water systems in a diver's protective clothing are a necessity if he or she is to perform deep-sea tasks with any proficiency and comfort while breathing the chilling gas. The lightness of helium changes the resonant frequency of the human vocal tract and causes a faster vibration, which distorts the voice by giving it a higher pitched, "cartoon character" quality. Sometimes the use of unscramblers is required to interpret the sounds made by the diver.

Oxygen Toxicity

Breathing extremely high partial pressures of oxygen can lead to a reaction known as *oxygen toxicity*. Experimental evidence indicates that divers can suffer from two different forms of oxygen toxicity.

The first and most serious form of oxygen toxicity affects the *central nervous system (CNS)*, causing convulsions similar to those brought about by an epileptic seizure. Total loss of muscle control occurs, and the diver suffering from the effects of CNS oxygen toxicity can become unconscious. These dangers eliminate the use of pure oxygen as a breathing medium in commercial operations.

The second form of oxygen toxicity involves the pulmonary muscle and can occur at depths even more shallow than those that cause CNS oxygen toxicity. Symptoms include pains in the chest area, coughing, and painful inhalation.

Oxygen does have beneficial effects in diving. During surface decompression, divers breathe 100% oxygen at partial pressures of up to 2.8 atmosphere absolute (ata) average atmospheric pressure.

Decompression Sickness

Any dive beyond the safe *No Decompression Zone* of about 30 feet (9 metres) carries with it the risk of decompression sickness, or the *bends*, so named because the bending joints of the body are most often affected. Nitrogen or helium bubbles in the bloodstream or tissues result from breathing air or mixed gases at increased pressures and not allowing sufficient time for the inert gas to dissipate. If the decompression procedure is not carefully executed, a diver can suffer numbness, weakness, pains in the chest or limbs, paralysis, residual bone disease, blindness, or loss of hearing. If the central nervous system is affected, death can occur if proper treatment is not administered promptly.

> Toxicity attacks the central nervous system; therefore, pure oxygen is not used in commercial dives.

The bends affects different areas of the body in different ways. Knees, elbows, and shoulders are common sites for bends pain. Problems in some tissue areas can be more acute than in others, but, as in many other diving instances, an individual's own physiological makeup determines the seriousness of the response. The nervous system is extremely sensitive. Bubbles in the brain or spinal cord can cause permanent damage.

Decompression sickness is usually noticeable within 30 minutes after a diver has surfaced and can also occur during ascent. The bends can also occur after long delays of 24 to 32 hours.

The sole way to treat decompression sickness is to enter a recompression chamber.

If the bends are suspected after a diver's ascent, he or she is assisted to a *recompression* chamber by diving tenders (fig. 8). The surface crew helps remove the diver's suit, and the timekeeper prepares the decompression charts and data sheets for monitoring recompression. During recompression, the chamber pressure is monitored, the diver's vital signs are checked, and communication is maintained via electronic equipment. After treatment decompression is complete, the diver leaves the chamber and is directed to the on-board medical station. The diver's vital signs are thoroughly examined to ensure there is no continued suffering from the illness. The diver might also be required to return to land for further examination by a physician. The bends are a serious threat to any diver and have been responsible for many diving deaths. Treatment by recompression is required any time bends are suspected.

The discovery that breathing high partial pressures of oxygen while resting after a dive reduces the risk of getting the bends was a significant achievement in understanding diving physiology. This process is known as *surface decompression*. Before this discovery, the most effective method for eliminating inert gases from the tissues was inordinately long in-water decompression times. Breathing high concentrations of oxygen creates a maximum outward pressure between the tissues loaded with inert gas and the bloodstream. This method effectively scrubs the inert gas from the tissues and the bloodstream.

Courtesy of Epic Diving and Marine Services LLC

Figure 8. Diver entering deck chamber for surface decompression

Carbon Dioxide Excess

Hypercapnia, or excess carbon dioxide in the body, is caused by interrupting the elimination of CO_2 from the body. It often results from a diver over-breathing in the diving helmet or from insufficient ventilation of the helmet. Hypercapnia causes blood vessel dilation and increases the flow of blood to the brain. This increased blood flow can cause oxygen toxicity and expose the diver to a loss of muscle control.

When breathed in excess, carbon dioxide can increase breathing rates and cause a diver to black out.

All bodily tissues are susceptible to hypercapnia, but brain tissues are the most sensitive. Symptoms of CO_2 excess include loss of motor coordination, confusion, and ultimately, unconsciousness. Hypercapnia rarely leads to death, and when given fresh air to breathe, the diver can usually recover quickly. However, he or she might still suffer from headaches and nausea after initial recovery.

The body attempts to compensate for CO_2 excess by increasing the breathing rate. An experienced diver will be aware of this increase and be forewarned of a possible blackout.

Low breathing rates can also cause hypercapnia and possible self poisoning, which is another reason why breathing should always be at a constant, normal rate when diving. Other causes of self poisoning by CO_2 excess include defective equipment, overexertion, and great depths.

High-Pressure Nervous Syndrome

Although the narcotic effects of nitrogen have been known for many years, the effects of deep diving using helium have been known only since 1967 when the first dives in excess of 600 feet (183 metres) were made in the Gulf of Mexico. Working dives at this depth and greater are very common, and the diving community is fully aware of the HPNS reaction associated with these high-pressure dives.

The first dive over 600 feet occurred in Mexico in 1967.

Data on rapid compression and descent have been gathered through the use of chambers, where the average rate of descent is 75 feet (23 metres) per minute. Few divers will exceed this rate because the free air spaces in the body need at least that much time to adjust to the pressure changes. Rapid descents in depths greater than 600 feet (183 metres) might cause symptoms of HPNS.

HPNS is a phenomenon of deep-sea diving, and the medical community is continuing to gather data on the effects and causes of this reaction. Rapid descent seems to be one factor that might bring about symptoms. Experiments on test animals have shown symptoms of fatigue, muscle tremors, and convulsions. Divers have suffered from fatigue and tremors, but convulsions have been limited to lab experiments with animals.

All divers will not react with HPNS, and individuals will present varying degrees of susceptibility. Close monitoring by the surface crew and slow descent rates, especially below 600 feet (183 metres), will usually prevent adverse reactions. Diving companies have specific compression schedules for deep diving that alleviate the effects of HPNS.

To summarize—

- In diving, there can be no difference in pressure between the lungs, middle ear, or the sinuses. Breathing gas must have access to all cavities or sickness can occur.
- When the openings to the middle ear and sinuses are closed in descent, divers will experience severe pain called squeeze.
- There are different types of squeeze. A reverse squeeze is when the cavities are closed during ascent. Thoracic squeeze compresses the lungs when breath is held during ascent.
- Holding one's breath over expands the lungs and forces air bubbles into the pulmonary artery. This is called embolism.
- Nitrogen narcosis is caused by breathing high pressures of nitrogen and can be alleviated by increasing helium levels.
- High partial pressure of oxygen in the lungs leads to oxygen toxicity, and seizures and unconsciousness can occur.
- Decompression sickness is when nitrogen or helium bubbles enter the bloodstream. When divers experience this, they must surface and enter a recompression chamber to return the body to normal levels.
- Over breathing in a diving helmet or insufficient ventilation in a helmet can cause excess carbon in the body, called hypercapnia.
- Rapid and deep descents can cause:
  — fatigue
  — muscle tremors
  — convulsions

Diving Equipment

In this chapter:

- Self-contained equipment provisions
- Types of surface diving
- Proper diver equipment and gear
- Categories of air and gas supplies
- Radio communication for divers
- Equipment contained in the dive control van
- Usage of diving umbilical cords
- On-deck decompression chamber requirements
- Air used in surface-supplied air diving
- Surface mixed-gas diving equipment
- Systems and modules used in saturation diving systems

A wide range of equipment is used in today's diving operations. Provisions include self-contained equipment, surface-supplied gear, and deepwater systems and remote-operated vehicles capable of exploring at extreme depths (fig. 9).

Self-Contained Equipment

Diving equipment has been used in various forms for many decades. However, the advances made in diving apparatus during World War II brought scuba to the forefront as a reliable and available system for underwater use. The introduction of the demand regulator by Frenchmen Emile Gaguan and Jacques Cousteau in 1943 made practical the use of compressed air in a self-contained apparatus.

Courtesy of Epic Diving and Marine Services LLC

Figure 9. Diver preparing for dive

Advantages offered by scuba equipment include horizontal mobility, flexibility, and ease of buoyancy control. However, the system is limited in depth (safe limits are about 130 feet (40 metres) under ideal conditions), in time, and in the amount of breathing supply. The physical exertion caused by breathing under pressures that differ from atmospheric is another disadvantage. Breathing is sometimes a significant task when using scuba gear, and this can adversely affect a sport diver. Two-way communication, one of the most important factors in offshore commercial diving, is usually not possible between a scuba diver and the surface crew. Lack of communication eliminates scuba as a preferred mode for working divers. Improved communications can be achieved by using surface-supplied gear. Scuba diving is not considered a safe or viable option for supporting the offshore oil and gas industry.

Surface-Supplied Diving Equipment

Because of the inherent limitations of scuba diving, offshore contractors find it safer and more efficient to use other methods of completing the varied underwater tasks that are necessary in the offshore oil and gas industry. One way to complete these assignments is by using surface-supplied equipment.

Three modes of diving use surface-supplied diving equipment:

- Surface-supplied air diving
- Mixed-gas diving
- Saturation diving

Modes of surface-supplied diving equipment:
- Surface-supplied air diving
- Mixed-gas diving
- Saturation diving

The mode of diving is chosen based on working depth and work scope. The components that make up a diving system are often the same, but the capability and function of the equipment is enhanced.

Surface Diving Equipment

Surface diving is defined as any mode of diving where the diver leaves the surface and returns to the surface at atmosphere. This includes scuba, surface-supplied air and mixed-gas, no-decompression, and surface-decompression diving. *Bell diving* and saturation diving use much of the same equipment as surface-supplied diving, except the diver does not return to normal atmospheric pressure; rather, the diver returns to a pressurized habitat.

Diver-Worn Equipment

The diver's personal equipment can vary greatly according to water temperature, depth, type of work, and physical environment. It always consists of the following items at a minimum:

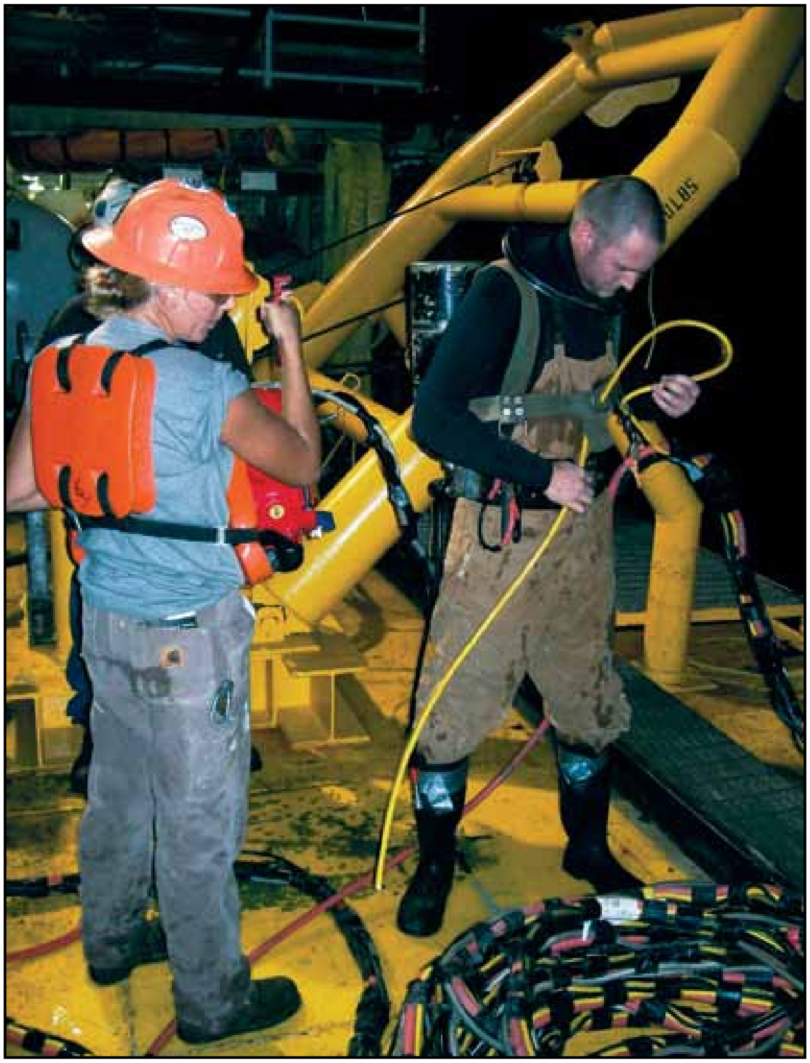
- **A safety harness**. When using surface-supplied diving equipment, it is necessary to wear a harness to provide a secure attachment for the *umbilical*. It usually provides a way to wear the emergency gas supply bottle. The harness also provides lifting points if the diver requires assistance when being removed from the water.
- **A weight belt.** The diver uses a weight belt to adjust buoyancy. The amount of weight worn generally depends on the task to be carried out. For bottom work, the diver needs to be negatively buoyant. Conversely, for mid-water work, the diver needs to be neutrally buoyant. The commercial diving *weight belt* differs from a sport diving weight belt in its ruggedness and weight-carrying capacity. It also has a more secure buckle system.

Types of helmets:
- Free-flow helmet
- Demand helmet
- Reclaim helmet

- **Helmet or mask.** Full-face masks are not commonly used today because they are unable to protect the diver's head from impact. Many diving contractors have prohibited their use. Helmets, commonly called dive hats, or just hat*s*, provide better protection and communication. They also allow easier installation of video cameras and lights. The two types of gas delivery systems for modern diving helmets are free-flow and demand.
  - In a *free-flow helmet*, the gas enters the helmet in a constant stream, and flow can be controlled by the diver. It is constantly venting out of the exhaust so there is always positive pressure in the helmet. Because of this constant free flow, they are only used in shallow water applications or in contaminated diving. Free-flow helmets require a constant, large volume of air, so the use of a diver-worn emergency gas bottle is not functional.
  - Demand helmets are the most commonly used breathing device in commercial diving. A *demand helmet* breathes like a scuba regulator. Upon inhalation, the diver is supplied with gas, and upon exhalation, the gas exits the helmet. This type of helmet mimics a person's normal respiratory cycle. The demand helmet is also much quieter than a free-flow helmet, so communication is greatly improved. Demand helmets can also function as free flow. This way a diver can vent the helmet during a heavy workload or clear the faceplate of water condensation that leaks in from the helmet. Demand helmets can also be fitted as reclaim helmets.
  - A *reclaim helmet* allows the diver's exhaled gas to return back to the surface through another hose in the umbilical, be scrubbed of CO_2, and replenished with oxygen, stored, and reused. Because of the high cost of helium, this package is useful in saturation diving where large quantities of helium are required.

The depth and temperature of the water determine the type of suit a diver should wear.

- **Diver's dress.** A diver's dress consists of a wet suit, dry suit, or hot-water suit (fig. 10). The depth and temperature of the water determines which suit a diver wears.
  - The *wet suit* is made of a tight-fitting *neoprene* that traps a layer of water between the skin and insulating rubber. As the diver descends, the neoprene is compressed, losing much of its insulating properties.



Courtesy of Epic Diving and Marine Services LLC

Figure 10. Dressing diver on the surface

The wet suit is the most common thermal protection for air-diving operations in water temperatures from 60°F and to depths of about 180 feet of seawater (fsw). It is not suitable for very deep or cold applications or when diving using a helium mix.

— The *dry suit* can be made of a variety of materials. It keeps the diver completely dry but not warm. The diver must wear insulating layers under the suit. It is used most commonly for inland diving where no surface decompression is required. They are also the only choice for diving in contaminated waters.

Three varied suits for diving:
- Wet suit
- Dry suit
- Hot-water suit

> Helium transfers heat six times faster than air and is frequently used in hot-water suits

— The *hot-water suit* is a loose-fitting neoprene suit that disperses hot water pumped from the surface around the diver. The suit has a valve to which a hose from the diver's umbilical is connected that allows the diver to regulate the flow of water. There are tubes in the suit that direct a constant flow of water to the diver's arms, legs, chest, and back. The temperature is controlled at the surface. The hot-water suit is mandatory for dives conducted using a helium-oxygen mix, called *Heliox*, or any saturation diving, because of the high thermal conductivity of helium. Helium transfers heat six times faster than air, so a diver's core temperature drops rapidly while breathing Heliox. Divers often wear protective clothing over the thermal protection suits, such as nylon chaps or heavy coveralls.

> Divers carry backup equipment such as emergency gas supplies and a knife.

- **Diver-carried emergency gas supply.** The divers *emergency gas supply (EGS)*, or *bailout bottle*, can range from a common scuba bottle fitted with a regulator and hose connected to a valve on the helmet to a complex closed-circuit system for very deep water. The common bailout for surface-supplied diving is 50 cubic feet (1 cubic metre) at 3000 psi. For diving below 300 fsw, larger bottles up to 120 cubic feet (3 cubic metres) at 2500 psi will be used. They might even be coupled together with a manifold to increase duration. The closed-circuit systems are common in extremely deep applications from 700 fsw to a maximum of 1650 fsw. They are reported to deliver up to 15 minutes at maximum depth rating.
- **Ancillary equipment.** The diver must also carry at least one sharp knife. This is an important piece of safety equipment to prevent being *fouled* in debris and is an effective tool used in rigging. A knife is often supplemented by a pair of wire cutters. Gloves are an important safety item that must be worn on all dives. There are many types and styles of gloves, with some offering thermal protection. Many contractors require divers to wear Kevlar® gloves that help prevent cuts and scrapes. Divers also wear *bottom boots* to protect from punctures and foot and ankle injuries. These are usually rubber boots with a steel shank in the sole and a steel toe. When working in mid-water or performing a *swim-by*, inspection divers can wear *fins*. Although fins are helpful while working off bottom, many divers prefer to wear boots instead of fins.

Air and Gas Supplies

Air Compressors

Breathing air is usually supplied by low-pressure diesel-powered or electric compressors. The compressors vary in size and are rated according to the volume of air and supply pressure delivered. The air is compressed and stored in a volume tank where it is filtered before passing through the air manifold to the diver. The filters are designed to remove moisture, toxic gases, and solid particles. The compressor is specifically designed to provide breathing quality air and uses special oil that is non-toxic. No diving should ever be conducted using any other low-pressure compressed-air source other than a diver's breathing air compressor.

High-Pressure Gas Bottles

Bottle racks containing from 4 to 64 bottles are used to provide breathing gases to divers. The bottles are high pressure, up to 50,000 cubic feet (1,416 cubic metres) at 2,800 psi, and are together in manifold to create a large volume of available gas. The *gas racks* can contain breathing air for a secondary source of air in the event the compressor fails. They also contain oxygen for surface decompression or metabolic use during saturation diving, and are used for mixed-gas diving operations. Large quantities of pre-mixed Heliox are needed for surface-supplied mixed-gas and saturation diving. These gas supplies are passed through the dive control panel or manifold and regulated to appropriate pressures.

Volume Tank

This tank is a pressure vessel connected to the outlet of a compressor and used as an air reservoir. It also allows the compressed air to cool and drop out some moisture before being filtered and delivered to the dive control panel. In the event of compressor failure, it gives the supervisor time to switch the diver to the backup high-pressure air supply.

Dive Control Panel

The dive control panel or manifold is often referred to as the *rack*. For shallow or air-diving operations, the manifold supplies two or three divers with low-pressure air and a secondary high-pressure supply. It should have gauges that allow the operator to monitor the low-pressure and high-pressure supplies and the regulated pressure from the high-pressure supply. It should also have gauges that allow the rack operator or supervisor to monitor each diver's depth. These are known as *pneumofathometer* gauges or pneumo gauges. The pneumo gauge is connected to a small hose in the diver's umbilical that is purged from a supply at the control panel. After the diver notifies *topside* by saying "I have bubbles," the supply is closed and the pressure in the hose is read in feet or metres at the surface. Dive control panels can be a simple two-diver system that fits in a small hand-carried case, or a complex array of gauges and valves large enough to fill a room.

Communications

Common two-wire push-to-talk radios:
- Dive radio
- Com box

Hard-wired communications between the diver and topside are mandatory for all commercial diving operations. The communications system is often referred to as a *dive radio* or *com box*. They are commonly a two-wire push-to-talk system where the diver's audio is constantly monitored and the supervisor pushes a button to talk. When topside presses the button to talk, the diver's audio is cut off until the microphone button is released. This two-wire system is the most common type of communications in use. There are more complex four-wire round-robin-type systems where all parties can be heard at the same time; these are much like talking on a telephone.

Dive radios used specifically for unscrambling helium speech are used for mixed-gas and saturation diving (fig. 11). Helium unscramblers are not perfect, and it might be difficult for an observer to understand everything the diver is saying. Experienced personnel often do not use unscramblers. They report finding the helium-distorted speech easier to understand after having experienced the effect themselves. A universal rule in commercial diving operations is that, if communications are lost, the dive is terminated until satisfactory repairs can be made and tested.

Courtesy of Amron International

Figure 11. Two-diver communications unit

Diving Umbilical

The *diving umbilical*, sometimes referred to as a *dive hose*, is the diver's lifeline to the surface (fig. 12). It provides four *members*: breathing gas, depth monitoring, communications, and a safety strength unit. Most air-diving umbilicals are from 300 to 600 feet (91 to 183 metres) in length. They often incorporate a video and light cable. Umbilicals for cold water or mixed-gas diving also include a hot water hose. The umbilical members are commonly joined together with high-strength duct tape to maintain the members or add new ones. Diver umbilicals can also be constructed by braiding or twisting the various components together. This type is most often used in *bell diving* as the diver's *excursion umbilical*. The diver's hose is a critical piece of life support equipment and should be treated carefully and maintained for safety.

In mixed-gas saturation diving, radios are used to unscramble helium speech.

Courtesy of Epic Diving and Marine Services LLC

Figure 12. Diver's umbilical providing breathing gas, video, and communications support while setting down line to send and receive tools from topside.

Deck Decompression Chamber

Decompression uses 100% pure oxygen in a dry secure environment.

Deck decompression chambers (DDC) are mandatory on any job occurring in over 80 fsw or where decompression diving is planned. The common offshore deck chamber is a 54-inch-diameter dual-lock *hyperbaric* chamber (fig. 13). Dual lock refers to the inner lock and outer lock that are separated by a hatch, allowing the outer lock to be brought to the surface while the inner lock remains at depth. The chamber is used in treating decompression sickness and in the surface decompression process. This process is one in which the diver completes an abbreviated in-water decompression obligation, returns to the surface, and then enters the chamber where he or she is compressed to complete decompression using 100% oxygen in a dry and controlled environment. Both the inner and the outer lock have identical controls for air and oxygen regulation.

Oxygen or any breathing mix can be supplied to breathing masks inside the chamber. This system is known as the *built-in breathing system (BIBS)*. A BIBS consists of a demand-valve breathing mask and exhaust dump valves that allow exhaled gases to escape from the chamber. The exhaled gas contains a high percentage of oxygen. If the gas were allowed to remain in the chamber, the oxygen content would rise rapidly and cause a high risk of fire. Other chamber penetrations allow for an overpressure relief valve, gas analysis, power supplies, lighting, and communications. Many deck chambers also have a small medical lock to allow food and supplies to pass in and out under pressure. Many jobs require more than one DDC to support continuous diving operations because a vacant chamber is always required for dives in progress.

Courtesy of Epic Diving and Marine Services LLC

Figure 13. Chambers such as these above are used offshore during diving operations for surface decompression and recompression treatment

Diving Stage

A *diving stage* is essentially a basket where the diver can both perform decompression stops and enter or exit the water (fig. 14). The stage is constructed as a basket open on one side with hand holds inside and protection around the occupant. The stage is lowered from the surface by a *davit* and winch. A crewmember controls the winch while being directed by a supervisor. When there is a large air gap from the water surface to the diving platform, a diving stage is the preferred method of entering and exiting the water.

> Diving stages assist divers on and off the boat and are also equipped to decompress.

Courtesy of Epic Diving and Marine Services LLC

Figure 14. Diving stage

Surface-Supplied Air Diving

Surface-supplied air diving uses:
- Shallow air
- Immediate air
- Deep air

Surface-supplied air diving is appropriate from the surface to about 190 fsw. Although air can be breathed to 220 fsw, the narcotic effects of nitrogen make it ineffective. A surface-supplied diving system is any system where the diver's breathing gas supply is stored, controlled, delivered, and monitored from the surface and supplied to the diver through an umbilical hose.

The main components of an air-diving system include:

- Diver-worn equipment—helmet, protective clothing, and safety devices
- Primary air supply—usually a low-pressure compressor
- Secondary air supply—usually high-pressure bottles
- Volume tank
- Air manifold or rack—including pneumofathometer gauges
- Communications
- Diving umbilical
- Deck decompression chamber

Surface-supplied air diving includes three subcategories: shallow air, intermediate air, and deep air, defined as follows.

Shallow Air

Shallow-air diving is any diving activity up to 80 fsw where the diver will not have decompression obligations. A shallow-air diving package is compact and contains at least the following equipment:

- Low-pressure air compressor
- High-pressure backup air supply
- Air manifold with pneumo gauges
- Volume tank
- Two dive radios
- Two diving umbilicals with air hose, pneumo hose, and communications wire
- Two sets of diver-worn equipment

The minimum personnel requirements of this operation are three: a diving supervisor, diver, and diver/*tender* who are competent and physically able to enter the water as standby divers. Most diving contractors add a fourth team member, as a minimum, to act as a designated standby diver who has no other duties and can be equipped and ready to enter the water in an emergency.

Intermediate Air

Any diving from 80 fsw to 130 fsw is considered intermediate air range. More equipment is added according to the diver's depth. The following equipment is the minimum package:

- Two low-pressure compressors
- High-pressure backup air supply
- Two volume tanks
- Air manifold with pneumo gauges
- Two dive radios
- Two diving umbilicals
- Two sets of diver-worn equipment
- One deck decompression chamber
- High-pressure oxygen for chamber decompression or treatment
- Dive stage and handling system, required when working over 100 fsw or where the air gap exceeds 15 feet (5 metres)

The minimum personnel requirement is increased to four; however, five is the preferred number. Additional equipment and personnel is often also required to allow continuous operations.

Deep Air

Deep-air diving is from 130 fsw to 220 fsw. The cutoff depth for most diving contractors using air is 190 fsw, but the USCG CFR 46 197 Subpart B-Commercial Diving allows air diving to 220 fsw for up to 30 minutes. The following equipment is necessary:

- Two low-pressure compressors
- High-pressure backup air supply
- Two volume tanks
- Air manifold with pneumo gauges and gas analysis
- Two dive radios
- Two diving umbilicals
- Two sets of diver-worn equipment
- Two deck decompression chambers
- Two racks of high-pressure oxygen for chamber decompression or treatment
- High-pressure gas rack of in water decompression gas
- Dive stage and handling system

The minimum personnel requirement for deep-air diving is five. A *non-diving supervisor* is required. A non-diving supervisor must never dive or enter the chamber. A non-diving supervisor is also required on any diving project with eight or more persons working at the same time. A crew of eight or more is often used while performing deep-air diving operations.

Surface Mixed-Gas Diving Equipment

Mixed-gas diving, often called *gas diving*, avoids the problem of nitrogen narcosis by substituting helium for nitrogen. Close monitoring of the gas mixtures by a surface team ensures a diver is getting the proper mix for the particular depth. All of the equipment described previously is incorporated into mixed-gas diving. The additional equipment necessary for gas diving is primarily the diving control panel and supply of a helium-oxygen mixture (HeO_2).

Mixed-Gas Diving Control Panel

The control panel is built into a dive control van and is equipped to supply at least three divers.

The mixed-gas control panel is often built into a *dive control van*, which is a structure built specifically to house the panel, communications, analysis, and audio/video monitoring equipment (fig. 15). The panel itself should be able to supply a minimum of three divers with any gas available without interrupting each other. The third outlet is often used to supply the *wet bell*.

The panel should be able to supply low-pressure air, high-pressure air, two separate banks of HeO_2, and a decompression gas to all the outlets individually. It should also be capable of analyzing the gas mixture being delivered to each individual outlet. Each outlet has its own pneumo gauge. The operator must be able to direct any of the gases available to the pneumo hose, so in an emergency, the pneumo hose can be pushed up into the helmet as a breathing supply.

Figure 15. Mixed-gas diving control panel operator in dive control van

Courtesy of Epic Diving and Marine Services LLC

Wet Bell

The terms wet bell, open bottom bell, or Class-II bell are often used interchangeably because they are exactly the same thing. A wet bell is legally required on all surface gas dives deeper than 220 fsw or where the diver will face in water decompression of 120 minutes or greater. Common practice is to use a wet bell on all mixed-gas dives.

The wet bell is a stage with a dome on top that is open at the bottom, allowing a diver to insert his or her head inside a dry environment (fig. 16). This arrangement serves the diver well in an emergency when the breathing supply is lost. The diver can get to the bell, which should be stationed close by, and remove his or her helmet to breathe.

> An open-bottom bell or Class-II bell provides divers with an emergency supply of air when power is lost.

Courtesy of Brian Derby

Figure 16. Wet bell

The bell has its own umbilical that provides fresh gas and depth readings.

In addition to the dome as an emergency breathing supply, the wet bell is equipped with emergency gas cylinders. The cylinders are manifolded together and have a hose that can be connected to the dive helmet and/or a scuba regulator from which to breathe. The wet bell is also equipped with its own umbilical, which can supply the dome with fresh gas and take depth readings from a pneumo hose. There is also a communication speaker in the dome.

The wet bell requires a davit or A-frame handling system. This handling system usually incorporates a secondary means of recovery and an extra power source. Most diving contractors have two winches available to recover the wet bell if the primary winch or power source fails.

Helium Unscrambler

A dive radio electronically synthesizes a diver's speech, slowing it down and adding a bass quality. These radios must be included in the equipment package for gas diving. However, many experienced supervisors and *life-support technicians (LST)* do not need them to understand helium-modified speech.

Hot Water Machine

Hot-water machines heat the water to a high temperature as the water cools significantly moving through the hose.

A hot water machine is either a diesel-fired or electric boiler that heats seawater to be pumped to the diver through a hose in the umbilical. The temperature is controlled from the surface. A series a valves allows the flow to be directed to the diver or dumped overboard. Water loses heat in long runs of hose, so the water must be heated to relatively high temperatures to ensure it is comfortable when it reaches the diver. Various safety devices are built into machines to prevent water that is too hot from reaching the diver. It is recommended that the supervisor use a gauge to indicate the output temperature of the water. An audio alarm is also commonly used to signal the point at which the water reaches a hazardous temperature.

High-Pressure Mixed Gas Cylinder Racks

The gas used for diving operations is supplied as premixed HeO_2. The high-pressure gas cylinder racks come in many sizes and configurations. The most common are 16- and 25-bottle racks. A surface-supplied mixed-gas diving operation requires that a minimum of two separate racks of HeO_2 be supplied to the dive control panel. One is considered the main supply, and the second is a standby rack for emergency use. Often many racks of gas are carried on a project where continuous diving is required.

Minimum personnel needed for a high-pressure mixed dive is at least six, including one LST operator.

The minimum required equipment for surface gas diving is as follows:

- Two low-pressure compressors
- High-pressure backup air supply
- Two column tanks
- Mixed-gas dive control panel with pneumo gauges and gas analyzers
- Two helium unscramblers
- Two diving umbilicals that include a hot water hose
- Two sets of diver-worn equipment
- Two deck decompression chambers
- Two racks of high-pressure oxygen for chamber decompression or treatment
- High-pressure gas rack of in-water decompression gas
- Two high-pressure gas racks of HeO_2
- Wet bell and handling system
- Two hot water machines

The minimum personnel requirements for surface-gas diving operations are six. An LST or rack operator is also added. Commonly, the crew consists of ten or more persons to allow for more dives.

Saturation Diving Systems

To safely conduct a saturation dive, divers use:
- Unlimited duration excursion tables
- Procedures for saturated diving

With the use of saturation diving techniques, a significant increase in diver bottom time can be realized, which results in more efficient and timely project completion. The primary advantage of saturation diving is that the total decompression time is constant for any depth without regard to length of time. This advantage allows divers to remain at working depths for durations that are not limited by decompression considerations.

Divers are maintained in the deck chamber complex continually at a depth, which permits them to work for extended periods on bottom and return directly to the deck complex by the use of the bell without decompression. By following the Unlimited Duration Excursion Tables and Procedures for Saturation Diving, divers are allowed a wide vertical range of working depths without time limits or additions to the decompression time.

Helium-oxygen saturation diving requires operational procedures, chamber complexes, and life-support systems that control the depth, oxygen partial pressure, carbon dioxide partial pressure, temperature, and humidity. The system is designed to accommodate from 6 to 24 divers for periods of one month or longer (figs. 17 and 18).

Courtesy of Robert Sanchez

Figure 17. Portable saturation diving system

COURTESY OF EPIC DIVING AND MARINE SERVICES LLC

Figure 18.   Saturation diving controls

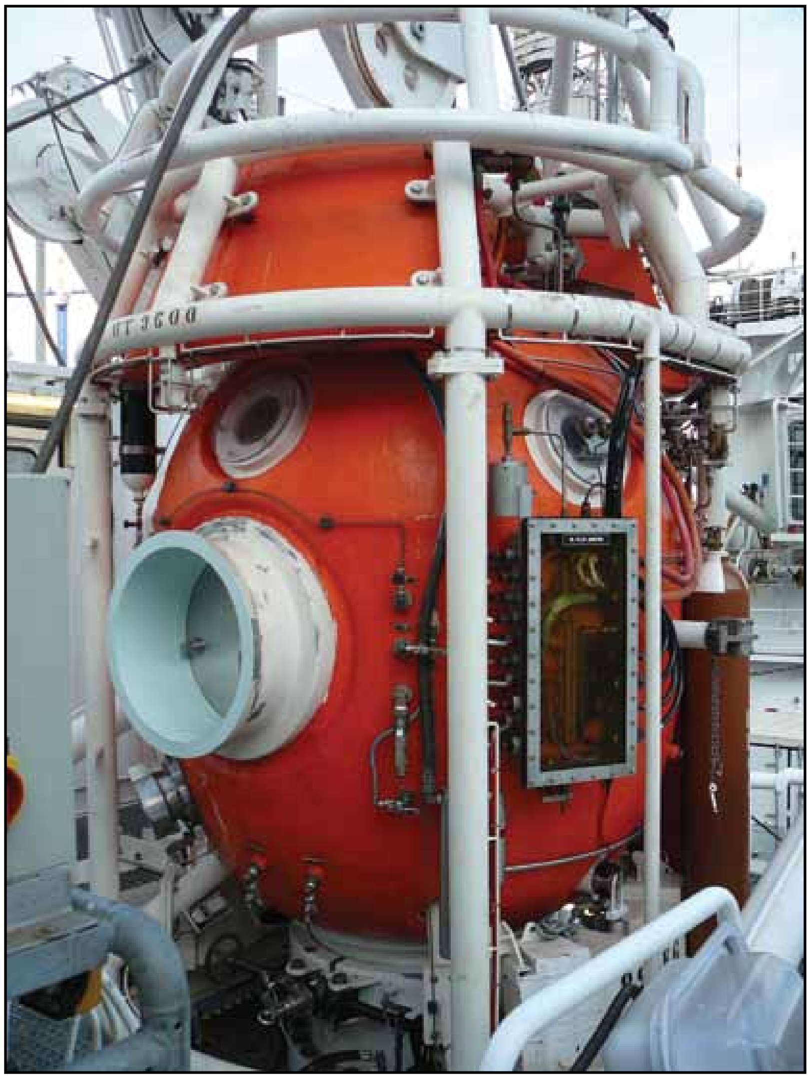
The main components of a saturation diving system include:

- Diving bell
- Bell-handling system
- Dive control
- Deck decompression chamber complex
- Chamber control (saturation control)
- Life-support systems
- Hyperbaric rescue chamber
- Gas reclaim system

Diving Bell

A submersible decompression chamber is a facility where divers can depressurize under water.

The diving bell, or *submersible decompression chamber (SDC)*, is essentially an elevator that transports the divers from the living chambers on the surface to the work site while remaining under pressure (fig. 19). The bell can be designed for two or three occupants. It is essentially a chamber and is fitted with facilities for pressurization, exhaust, BIBS, depth and gas analysis monitoring, hot water, environmental control for carbon dioxide removal, communications, power, video, and gas reclaim. These functions are supplied from the surface through the bell umbilical. The bell umbilical also serves as an emergency recovery device and must be strong enough to lift the bell if the main cable fails.



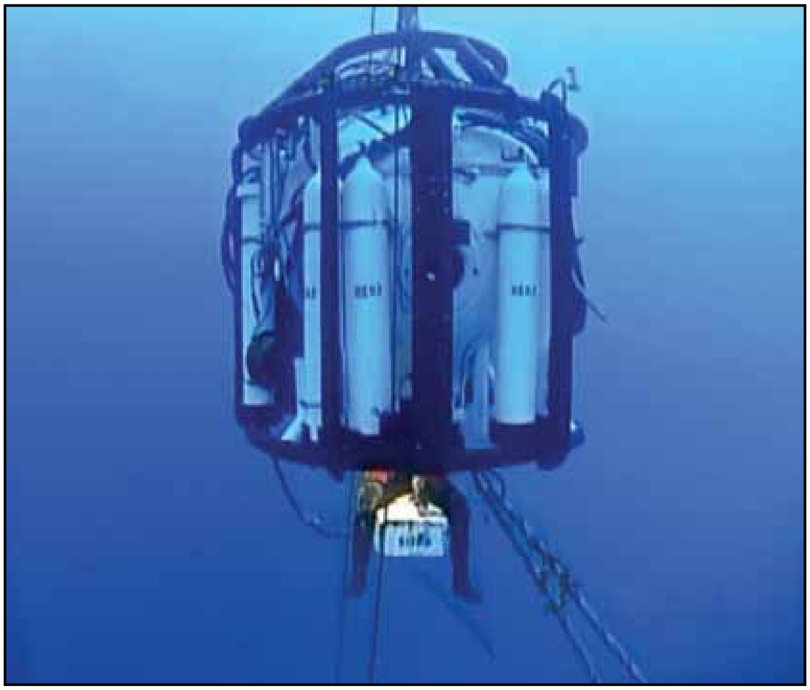
Courtesy of Epic Diving and Marine Services LLC

Figure 19. Diving bell locked on trunking

The bell is designed to mate or lock onto a transfer chamber on the surface complex. Many different designs can achieve essentially the same result, which is *transfer under pressure (TUP)*. The bell clamps onto the transfer chamber by its bottom or side *trunking*, depending on the design (fig. 20). Trunkings allow divers to pass between chambers through a small tube with hatches on both sides. The bell trunking has two doors to contain pressure or resist external pressure. The divers transfer under pressure from the chamber complex to the bell. The bell is lowered to working depth when the internal pressure equals the external pressure. Then the door can be raised and the divers can "lock out" of the bell to work.

A diving bell allows divers to transfer under pressure.

The bell is also equipped with extra emergency systems. The bell carries an onboard gas supply that includes a breathing mix and sometimes oxygen for metabolic makeup of the bell atmosphere. The bell must be buoyant. It has external weights that can be released from inside the bell to sink it. All bells carry an emergency location transponder in case it breaks free from the umbilical and lift wire. Backup through water wireless communications must be fitted to all diving bells. They are also fitted with an onboard emergency power supply battery that can run CO_2 scrubbers and essential equipment.



Courtesy of Robert Sanchez

Figure 20. Diving bell in use

Heat conservation is necessary to survive in a stranded bell. To assist survival, the diver is supplied with insulated survival suits that have a breathing mask attached to a soda lime CO_2 removal filter and heat-regeneration system. First-aid and tool kits along with emergency food and water are standard equipment as well.

The bell functions as a base for the diver and supplies everything through the bell umbilical. The diver has an umbilical to enable leaving the bell to work. This is called an excursion umbilical and is typically about 100 feet (30 metres) in length. The *bell man* acting as the working divers stand-by must have an umbilical that is at least 6 feet (2 metres) longer to ensure it can reach an injured diver.

Bell-Handling System

The preferred mechanism used to launch a bell in the water is a moon pool.

The bell-handling system is commonly referred to as the *launch and recovery system (LARS)*. The primary function is to transport the bell from the mating trunk to the work site and back without damaging the equipment or causing injury to the occupants.

The two ways to launch a bell are: over the side of a vessel or platform or through a *moon pool*, which is a hole that penetrates from the deck of a vessel to the water. A moon pool is the preferred method for launching a bell because the wave action is greatly reduced and the bell can be easily controlled. The bell is lowered with the main lift wire and is prevented from spinning with guide wires that are run through a clump weight and launched before the bell.

The clump weight also acts as a secondary means of recovery. The main winch is generally hydraulic or electric and fitted with secondary motors and power sources. The bell umbilical is usually handled by the LARS and might have its own winch or be run from a large basket where it is coiled over a powered sheave. This arrangement keeps it in line with the lift wire. It also allows the bell umbilical to be lashed to the lift wire at periodic intervals to prevent any excessive slack and prevent impact from currents.

Dive Control

During a dive, the diving supervisor is normally located in the dive control van. The control van is often situated near the bell launch point so the supervisor can direct the launch and recovery.

A typical control van is an insulated, air-conditioned, building structure mounted on a skid specifically designed for use aboard a vessel or platform (fig. 21). The interior equipment generally consists of:

- A bell and mixed—gas diving supply manifold
- A pneumofathometer panel
- A communications system including:
  - — voice unscramblers
  - — a deck public-address system
  - — a burning and welding knife switch
- Inside, deck, and underwater lighting controls
- Diving gas analyzing equipment
- Audio- and video-monitoring systems

Most bell-diving systems are fitted with a gas reclaim controlled by the dive supervisor. The dive control van can monitor all systems of the bell and the diver in the water. The internal and external bell pressure (depth) is available on separate gauges.

A control van is equipped with:
- Bell and gas supply
- Pneumofathometer
- Communication system
- Deck and lighting controls
- Gas analysis equipment
- Audio-video capabilities

Courtesy of Epic Diving and Marine Services LLC

Figure 21. Saturation diving control console

The diver's depth, the gas mix, and the supply pressure are all monitored while being delivered. Video is often recorded from both the diver's helmet and inside the bell, and communications are linked to the diver and inside the bell. The bell has a sound-powered phone hard-wired to the surface and to the unscramble radio, which serves as a back-up communication system. The dive control is also fitted with several other forms of communication such as VHF and UHF radios, intercoms, and public-address systems that transmit to different areas of the deck or facility. While diving operations are underway, communication with all parties is of critical importance (fig. 21). When using cranes and lifting equipment or moving the vessel, the dive supervisor is in complete charge of all operations.

Deck Decompression Chambers

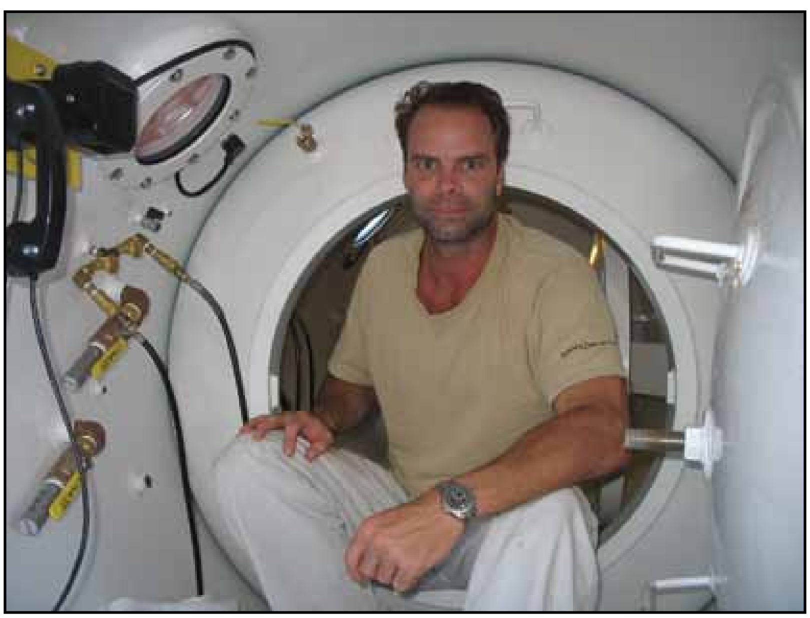
> Locks are chambers where divers transfer under water and have access to eating, showering, and toilet facilities.

The chamber complex might consist of as few as two or as many as eight or more interconnecting chambers (figs. 22 and 23). The chambers might be subdivided internally by pressure bulkheads or simple partitions. The various chambers, or *locks*, provide sleeping, eating, showering, and toilet facilities. The transfer lock is where the bell mates and the divers perform transfer under pressure. They will also change into and out of diving suits and use the shower and toilet facilities in the transfer lock. This way, the living chambers are kept dry and clean. The transfer lock is also sometimes called the wet lock. It is very important to keep the living chambers dry and clean because divers living in *hyperbaric* environments—where pressures are higher than normal atmospheric pressure—are extremely susceptible to infections. Hygiene is a primary concern in saturation chambers. Smaller medical locks and equipment locks are used to pass food, laundry, and supplies in and out of the chamber complexes.

During saturation, divers might live at different storage depths with some divers decompressing in different chambers in the complex. The chambers are linked together by trunkings so divers can pass between chambers. Some chambers are divided into compartments by trunking doors to isolate areas of the system, which allows individual chambers to be compressed or decompressed.

Courtesy of Epic Diving and Marine Services LLC

Figure 22. Inside living area of a saturation diving system



Courtesy of Epic Diving and Marine Services LLC

Figure 23. Diver exiting deck chamber

> Scrubbers clean the living chamber air by removing carbon dioxide from the air with soda lime.

The living chambers are fitted with bunks, individual lighting, drawers, tables, and shelves. Living conditions are sparse, and the divers live in a very small area. The atmosphere is controlled by environmental control units—called *scrubbers*—that remove CO_2 from the breathing atmosphere by using a granulated chemical called soda lime. The gas is circulated through these filters and a chemical reaction removes the CO_2. The soda lime filter element becomes inactive and needs to be changed on a regular basis. All chambers have hull penetrations for pressurization, exhaust, BIBS, depth readings, gas analysis, heating, bilge drains, communications, light and power. All decompression chambers are required to have valves fitted on both sides of the chamber hull so that, in the event that a penetration is knocked off on the outside, it can be isolated internally. All environmental control and chamber functions are controlled by a life-support technician (LST) from the outside.

Chamber Control

Chamber control, commonly referred to as *Sat* (saturation) *control*, is where the LST monitors all aspects of the chamber complex. Each chamber has a separate control panel located in Sat control along with gas analysis and communication equipment. Sat control regulates all compression and decompression procedures. The LST monitors gas analysis for the chambers' atmosphere and breathing mixtures. All communications to the chambers is routed through Sat control. The LST regulates temperature and humidity in each chamber, and Sat control monitors and operates the equipment locks and any transfer of equipment, food, and supplies.

Life-Support System

The *life-support system* has several functions that are continuously regulated and monitored. The system removes CO_2 by the means of scrubbers. The level of CO_2 must never exceed 0.005 atm in the chamber atmosphere. The atmosphere is then cooled to condense water vapor and remove it to maintain constant humidity between 50% and 60%. Prolonged periods of high humidity can cause respiratory problems and increase the risk of infection. The gas is then heated to around 85°F to 89°F to maintain a safe and comfortable level. Oxygen, which is consumed at a rate of 25 cubic feet (1 cubic metre) per diver per day, is added as necessary. Gas analyzers continuously monitor the oxygen level, which must be maintained at 0.45 ata of the chamber atmosphere. Each chamber of the complex has its own designated life-support equipment.

Hyperbaric Rescue Chamber

Hyperbaric rescue chambers (HRCs) are designed to evacuate the divers from the saturation complex in the event of a catastrophe that renders the complex uninhabitable (fig. 24). Examples of such events are a sinking vessel or platform or a fire that is out of control. HRCs are fairly simple floating chambers that can float free when launched or are actually powered lifeboats. The critical component of their design is that the chamber must support the maximum number of chamber complex occupants for an extended period of time.

Courtesy of Epic Diving and Marine Services LLC

Figure 24. Hyberbaric rescue chamber

All life-support and environment functions are self-contained within the rescue chamber. Hyperbaric evacuation must be the last resort in an emergency, because evacuation procedures can generate greater risk to divers than the emergency itself. An HRC is always kept locked onto the chamber complex and pressurized to depth. Hyperbaric evacuation systems are also designed with a special life-support equipment package kept nearby. This practice is done so the HRC can be recovered and then connected to the emergency package to enable full decompression capabilities.

Gas Reclaim System

A gas-reclaim system can recover 80% of gas by removing the carbon dioxide from the exhaled air and returning it to the diver's umbilical.

In saturation diving operations, the mixed gas often contains from 90% to 98% helium. Helium is expensive and uneconomical to breathe using an open circuit system in which the diver exhales the gas into the environment where it is lost. In addition, the very large volumes of gas needed to support operations cannot be accommodated in the space available.

A gas reclaim system allows the diver's exhaled gas to be routed back to the bell through a return line in the diver's umbilical. There, some moisture is removed, and then it is sent to the surface where the exhaled gas is reconditioned. This reclamation is done by removing the carbon dioxide, adding oxygen, and separating the water that is then stored or recirculated to the diver. Extra control devices monitor oxygen and carbon dioxide levels and regulate positive and negative pressures in the system.

This type of system can recover 80% to 90% of the gas used, saving a large amount of cost and space. The equipment consists of a control console operated by the dive supervisor. The console controls and monitors the gas booster, oxygen content, diver supply pressure, and negative exhaust hose pressure.

Bell equipment is placed internally and externally and includes the back-pressure regulator and water traps to remove moisture before being sent *topside*. The gas booster increases the gas pressure when being pumped into storage or when delivering gas to the diver. The gas reprocessing unit further dries the gas and scrubs the carbon dioxide and other contaminants. It also stores gas to be recirculated to the diver.

Many large saturation systems are equipped with a chamber reclaim, which allows almost all gas to be recovered and reprocessed. While venting gas to decompress, a chamber or operating equipment locks the gas so it is not lost. Systems with this capability are becoming more common and becoming increasingly necessary to remain cost effective.

To summarize—

- Advantages of scuba equipment include but are not limited to horizontal mobility, flexibility, and buoyancy control.
- Disadvantages of scuba diving are the exertion of breathing under pressure, lack of two-way communication, and the fact that many consider scuba inappropriate for use within the offshore oil and gas industry
- There are three types of surface-supplied diving modes. They are surface-supplied air diving, mixed-gas diving, and saturation diving.
- Surface diving is defined as any mode of diving where the diver leaves the surface and returns to the surface at atmosphere.
- Diving requires several pieces of equipment. This includes a safety harness, a weight belt, a helmet or a mask, a wet-dry or hot water suit, an emergency gas supply, and ancillary equipment.
- Supply of air and gas varies depending on the type of dive and might include delivery by high-pressure gas bottles, volume tanks, and dive-control panels.
- Communication while diving is done through a dive radio or com box. In mixed-gas diving, divers often use an unscrambler to clarify helium speech.
- Dives are controlled through the following means: a bell and gas supply, a pneumofathometer panel, communication systems, deck and underwater lighting controls, analyzing equipment, and audio-video monitoring systems.
- A diving umbilical, also called a diving hose, provides breathing gas, depth monitoring, communications, and a safety unit for the diver.
- Compression chambers come in two forms: a deck decompression chamber and a diving bell. Each are needed to decompress the diver periodically to alleviate decompression sickness.
- Surface-supplied air diving allows a deeper dive than surface-supplied diving. It provides up to 160 fsw for the diver to explore. There are three types of air dives: shallow air, intermediate air, and deep air.

- Gas diving prevents nitrogen narcosis by supplementing helium for nitrogen.
- Saturation diving systems became popular with the U.S. Navy during World War II. An advantage is that they allow divers to work for longer durations at depths not limited to decompression needs. Another advantage is that they can accommodate up to twenty-four divers.

Underwater Photo and Video Equipment

In this chapter:

- Digital still cameras and newer technologies
- Underwater video capabilities
- Classification of remotely operated vehicles
- ROV tasks, capabilities, and tools

Advances in digital photography and video equipment have allowed real-time transmissions of critical information (fig. 25). Many vessels have e-mail capabilities, allowing photos to be sent instantly after being captured from live video. It is also quite common to have live streaming video from a diver's camera sent over the internet to share with clients and engineers so they can request the diver to observe specific data.

Digital Still Cameras

Still cameras are used less frequently today because the presence and capabilities of computer equipment on job sites has made digital photography and instant transmission of images more desirable. Still cameras are still used frequently in underwater platform inspection for close visual weld inspection, but the cost and maintenance of these cameras are relatively high for the quality of the photos they produce. Video cameras and computer programs are close to achieving comparable results. Still cameras require waterproof and pressure-proof housings that must be specifically designed for the camera being used. Still cameras also have depth restraints.

Courtesy of Brian Derby

Figure 25. Today, advances in camera capabilities allow divers to capture details of work performed deep under water.

Underwater Video Cameras

Still cameras are being phased out by new video technologies. Underwater cameras now have remote access to third parties.

Underwater video cameras are used on almost all diving projects offshore. They have become extremely small and therefore mount easily on the diver's helmet along with a light source. The camera and light are fed through a cable joined in the diver's umbilical and monitored and recorded by dive control. In fact, the video feed is often piped to other areas of the vessel or installation to be monitored by interested parties.

A great advantage of underwater video is that the diver does not need to be trained to be a competent photographer. The camera can see more than the human eye, so the person monitoring the video can direct the diver remotely. The footage can then be edited on a computer and dispersed electronically. Underwater video has not only improved data-recording capabilities but is considered an effective tool in regards to safety. The supervisor can monitor a diver's movements and observe the "big picture," which helps to prevent injury and incidents.

Remotely Operated Vehicles

The term *remotely operated vehicle (ROV)* covers a wide range of equipment with no single vehicle described as typical (fig. 26). Not only are there numerous differences between basic design, but one basic ROV can be modified to carry out different tasks.

Four different classifications are commonly used to identify ROVs:

- **Class 1-Observation.** Pure observation vehicles are generally considered to be physically limited to video observation and fitted with a video camera, lights, and thrusters. However, these types of vehicles have now evolved to perform other tasks when properly fitted with additional sensing devices. Some of these vehicles can be extremely small, weighing as little as 8 pounds (4 kilograms).

There are four classifications of ROVs:
- Observation
- Observation with payload option
- Work-class vehicles
- Towed or tracked vehicles

Source: National Oceanic and Atmospheric Administration

Figure 26. A remotely operated vehicle (ROV) with headlights on and samplers begins its descent.

Work-class vehicles are outfitted with sensors and tools in addition to technological capabilities of Class I and II ROVs.

- **Class II-Observation with Payload Option.** In general, these vehicles are somewhat larger than those of a pure observation nature and can carry additional sensors such as still cameras, cathodic potential measurement devices, additional video cameras, sonar systems, and small manipulators.
- **Class III-Work Class Vehicles.** These vehicles are large enough to carry additional sensors and/or manipulators and commonly have a multiplexing capability to allow additional sensors and tools to operate without being hard-wired through the umbilical system. Class-III vehicles are generally larger and more powerful than vehicles of Classes I and II. Wide variations of power, depth rating, and capability are possible.
- **Class IV-Towed or Tracked Vehicles.** Towed vehicles can be pulled through the water by a surface craft or winch. Some might have limited propulsion power and limited maneuverability.

ROV Tasks

ROV capabilities are constantly being expanded as technology improves:

An ROV can perform the following tasks:
- Observation
- Surveys
- Construction
- Intervention

- **Observation.** Observation is the least complicated work mode. It can normally be undertaken by the use of a video camera without additional equipment. When monitoring divers, the vehicle is normally maintained in a near stationary position.
- **Survey.** Surveying activity normally consists of some form of observation of the intended area of operations, whether on the seabed or within an enclosed area such as a pipeline, platform, or subsea wellhead. Survey is also used as a post-construction or installation verification tool. The general purposes of surveying activity might include:
  — fixing geographical coordinates
  — verifying burial or debris removal
  — documenting damage
  — examining pipelines or structures
  — identification
- **Inspection.** It is often difficult to distinguish between inspection and survey, particularly because an ROV might carry out both types of tasks in a single dive. Inspection tasks usually concentrate on specific, predefined areas of concern and include detailed visual or other types of inspection using on-board sensors such as cathodic-protection measurement devices.

- **Construction.** These tasks normally require a larger vehicle capable of deploying at least one manipulator. Construction vehicles might be used for such tasks as removing debris, subsea intervention, connecting or removing lifting devices, or actuating valve components.
- **Intervention.** Many work-class ROVs have specially designed tool packages that can interface with subsea manifolds, wellheads, or control pods to facilitate installation, removal, maintenance, or repair functions.

ROV Tools

Tools in an ROV can be modified and upgraded to suit any project.

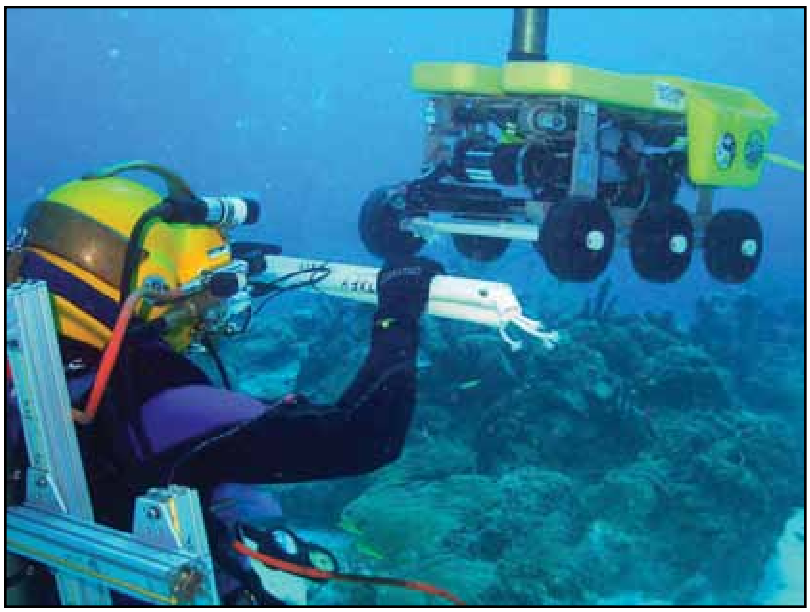
Tool packages can be varied to satisfy requirements with new devices constantly being developed and upgraded:

- **Cameras.** Cameras can be mounted in a fixed position or on a pan-and-tilt assembly. Video systems that can view in conditions of low light intensity and still cameras that can furnish high-resolution digital photos are common.
- **NDT Sensors.** The more commonly used sensors for nondestructive testing (NDT) are cathodic potential (CP) probes, ultrasonic thickness (UT) measurement devices, and flooded member detection systems.
- **Acoustic and Tracking.** Numerous acoustic sonar systems are available such as tracking and measurement devices, scanning, profiling, side-scan, subbottom profiling, bathymetric, and pipe tracking.
- **Cleaning.** ROVs can be used as a platform for cleaning devices used for structures or vessels. These devices can range from simple rotary wire or nylon brush systems to more sophisticated high-pressure water-jetting devices.
- **Stationkeeping.** Many ROVs can maintain heading, depth, and position. Attachment devices are available that allow the ROV to remain in a virtually fixed location. Some of these devices include:
  - — Docking cones and similar stabbing devices
  - — Suction pads and water pumps for hydrostatic attachment on smooth surfaces
  - — Manipulator-mounted hydraulic devices to grip structural members

Divers and ROVs

ROVs monitor a diver's safety.

It is becoming common to have an ROV and diver working together on the same project (fig. 27). The ROV can perform several roles from strictly observing the diver to assisting with work activities. But the ROV can be a serious potential hazard because it might entangle the diver's umbilical or interfere with an operation. The ROV can also be highly effective as a safety tool by presenting the supervisor with an overview of the diver and work site. The most important aspect of simultaneous operations using a diver and ROV is direct communication between the diving supervisor and the ROV pilot. The dive supervisor is in charge while the diver is in the water. The ROV team must be fully briefed on emergency diving procedures and must report any problems with vehicle operation immediately to the diving supervisor.



Courtesy of Canada Space Agency

Figure 27. Divers often work in tandem with ROVs in a variety of subsurface research projects.

To summarize—

- Advancements in digital photography have benefited divers. New technologies allow divers and third parties to share real-time information via cameras equipped with streaming video.
- Although underwater still cameras are water and pressure-proof, they have limited depth constraints.
- Underwater video cameras are often mounted on a diver's helmet and are light fed through a cable connected to the diver's umbilical cord.
- Remotely operated vehicles, or ROVs, encompass a wide range of equipment and vary in design according to task. There are four classifications of ROVs:
  - observation
  - observation with payload option
  - work-class vehicles
  - towed or tracked vehicles
- An ROV can perform numerous tasks including but not limited to observation, survey, inspection, construction, and intervention.
- ROV tool packages vary and can be altered to suit a particular task. ROVs are often equipped with cameras, nondestructive testing sensors, acoustic tracking, cleaning devices, and stationkeeping attachments.
- It is common for divers to use ROVs at a work site. ROVs can successfully monitor a diver's safety by capturing images of the diver through real-time video.

Diving Services

In this chapter:

- Differences between specific diving operations
- Diving platforms and diving-related vessels
- Fixed-platform inspections versus pipeline inspections
- Installation and repair of platforms and pipelines
- Procedures for terminating platforms and pipelines
- Pipeline salvage and removal
- Underwater cutting and welding technologies
- Benefits and detriments of underwater burning and non-destructive cutting

Diving Operations

Commercial oilfield diving has always been seen as a mysterious operation that only a few dare to engage in as a career. Workers on dive vessels or other work platforms often see a diver leave the surface and dive into the unknown, then surface again sometime later to immediately enter a decompression chamber to prevent the bends or to reverse some other adverse effect of being under pressure. A lack of understanding of safe diving has kept many from entering into this occupation.

The fact is, the normal commercial diver performs the same tasks as many others who embark on similar trades, except usually the diver must be well trained in the many different aspects of the offshore oil and gas environment. Because of restrictions to work sites under water, the diver generally works alone on location and therefore cannot call colleagues for immediate assistance. If the diver cannot complete a task or operation due to a lack of skill in a certain area, the operation must be shut down and the diver must return to the surface and complete all required decompression before resuming the operation.

Oilfield diving is a timely process and requires specific skills.

This extended turnaround of personnel has resulted in the need to train the average commercial diver in multiple areas to maximize his or her time on the worksite under water. The average oilfield diver is well versed in different skill sets such as:

- Pipeline construction
- Platform and weld inspection
- NDT techniques
- Cathodic-protection systems
- Welding
- Many other specialized areas

Courtesy of Brian Derby

Figure 28. Diver removing marine growth from a node with a rig axe to prepare for visual inspection.

As tooling and technology have advanced over the past twenty years, divers have been able to work at deeper depths and use tools that enable oil and gas operators to install larger and more advanced platforms and transportation pipelines that make exploration and production operations more efficient (figs. 28 and 29).

Pipeline construction, repair, and inspection require long periods of time under water at great depths.

Courtesy of Epic Diving and Marine Services LLC

Figure 29. Construction and repair work requires long periods deep under water.

Diving Platforms

It is important for the diver to have a proper work platform to perform the many different diving operations offshore. Historically, diving operations were performed on a typical offshore supply vessel, but over the years, the available work platforms have expanded to provide vessels that make offshore operations safer and more efficient.

Dive Support Vessels

Although dive support vessels (DSVs) have evolved, a long-lasting standard in the diving vessel arena is the typical offshore supply vessel (fig. 30). These vessels can be between 100 and 200 feet (30 to 61 metres) in length and are usually tied up alongside the offshore platform from which work will be performed. The main characteristics of a suitable supply vessel include:

- The amount of deck space needed and available from which to dive
- The number of available berths (beds) on board the vessel

To be safe and effective, commercial diving requires a large number of personnel. Without a sufficient number of berths to accommodate personnel, the operation risks being shut down.

Courtesy of Epic Diving and Marine Services LLC

Figure 30. Utility DSV. Typical offshore supply vessel and diving support vessel.

Four-Point Anchor Vessels

The diving vessel must stay on the worksite even though no structures provide mooring support. To serve this need, the (four) 4-point anchor vessel was developed (fig. 31). The vessel travels to the worksite and then, either by systematically lowering the anchors down to bottom or through the assistance of an anchor-handling tugboat, all four anchors are placed on the bottom. The vessel positions itself by letting out and taking in the anchor wire on the winches. This practice allows the vessel to make precise movements without using the main engines or bow thrusters.

Most 4-point anchor dive support vessels are specifically built for commercial diving and are outfitted with the required operating equipment. The berthing is expanded to fill larger personnel demands. Dive gear can be stored below the vessel's deck to maximize deck space and protect the running gear from weather. A main component on a 4-point dive support vessel is the onboard crane or A-frame. This component allows the diving vessel to raise or lower tools and material to the worksite on the bottom. The 4-point dive support vessels can be used for surface diving operations, or a saturation system can be placed on the deck or permanently installed below the deck to maximize space.

Characteristics of a suitable supply vessel:

- Deck space
- Number of berths

Courtesy of Epic Diving and Marine Services LLC

Figure 31. Four-point anchor vessel

Dynamically Positioned Dive Support Vessels

DP DSVs use satellites and global positioning to keep stationed at a work site.

As the working depths have become deeper and computer technology has developed, a more recent diving platform design has been produced. The *dynamically positioned dive support vessel (DP DSV)* was introduced into the commercial diving industry to meet current demands (fig. 32). Like the 4-point anchor vessel, the DP DSV can maintain its location on the work site without having to tie up alongside a structure. However, instead of using anchors to hold the vessel in position, it uses satellites and global positioning to communicate with the vessel computers. The vessel uses the main engines and thrusters to make precise movements to keep position on the worksite.

As the technology has improved, the DP DSV has grown to become a primary diving platform in many regions. The sizes of the vessels have increased to reach lengths of 400 feet (122 metres), and the cranes can safely lift as much as 250 tons (227 metric tons).

Courtesy of Adams Offshore

Figure 32. Dynamically positioned dive support vessel

Spud Barges

Barges

When the depth of water in which divers are working is too shallow for a DSV to safely navigate, *spud barges* can be used (fig. 33). Spud barges are work platforms that lack engines and must be pushed onto location. When the barge reaches its work location, piles are lowered through the barge to penetrate the seafloor. This support provides a stable platform for divers, much like a 4-point anchor vessel provides. Generally, a crane is installed on spud barges to move equipment and materials.

> Spud barges work in shallow waters and do not have engines.

Courtesy of Epic Diving and Marine Services LLC

Figure 33. Spud barge

Pipelay barges use both anchors and a dynamic positioning system.

Pipelay Barges

Pipelines are an integral part of the offshore oil and gas industry. The placement of pipelines on the seafloor requires special equipment. A *pipelay barge* can be positioned and held in place by either anchors or by a dynamic positioning system (fig. 34). Pipe segments are loaded on the barge either by joint or on a spool. If the pipe is loaded on by joint, the pipe is welded together and travels down the side of the barge in an assembly line process.

After the pipe reaches the stern of the barge, it moves off the barge and onto a *pipeline stinger system* that transitions the pipe safely from the barge deck to the seabed without bending the pipe beyond its limits or otherwise adversely affecting the integrity of the pipe. After the pipeline is on the bottom, *dredging gear* is lowered down on top of the pipeline (fig. 35). High-pressure water is used to excavate the soil from around the pipeline, and large air-lifting equipment is used to float the removed soil off the bottom and away from the newly formed pipeline ditch. If pipe is spooled onto a reel instead of welding the pipe in the assembly line, the pipe is spooled off the barge through the pipeline stinger and then buried with the dredge equipment.

Figure 34. A pipelay barge held by a dynamic positioning system

Courtesy of Gulfstream Natural Gas System, LLC

Courtesy of Brian Derby

Courtesy of Epic Diving and Marine Services LLC

Figure 35. Two views of jet sled dredging gear lowered on top of the pipeline used to help excavate the soil from around the pipeline

Derrick barges can lift up to 4,000 tons and use a crane instead of a spool to lift a pipeline.

Derrick Barges

Derrick barges or heavy-lift barges are work platforms used for lifting large components offshore, such as installing or removing offshore platforms (figs. 36 and 37). These types of barges, like pipelay barges, can be positioned with anchors or a dynamic positioning system. Instead of having the assembly line or spool for laying pipe, these types of barges have an extremely large crane (fig. 38). Some of these barges can lift loads in excess of 4,000 tons (3,629 metric tons). These barges are also used when working on vessel salvages and platforms that have toppled because of a storm surge.

Courtesy of Epic Diving and Marine Services LLC

Figure 36. Derrick barge used for installing or removing offshore platforms

Courtesy of Epic Diving and Marine Services LLC

Figure 37. Derrick barge lifting with portion of platform (surface-gas diving equipment in background)

Courtesy of Epic Diving and Marine Services LLC

Figure 38. Typical crane block to perform lifts on a derrick barge

Lift Boats

Lift boats keep position at a work site via legs affixed to the seafloor.

Lift boats were designed in the United States in the state of Louisiana over 30 years ago to provide a stable work platform in water. Lift boats did not require anchors to stay on the worksite. They are self-powered to move onto location (fig. 39a and b). After the vessel determines the position and heading required, three to four legs on the vessel are lowered to the seafloor. After the legs are on the seafloor, they continue to push downward and slowly pick the vessel out of the water. These types of vessels are suitable for operations that cannot allow the materials being lowered to bottom by the crane to swing, which results from wave action in the ocean. These types of vessels have a maximum working depth of approximately 220 feet (46 metres) of water.

Courtesy of Brian Derby

Figure 39a. Lift boats are self-powered.

Courtesy of Epic Diving and Marine Services LLC

Figure 39b. Lift boats provide a stable platform in water.

Surveys and Inspections

Fixed-platform inspections

To ensure the offshore platforms and pipelines are working properly and that no problems exist that could cause a system shutdown or catastrophic failure and subsequent spill or release of product, the federal government has established regulations that determine when and how platforms and systems must be examined. These inspections generally use divers and ROVs to conduct the survey. The types of inspections on fixed platforms are categorized into Level I, II, III, and IV inspections:

> Level-I inspections conduct cathodic potential surveys and do not require an ROV or diver as do a Level-II survey.

- **Level-I** inspections are comprised of *cathodic potential surveys* of the platform at predetermined locations and depths on the platform. Generally, cathodic potential readings are taken at each leg of the structure. Readings are recorded at 10-foot (3-metre) increments until reaching the seafloor. Engineers review cathodic potential outcomes to determine if the *sacrificial anodes* are doing their jobs to prevent the electrical current in the water from corroding and deteriorating the structure. Level I surveys can usually be done with or without the use of a diver or ROV.
- **Level-II** surveys are performed periodically to provide the operator a more detailed view of the platform below the water line. As with a Level-I inspection, cathodic potential surveys are performed. However, instead of a drop cell being lowered from the surface, a diver swims the cathodic potential probe along every member of the structure to survey for visual damage while taking readings for corrosion. The diver also inspects each sacrificial anode to determine the amount of waste from deterioration and to help engineers

Ultrasonic systems measure wall thickness, identify cracks, and determine failure.

determine the future time at which the anodes on the structure should be replaced. During a Level-II survey, a diver examines all members to include conductors, intakes, boat landings, clamps, and risers on the platform to ensure the platform and pipeline systems are safe for use. Finally, the diver surveys the seafloor where the platform is situated to ensure there is no significant buildup of scour that could affect the stability of the platform or pipeline systems.

- **Level-III** inspections include nondestructive testing methods that are approved by regulatory agencies. Typical nondestructive testing by divers includes visual inspections of welds on selected nodes of the platform. *Magnetic particle testing* is used as prescribed by a client or when there are visual indications during close weld inspection (fig. 40). Other types of nondestructive testing involves the use of ultrasonic systems that can measure the wall thickness of steel, identify cracks, and determine whether a member of a platform has flooded with seawater due to failure in the steel.

A mounted video camera on the diver's helmet records all inspections to provide a permanent record of the survey. Digital photography has become an essential way to provide specific records of weld inspections, anodes, pipeline systems, and the amount of marine growth on a structure. More recently, the addition of live video feed has become available to give a client real-time access to the diver's point of view so they can make any needed decisions immediately.

Courtesy of Brian Derby

Figure 40. Diver preparing for magnetic particle testing of a weld on a node

Pipeline Surveys

Pipeline systems are another subsea component that must be surveyed to ensure they are safe to use. Problem areas need to be located and repaired before any type of damage to property or the environment occurs.

Pipelines in less than 200 feet of water must be placed at least 3 feet below sea level.

As a general rule, regulations require that all pipelines in less than 200 feet (61 metres) of water be buried a minimum of 3 feet (1 metre) below the seabed. Divers inspect pipelines and take measurements to determine whether pipeline systems are properly buried. If a pipeline is found to have insufficient cover, it will need to be lowered to a suitable depth of cover or be covered with either sand or cement bags or concrete mats to provide the pipeline with sufficient protection (fig. 41). Pipelines that cross other pipelines must also have sufficient cover and separation between them to prevent them from damaging one another through contact. The standard method for maintaining the required separation between pipelines is to use the sand or cement bags or concrete mats that come in different dimensions.

Pipelines are coated with different materials that provide protection to the steel and provide weight to the pipeline to help keep it stationary on the seafloor (the product in the pipeline causes the pipe to float). Divers inspect the coatings on the pipelines to determine whether any areas need repair.

Courtesy of Epic Diving and Marine Services LLC

Figure 41. Concrete mats

Pipeline Repair

When a pipeline failure occurs, divers survey the damage and determine a suitable repair method.

A large percentage of a diver's work is associated with repairs needed on existing pipeline systems. Although measures are taken to minimize damage to pipelines by ensuring they are buried and sufficient anodes are installed to prevent corrosion, damage and failures still occur. Pipelines can fail due to many situations, such as anchors from vessels being dropped or dragged on the pipeline, or natural events such as hurricanes or mud slides that can move pipelines and stretch them beyond their limits. Whatever the reason for the system failures, divers are brought in to survey the damage and, after the engineers and operators decide on a suitable repair method to repair the pipeline.

Because of advancements in pipeline technology, the repair process has become easier and faster over the years. In the past when a pipeline broke, it would often be raised by its ends up to the surface to weld a flange on the ends of the pipeline, then lowered back to the bottom where a diver would install bolts and tighten the flanges in place. This process had limitations because pipelines have gotten increasingly larger in diameter and the depths of these pipelines have gotten deeper, with platforms located in many thousands of feet (or metres) of water. Because of these and other issues, multiple suppliers in the current market manufacture end connectors that slip onto the end of a pipeline and are secured in place using a type of gripping mechanism (fig. 42).

Courtesy of Robert Sanchez

Figure 42. End connectors slip onto the end of a pipeline and are secured in place using a type of gripping mechanism.

Seals are then engaged. The newer pipelines have a flange on the end that can be connected to another end-connector-type flange. These types of repairs are considered permanent and can last for the lifetime of the pipeline system itself.

Split-sleeve repair clamps encapsulate the pipeline's failure point.

Another type of common repair on a pipeline failure is a hole in the pipeline. A hole might be caused by abrasives inside the pipeline while product is flowing, by external corrosion, or by external wear caused by the pipeline being in contact with foriegn objects. When an isolated area in the pipeline has failed, the quickest and most cost-effective repair is to install a *split-sleeve* repair clamp.

A split-sleeve repair clamp is a two-part clamp that uses sealing surfaces around the edges of the clamp to encapsulate the failure point on the pipeline. As the bolts along the seam of the clamps are tightened, the clamp seals are pressed against the pipeline and the leak is contained to the inside surface of the clamp. These types of split-sleeve clamps are quite common and are used to permanently repair the pipeline.

There are times when no catastrophic failure has occurred but the pipeline coating has been damaged, so the coating needs to be repaired. This repair is generally performed by wrapping the damaged area with an approved material such as a fiberglass and resin mixture. The area can also be covered with a sleeve and then injected with resin or grout. This process displaces the water and provides a barrier to the seawater.

Valve Maintenance

During the life of the pipeline system it might be necessary to perform general maintenance on subsea valves and assemblies. The typical valves used on subsea pipeline systems are ball valves, gate valves, and check valves. The general maintenance performed on valves by divers includes cycling the valves to allow movement of the components and greasing the moving components through the grease fittings located on the valves.

New Construction

Platform Installations

The placement of fixed platforms on the seabed must be precise. Most of the time, divers ensure the seabed is clear of debris and examine the final placement of the platform. The platform is set in the water by using a crane on a derrick barge. The diver guides the platform into position. The diver generally uses a well as a guide for the platform. The diver slides the *bell guide* of the platform over the top of the well. After the platform is sitting on bottom, the diver might have to open flooding valves located on each leg of the platform so that the platform legs will fill with seawater to position the platform in its final resting place. The diver might also visually inspect the platform after installation to ensure it has not been damaged during installation.

Pipeline Installations

Pipelines that carry product from the wellhead to shore or to other storage facilities are integral to the offshore oil and gas industry. Divers play a role in the installation of pipelines and the associated systems of manifolds and termination points.

> In shore-base pipeline laying, the pipe is simultaneously welded and spooled.

Pipe-lay barges use different methods to deploy pipelines to the seabed. The traditional method involves the process of welding joints of pipe together on the barge and then lowering the pipeline to the bottom off the stern of the barge as the barge is pulled forward by anchors or moved ahead by thrusters.

Another proven method for laying pipe uses shore bases in which pipe is welded together and simultaneously reeled onto a spool. After the spool has been filled to capacity with a length of pipeline, the spool is transferred to a barge and *spooled off* on location from one point to another. This method minimizes the length of time the barge stays offshore and lowers costs while minimizing other risks such as offshore weather impact. No matter which type of pipe laying is used, divers are a common part of the operation.

As the pipe is moved off the stern of the barge or vessel and lowered to the seafloor, it must be inspected for defects or damage that might have occurred during pipe laying. Another function of divers is to ensure that while being lowered to bottom the bend of the pipeline never exceeds the maximum bend radius that would damage the integrity of the pipeline. The diver makes this inspection traveling down the pipeline and taking depth readings at specific field joints on the line. Engineers can calculate the data and make a decision to increase or decrease the bend radius on the pipeline as necessary to maintain its integrity. ROVs can also carry out this process to inspect the pipeline if the water depths restrict the use of divers.

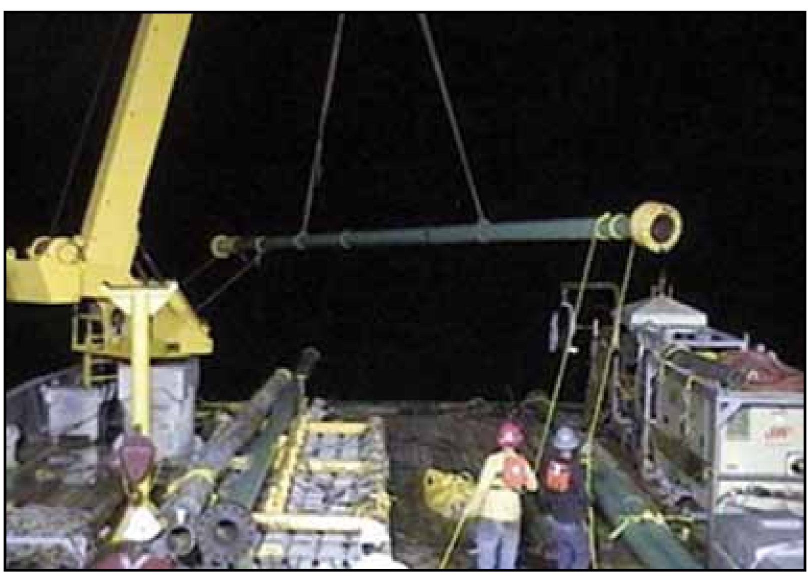
Pipeline Terminations

After the pipeline has been laid on bottom from one location to another, the next task is to terminate the ends of the pipeline to the platform, subsea wellhead, or another pipeline. This task is a primary role for the diver in the offshore environment.

When pipelines are laid on bottom, they can be placed in close proximity to the termination point, but ultimately the pipeline must be aligned and *spool pieces* must be built to connect the pipeline to the tie-in point (figs. 43 and 44). Divers use cranes and lift bags to move the pipeline to properly line up the end with the termination point.

Courtesy of Robert Sanchez

Figure 43. Preparing to launch pipeline spool piece down to diver



Courtesy of Robert Sanchez

Figure 44. Spool piece entering the water

Metrology jigs measure the end of the pipeline to its termination point.

After the pipeline has the proper orientation, the diver takes measurements from the end of the pipeline to the termination point by using a measuring device called *metrology jigs*. The angles on which the measurement wire attaches to both ends of the planned termination points and the length of the wire can be used to calculate dimensions for building spool pieces. A spool piece should fit properly between the two points and negate further field adjustments.

After the spool pieces have been fabricated onsite, the diver positions them in place and installs a type of gasket between the ends. Then, the diver installs the bolts and tightens them using a process that the operator determines. The historic method of tightening flanges involves using hand wrenches. The newer technique of using hydraulic impact wrenches allows the diver to draw the flanges together evenly (fig. 45).

Courtesy of Epic Diving and Marine Services LLC

Figure 45. Hydraulic impact wrenches draw the flanges together evenly.

The diver torques the bolts to the desired tension and measurement. If the client requires a more accurate torquing method, the diver can use a hydraulic torque wrench to achieve the desired tension one bolt at a time. Since the mid 1990s, a more efficient method has been used that simultaneously tensions all of the bolts at one time and allows the flanges to tighten evenly. This process is known as *bolt tensioning* and is a preferred method of tightening large-diameter flanges (fig. 46).

Bolt tensioning lets a diver tighten pipe bolts simultaneously.

Courtesy of Epic Diving and Marine Services LLC

Figure 46. Bolt tensioners tighten large-diameter flanges.

Points of Termination

Subsea pipelines have three main points of termination. All the connections generally made by pipelines underwater are flanged connections, and they use one of the tightening methods discussed in the section on Pipeline Terminations. The following sections focus on the *riser*, *subsea assembly*, and *hot tap* termination points.

Riser Connection

The riser is a common connection for pipelines. It consists of a predetermined bend in the pipeline by as much as 90 degrees from the seafloor. The bend, or tube turn, is used to redirect the pipeline to a vertical position and allows the pipeline to travel to the surface of the water. Additional sections of pipe are welded or flanged to the tube turn. The pipeline travels up the side of the platform or to a floating platform so that product can flow to or from the platform. Risers are usually installed in a clamp attached to the leg of the platform or supporting members within the structure. Risers used on deepwater structures are secured at the point where the riser enters the structure.

Subsea Assembly

Subsea manifolds consist of multiple valves and termination points that allow product flowing in a pipeline to be transferred to other pipelines within the subsea manifold assembly. Subsea manifolds are generally attached to a transmission line that accepts the product from many pipelines from multiple operators. The subsea manifold has ball valves that allow the diver to isolate pipelines for removal or repair and also check valves to control flow direction of the product in the pipelines. Subsea manifolds can be attached to taps in pipelines that were installed on the transmission pipeline during its construction. Or, hot taps can be used at a later time while the transmission line is operating.

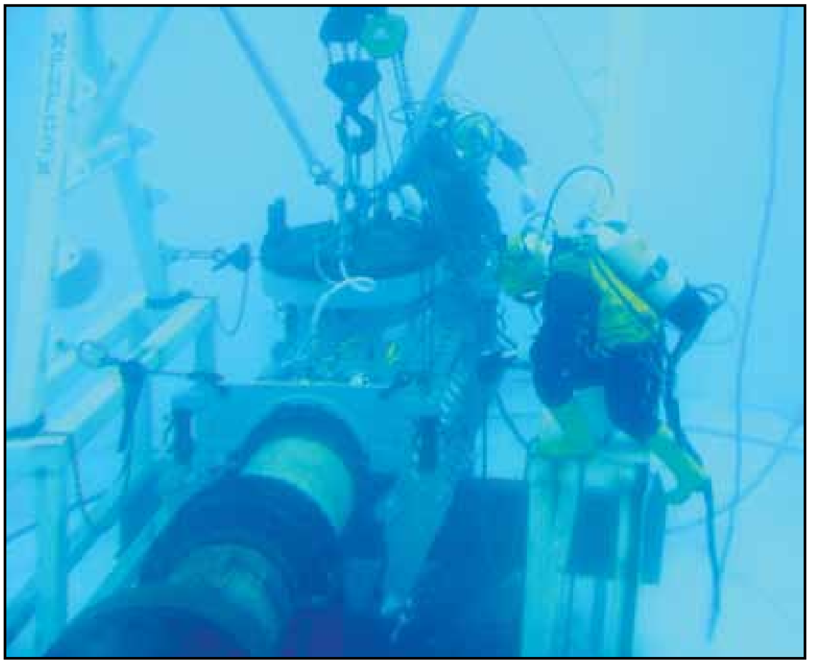
Hot Taps

Hot taps allow an operator to connect pipelines without stopping flow.

The use of mechanical hot taps on subsea pipelines became common practice in the early 1990s. The idea was to allow an operator to connect to an existing pipeline without having to stop the flow of product. The operator raises the pipeline to the surface and welds a side tap with a flange. After the operator sets the pipeline back on bottom, a diver can connect a new lateral pipeline segment to the existing system.

The process used to hot tap an existing pipeline is similar to the common end connector used to make pipeline repairs (figs. 47 and 48). A clamp is lowered over the pipeline to be tapped and tightened in place using bolts and a gripping mechanism to secure the tap. As the bolts are tightened, seals are compressed against the pipeline, creating an annulus within the clamp. After the annulus is pressure tested to ensure there are no leaks, a hydraulic drill is attached to a flanged port on the side of the tap.

The diver advances the drill to a predetermined depth, removes the drill, and then sends it to the surface for personnel to inspect and determine whether the hole was successfully cut by the drill. The personnel can verify this by using evidence from the sample pipeline cut. After the personnel verify that a successful cut was made, the diver attaches a subsea manifold, and secures the end of the pipeline to the manifold.



Courtesy of Subsea 7

Figure 47. New hot-tap technology in progress

Courtesy of Epic Diving and Marine Services LLC

Figure 48. Hot tap on deck

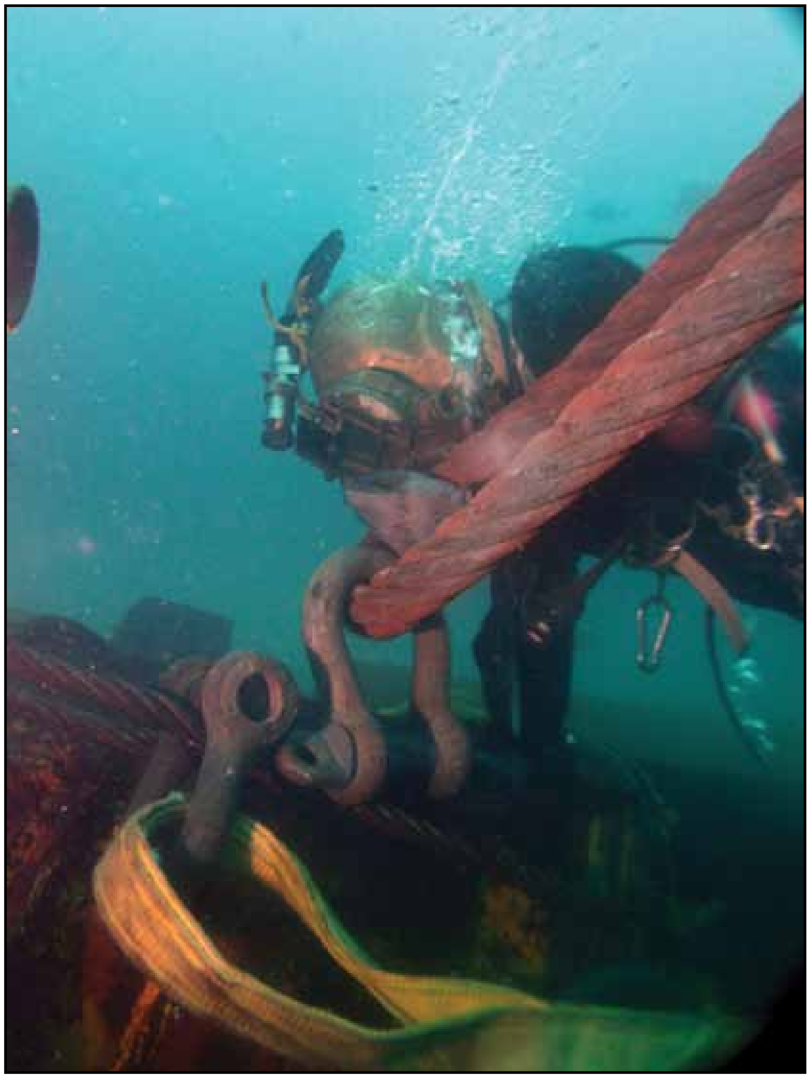
Three types of pipeline connections:
- Riser
- Subsea assembly
- Hot taps

Usually in any type of pipeline termination, the area is protected by being buried to a predetermined depth and then covered with sand bags or concrete mats. Concrete mats are used to more easily allow future access to the area to manipulate valves or inspect the area for damage.

Salvage and Removals

When a pipeline is inactive, divers free the platform from the seafloor and disconnect all pipelines.

After a platform or pipeline has exceeded its useful working life, certain measures must be taken to either remove the structure or plug and abandon the pipeline in place on the seafloor. Divers are used in these operations to free the platform from the seafloor and disconnect the pipelines in place on bottom (fig. 49).



Courtesy of Epic Diving and Marine Services LLC

Figure 49. This diver remains under water for long periods while rigging a derrick barge sling to a platform during a salvage project.

Platform Removals

A platform must be removed from its location offshore after the owner determines it has served its useful life. Typically, the platform is picked up from bottom and taken to shore to be scrapped or refurbished for sale or future use by its owner. Another option is to *reef* the platform by picking it up from its existing location and moving it to an approved area. After it is in the approved area, the platform is laid on the seafloor and becomes a habitat for marine life. No matter which method is used, divers can play a key role in removing the platform from its place of use.

The use of explosives to remove a platform is called underwater burning.

After the platform is slated for salvage, a derrick barge is sent to the location to perform the lift. Divers ensure that all pipelines are properly removed from the structure at the tube turn. They also inspect the area for any obstructions that can interfere with the platform being moved.

There are different methods for severing the piles of the platform from within the legs, but the most common is to either use an abrasive cutter inside the pile from the surface to cut the pile free or to use explosives. When explosives are used, they are lowered down inside the pile to the desired depth and detonated. It is common after detonation for divers to trim the bottom of the pile that was flared out beyond the circumference of the leg.

This task is done by using an *underwater burning package*, consisting of a hand torch with consumable alloy rods that are ignited with a combination of electricity and oxygen (fig. 50). After it is lit, the consumable rod burns at a temperature of 10,000°F or higher and easily cuts through the steel. After the flared piece of steel is cut free, the pile is pulled up through the leg on the surface.

Courtesy of Epic Diving and Marine Services LLC

Figure 50. Diver using underwater buring gear to cut a horizontal member on a platform

A diver might be used to attach the lifting rigging to the platform. Then, the crane on the barge lifts the platform off bottom. After the platform is removed from bottom, divers sweep the bottom for debris and remove it as required. After the site is determined to be clear of debris, the divers' work is complete.

Pipeline Abandonments

Federal and State regulations determine whether or not pipelines can be left on bottom after the owner of the pipeline has finished flowing product through them. If the pipeline is determined to be suitable to abandon in place, divers are called in for the job.

Before severing the pipeline, divers must flush it with a predetermined amount of seawater to remove any product that might be left from the transportation process. After the diver flushes the pipeline in a way that meets regulations, he or she chooses among many options to disconnect or sever the pipeline to accomplish abandonment.

One of the easiest methods is to disconnect the pipeline at a known flanged connection. This type of disconnect is usually done at the tube turn or riser, if it is being abandoned at an existing platform. Other common methods include using a circumferential pipe cutter or a reciprocating saw powered by either a hydraulic or air power source.

After the pipeline has been severed, the diver installs a plug in the end of the pipeline to remain on bottom and buries the pipe end to a predetermined depth. It is also quite common to place sand bags over the end to prevent it from being pulled off bottom by nets or anchors.

Downed Structures

When severe weather such as hurricanes move through an area in which offshore platforms and pipelines are located, the pipeline could be damaged or moved, or the platform could be toppled by a storm surge. If one of these events occurs, divers are called upon to help locate and remove the fallen structures.

Salvaging a downed structure is a slow-paced operation that follows a systematic procedure. Usually the structure still contains active wells and connected pipelines that contain product. Extreme care must be taken to plug and abandon the wells and pipelines while preventing any environmental impact from potential oil spills.

The first step in removing a downed structure is the inspection and assessment phase. This phase is done using divers and ROVs to develop a clear picture of how the structure is positioned on bottom and determine the procedure for plugging and abandoning the wells and pipelines and ultimately, removing the structure. After the assessment is complete, divers begin the *make-safe process* by removing parts of the structure from the shallowest portion downward to gain access to the wells and pipelines. The diver can use many different methods to remove sections of the platform during the make-safe phase.

For this process, everything from support members to buildings on the platform need to be removed. The diver uses cranes and rigging to bring loose pieces up to the surface. When sections of the platform need to be cut free, the diver decides how to do it.

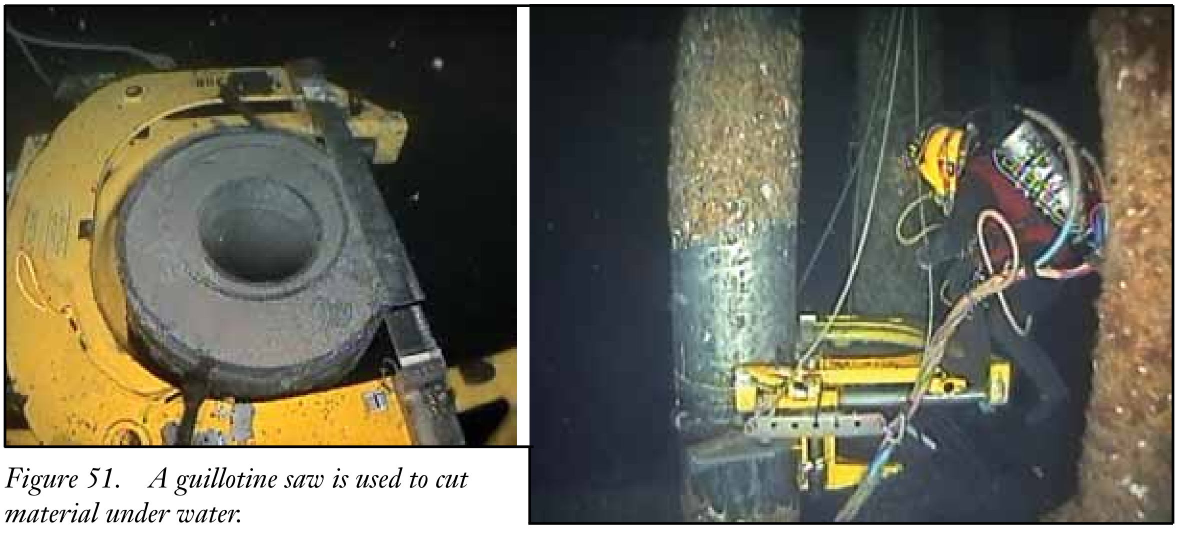
Historically, underwater burning was used to cut steel or concrete underwater. But as technology has improved and new tools have been developed, contractors have opted away from underwater burning because of its inherent risks. When burning underwater, excess oxygen not used during the burning along with hydrogen created during burning can collect behind the material being cut. If the trapped gas comes in contact with heat that the burning process produces, an explosion can occur that could injure or possibly kill a diver. Although certain safety measures are taken when a diver burns pipe underwater, some unknown risks cannot be engineered from the process. Therefore, safer methods of underwater cutting have been developed.

Newer methods of cutting objects underwater involve the use of different types of saws, lathes, and shears. The saws used are reciprocating saws or guillotine saws (fig. 51). Both types of saws use either hydraulic or air power to reciprocate the blade back and forth as the diver moves the blade through the steel.

Another type of saw being used is a diamond wire saw. Instead of a blade to cut through the steel, a diamond carbide wire roughly one-half inch in diameter is placed on the object and then rotated in a continuous loop pattern. Constant tension is applied to the wire, and the wire is pushed or pulled through the material to be cut.

Saws used to remove downed structures:

- Reciprocating saw
- Guillotine saw
- Diamond wire saw



COURTESY OF ROBERT SANCHEZ

Figure 51. A guillotine saw is used to cut material under water.

Other methods used to cut material under water are a lathe and hydraulic shears.

To cut a round surface, one might use an underwater lathe. For this method, a track is set up around the pipe to be cut, and the lathe is attached to the track. After the lathe is engaged, it travels on the track around the pipe and slowly advances the blade to shave deeper into the pipe until the cut is complete.

Yet another method to cut material underwater uses hydraulic shears. The shears are lowered around the object to be cut. After the shears are in place, the diver instructs the operator on the surface to engage the shears, then a strong hydraulic force begins to close the shears. The force of the closing shears cuts whatever is between the blades (fig. 52). This process works quickly as long as the material being cut does not need to be reused.

Courtesy of Robert Sanchez

Figure 52. Hydraulic shears

After the make-safe portion is complete, the diver begins the plug-and-abandon phase of the project:

- While the wells are being plugged and abandoned, hot tapping might be required to check for pressure or product before cutting the conductors and lifting them to the surface. If so, the same process of hot tapping is used as when hot tapping a pipeline. A clamp is set with seals and then a hole is drilled into the well.
- After it is determined that the well is safe to cut, the conductors are cut and brought up to the surface.
- Next, temporary wellheads are installed on the open well so that the plugging process can continue.
- Plug and abandonment crews lower hoses and other tools down to the diver who attaches them to the tree.
- The crew pumps cement into the well to create a plug and then uses explosives to separate the well below the seafloor.
- The remaining portion of the well is then brought up to the surface and taken to shore.
- The plug and abandonment process is done for the pipelines, and they are abandoned in place.

Make-safe operations and the hot tapping and plug and abandonment processes are repeated until all wells and conductors are removed, pipelines are flushed and abandoned, and only the frame of the platform remains. The platform is then salvaged to the surface and the area swept for debris. As with the platform removal process, not until the area is officially deemed cleaned can the project be called complete. Removing a downed structure is a slow process, and it can take months for one site to be completed.

In removing a platform, three steps must be performed:

- Make-safe operations
- Hot tapping
- Plug and abandon

Drilling Support

During exploration and drilling, divers assist drilling rig personnel in their daily routines. When drilling rig operations need to insert drill pipe and other tools into the well on the seafloor, divers are used on bottom to guide the pipe into the well. After the well is complete on bottom, divers can guide a net guard over the well to prevent the fishing nets and anchors from snagging. Divers also perform routine maintenance and inspections required on the drilling rig. Some of these processes are similar to the inspection and repairs performed on offshore platforms.

Underwater Cutting and Welding

In the past, cutting and joining pieces of metal was a major task for divers serving the oil and pipeline industries. This type of work can be performed under wet or dry conditions. Wet welding is the method used most often for salvage and emergency repair.

Wet Welding

SMAW requires the diver to use a stinger to manually provide filler metal for the weld.

Wet welding is done in a wet environment using special rods to increase weld strength and arc control. The process is as follows:

- An electric arc is maintained between the metal to be repaired and the coated electrode the diver-welder is holding. The arc vaporizes chemicals in the electrode coating, creating an inert gas pocket that protects and stabilizes the arc.
- The diver-welder then joins the pieces of metal together by lapping over or joining them in a V-shaped groove. Conditions in wet welding often create poor visibility, and the diver-welder might not see the arc that is only inches from his or her face. Fortunately, the groove acts as a guide, and through sense of touch, the diver can complete the job. Wet welding jobs depend heavily on a diver's sense of touch.

The wet welding method is a slow and expensive process (fig. 53). Even the most skilled wet welder finds that the wet method takes about four times longer than a similar job on land. Although the quality of wet welds has increased over the years, the finished product is still not the same quality as that of a dry weld. The surrounding water absorbs much of the heat and does not allow proper fusing of the two pieces of metal. Also, rapid cooling leads to brittleness of the welds.

Wet welding uses the *shielded metal arc welding process (SMAW)*, which is commonly referred to as *stick-welding*. The electrode is placed in a holder called a *stinger* and manually manipulated by the diver-welder. During the process, the electrode is consumed, which provides the filler metal for the weld.

Figure 53. Wet welding

The welding cable and stinger are insulated to prevent electric currents from entering the water.

The equipment used for wet welding is essentially the same as surface welding. A direct current (DC) welding generator set to reverse polarity provides the welding current. A knife switch that an operator controls topside allows the circuit to be opened or closed quickly and completely. The welding cable and stinger are specially insulated to prevent electrical current from escaping into the water. The electrodes are designed with waterproof coatings and fluxes. Wet welding was once considered inferior to surface welds, but advancements now allow good quality welds that are tested to recognized standards. To ensure control of the quality of welding and welders, it is normal practice to follow a code or specification. For example, the American Welding Societies Code D3.6M:1999 Specification for Underwater Welding is universally used for underwater welding projects.

Dry Hyperbaric Welding

> There are four classifications of ROVs:
> - Observation
> - Observation with payload option
> - Work-class vehicles
> - Towed or tracked vehicles

Dry hyperbaric welding is conducted at ambient pressure in a dry environment. This type of welding is achieved through the use of an *underwater welding habitat (UWH)*. The habitat is placed on the pipeline or structure being welding and then pumped dry. An umbilical from the surface provides the habitat with life support for the divers, power (electric and/or hydraulic), communications, and video. The diver has two methods of access to welding habitats:

- A dry transfer where the diving bell mates directly to the habitat
- A wet transfer, where the divers exit the bell and enter the habitat through a lock or an open bottom

There are three basic types of welding habitats:

- **A full-size welding habitat** allows the welder and equipment to work in a completely dry atmosphere. The habitat is pressurized with an appropriate gas mixture at ambient pressure. The diver-welders change from diving dress to welding clothes and wear full-face masks to provide breathing gases.
- **A mini-welding habitat** is a small chamber that encloses only the welding area and the upper portion of the diver's body. The water in the chamber is displaced by inert gas or air. The diver remains in wet diving dress and diving helmet.
- **A portable dry box welding habitat** encloses only the welding area. An inert gas displaces the water in the dry box. The box usually has windows, so the diver-welder can see his or her work. The diver-welder works in the water from outside the box and, wearing gloves that are constructed on the box, reaches into an opening on the bottom of the box.

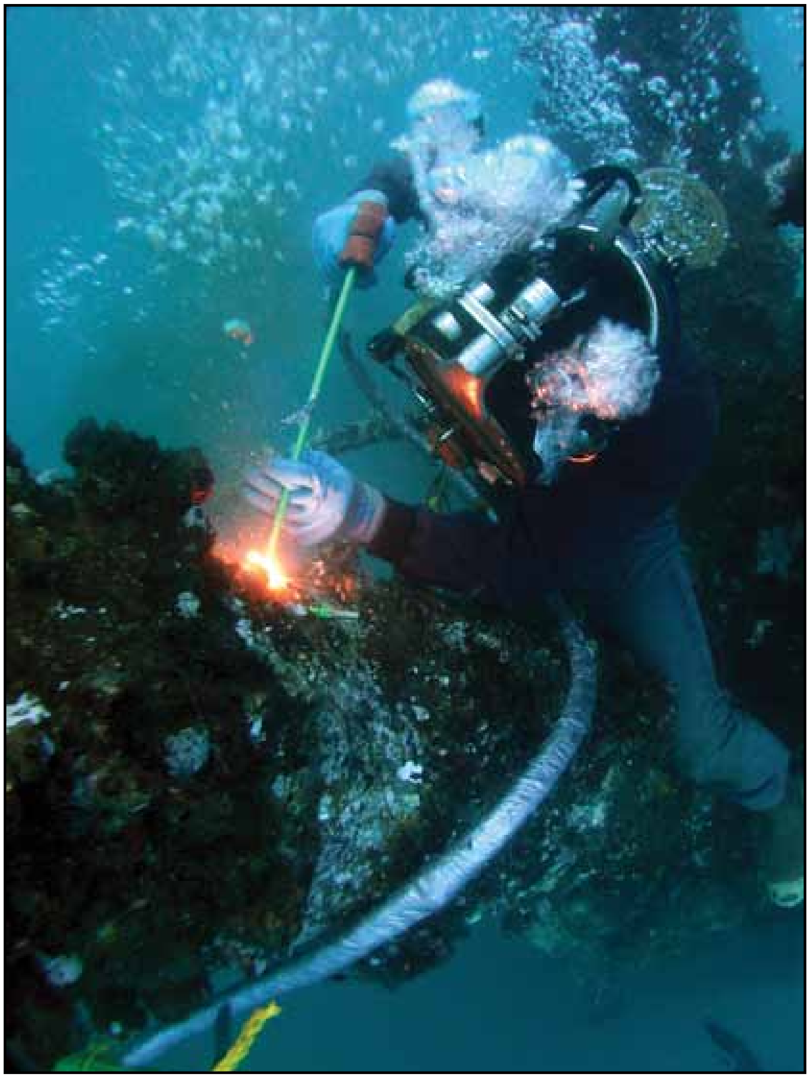
Two welding processes used in dry hyperbaric welding are the previously mentioned SMAW process and *gas-shielded arc welding*, commonly referred to as *Tungsten Inert Gas (TIG)* welding. This method involves an arc struck between a non-consumable tungsten electrode and the work piece. Filler metal is provided to the weld by a bare metal rod fed into the molten pool by the diver-welder.

Dry hyperbaric welding is not as common as it once was in the United States because of its high cost and extensive equipment requirements. Mechanical connectors for pipeline repair have become very reliable, cost effective, and easy to install, thereby eliminating the need for dry hyperbaric welding.

Underwater Burning

Underwater burning, called *oxy-arc cutting*, is a process where steel is cut using an electric arc, oxygen, and a *consumable rod*. This method of cutting can be very fast and precise when performed by a skilled diver (fig. 54).

Oxy-arc cutting uses:
- An electric arc
- Oxygen
- A consumable rod



Courtesy of Brian Derby

Figure 54. Underwater burning package

Oxy-arc cutting uses hydrogen, oxygen, and heat. If not performed properly, an explosion could occur.

The process of oxy-arc cutting involves creating rapid oxidation at very high temperatures between the electrode and base metal. The arc from the hollow electrode heats the steel, and a jet of oxygen blows away the molten metal. The problem with oxy-arc cutting is that hydrogen is liberated from the surrounding water by the electrolytic process. Hydrogen is an extremely combustible and unstable gas when allowed to collect in a void with unconsumed oxygen. This combination of pure hydrogen, oxygen, and heat can cause an explosion.

Many divers have been injured and killed by explosions caused by underwater burning. When underwater burning is used, the diver must ensure the work piece is vented so gases cannot collect. Gas pockets can form in mud pockets behind or under a work area, between steel and concrete, in annular spaces, under flat structures, in enclosed or tubular structures, and in very thick steel itself.

The equipment required for underwater burning consists of:

- DC welding generator
- Oxygen supply
- Knife switch
- Ground lead
- Umbilical, consisting of a 400-amp cable, oxygen hose, and cutting torch
- Cutting electrodes

Recently, the offshore diving industry has shifted away from *hot cutting* techniques (underwater burning) because of the extreme dangers presented if done incorrectly. Because of safety considerations, diving contractors now prefer to use *cold cutting* techniques. Cold cutting methods use saws, mills, or shears, as discussed earlier; however, cold cutting requires more equipment and longer setup time.

Nondestructive Testing

Any inspection method that does not destroy the item being tested is considered nondestructive testing (NDT). Visual, video, and photographic are all recognized methods of NDT but cannot always be relied on to detect defects. Many different procedures and instruments can be used in underwater NDT. The most common:

- Ultrasonic
- Magnetic particle inspection
- Cathodic potential probes

NDT requires that the diver have considerable skills in the procedure and experience in interpretation. Divers who perform NDT must be certified in the applications they are performing. Divers regularly perform NDT techniques during routine inspections of pipelines, production platforms, and drilling rigs to ensure compliance with government regulations. These techniques are used after storms or other events when damage can be expected.

Nondestructive testing uses the following inspection techniques:
- Visual
- Video
- Photographic

Ultrasonic Inspection

Ultrasonic (UT) inspection is primarily used for taking thickness readings of steel structures. High frequency sound waves are introduced to the metal by a diver-held transducer. The sound waves travel through the metal and bounce off the back wall. The instrument measures the time it takes to return to the transducer. The speed at which sound travels through the material is a constant, so the thickness can be determined. UT inspection can also be used underwater to identify whether structural members have been breached and flooded. UT inspection underwater also detects flaws in welds and parent metals. Flaw detection requires complex equipment and highly trained personnel topside to interpret the data.

Magnetic Particle Inspection

Magnetic particle inspection (MPI) is the technique used to detect flaws in welds or joints that cannot be seen by the naked eye. The weld is magnetized using an electromagnet and a slurry containing metal particles and fluorescent dye. The slurry is dispersed over the well in the magnetic field. Indications of flaws appear as the particles line up in the defect. The dye allows easy visual identification and photographic documentation. MPI is a highly reliable flaw-detection method if performed by a trained and certified, experienced diver.

Cathodic Protection Measurement

Cathodic potential (CP) probes or *bathycorrometers* are used to measure the deterioration of steel structures underwater. The meter measures the electrochemical potential of the steel structure against a *silver-silver chloride reference cell*. The information provided determines whether there is sufficient cathodic protection present on the structure, usually in the form of sacrificial anodes. CP meters can either be read by divers or the information can be transmitted to the surface for recording. These readings are quite easy to take, therefore minimal experience or training is required by the diver to perform them accurately.

To summarize—

- Commercial oilfield diving is a timely and complicated process. Divers often work alone with no communication with colleagues.
- The average oilfield diver is skilled in:
  - — Pipeline construction
  - — Platform and weld inspection
  - — NDT techniques
  - — Cathodic-protection systems
  - — Welding
- Diving platforms are constructed at the drill site. This is the diver's home base and also where pipelines are connected. The different platforms used are:
  - — vessels
  - — barges
- Vessels vary by pipeline specifications and include dive-support vessels, four-point anchor vessels, and dynamically positioned dive-support vessels.
- The four types of barges are:
  - — spud
  - — pipelay
  - — derrick
  - — lift boats
- To ensure the offshore platform and pipeline are working properly, surveys and inspections are performed. Fixed-platform inspections can be completed local and remotely from the pipeline.
- When a new platform is constructed, both the platform and the pipeline must be installed.
- When a pipeline is no longer active, the platform and pipeline must be terminated, salvaged, and removed. A pipeline can be repaired using underwater burning and nondestructive testing methods such as:
  - — ultrasonic
  - — magnetic
  - — cathodic potential (CP) meters

Diving Training

In this chapter:

- Practical and classroom training methods
- Processes to achieve further certification
- In-house training and advanced education

Formal commercial diver training in the United States is offered by nationally accredited vocational schools. Dive School students receive classroom and practical training in commercial diving procedures and techniques during training. This training includes both classroom and practical education.

Proper diver training focuses on:

- Diving physics
- Diving physiology
- Decompression tables
- Industrial and offshore safety
- Diving medicine

After a student understands the science and fundamentals of commercial diving, the education moves to the practical training so that the student can gain experience with the equipment and apply classroom knowledge. Practical training includes:

- Hyperbaric chamber operations
- Rigging
- Seamanship
- Diving equipment, maintenance, and function

Formal commercial diving instruction occurs in both practical and classroom forums.

- Underwater work
- Underwater tools
- Cutting and welding
- Other related topics

The training standard that reputable schools adhere to is the American National Standards Institute Standard for Commercial Diver Training (ANSI/ACDE-01-2009), developed by the Association of Commercial Diving Educators (ACDE).

In its attempt to foster quality vocational training, the ACDE developed standards-based qualifications that focus on competence in the workplace. This standard issues a certificate based on competence rather than merely completion of coursework. Competence is determined through written assessments; evaluation; diving logs; and trainee performance, attitude, and aptitude to conduct underwater work. Upon completing 625 hours of formal instruction and being deemed competent, the student is qualified as an entry-level commercial diver. In the offshore industry, this level of experience and training is often referred to as a *tender* or diver tender. Advancement beyond the designation of diver tender requires participation in commercial diving operations and demonstrated proficiency during working dives (fig. 55).

The diver tender generally works with his or her achieved skill set for an average period of two years, whereby the tender learns the safe operations and practices associated with the specific diving industry in which the individual will work. The tender performs a number of dives to become proficient in his or her skills and learn the common surface practices that support diving operations. After the tender has fulfilled the "apprenticeship" required to obtain the required skills to function in and out of the water, the tender is promoted to diver in a process known as *breaking out*. After becoming a full-fledged commercial diver, he or she begins diving as part of daily diving operations and begins training new tenders that have moved into place.

The Association of Diving Contractors International (ADCI) issues Diver Certification Cards based on field experience and proficiency. After a diver has accrued the required number of field days and working dives, he or she may submit a signed and verified diver's log book to his or her company to apply for a Surface-Supplied Air, Mixed-Gas Diver, or Bell/Saturation Diver Certification Card. Divers learn many skills and techniques through a combination of on-the-job training and company in-house training classes.

Once certified, a diver can receive more education and further certification on:

- Tenders
- Breaking out
- Surface-supplied air, mixed-gas diving, and bell diving

Courtesy of Brian Derby

Figure 55. Grit blasting a weld for inspection requires specialized training and certifications.

In-House Training

> Advancements in the trade require extensive training, often provided inhouse.

To ensure a safety-conscious and skilled workforce and to comply with industry standards, diving contractors offer highly technical and comprehensive training programs. It is commonplace in the offshore diving industry to require a good diver to be a "jack of all trades." Diving contractors know this, and clients expect the divers they hire to be proficient in the tasks to be performed. Advancement in the trade requires that divers be trained in an extensive and varied list of skills, tools, and techniques.

Company training programs in environmental health and safety (ESH) are mandatory for all levels of personnel on an annual basis. First aid and CPR along with water survival are also mandated certifications that must be conducted regularly. Companies often perform project-specific training if new techniques or tools will be used. Today's commercial diver is more of a diving technician than the underwater laborer of the past.

There are several types of common in-house training programs. The full list of training and certification requirements offered by diving contractors is too lengthy to appear here, but a brief list of common company training programs follows.

Diver Medic

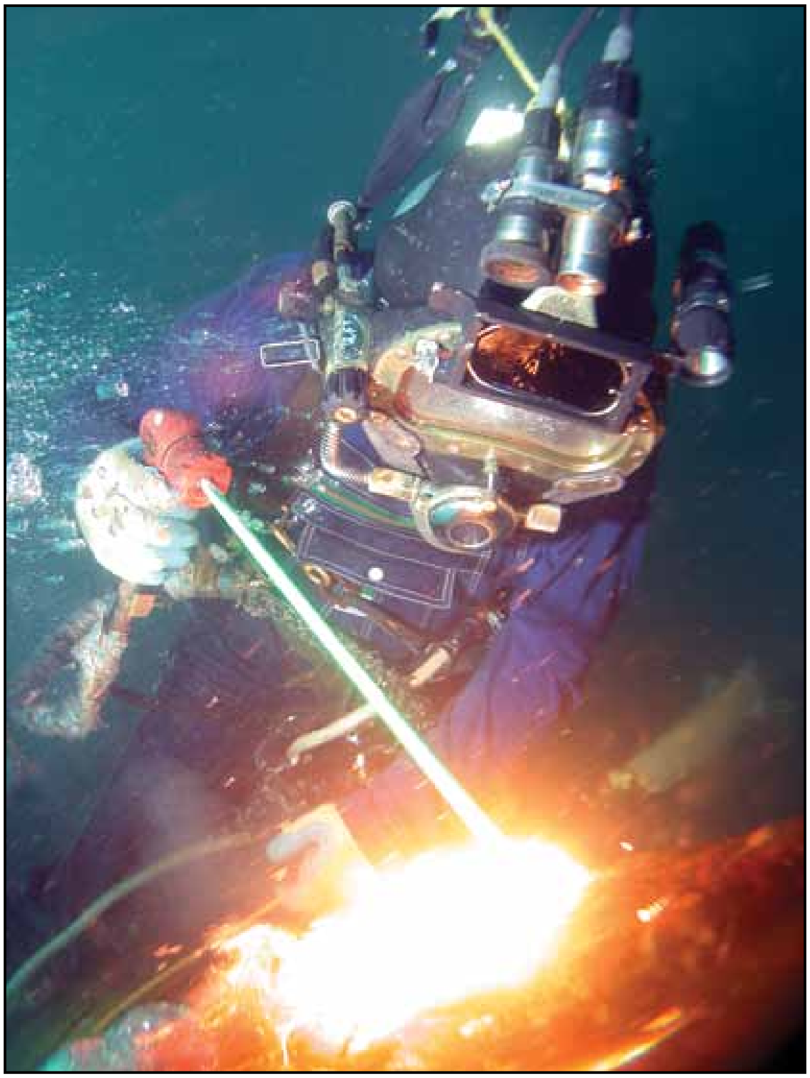
A *diver medic (DMT)* is a highly trained and nationally certified medical technician, who specializes in diving and hyperbaric-related maladies and emergency medicine.

Nondestructive Testing

Divers must be nationally certified to perform underwater NDT techniques that include magnetic particle testing and ultrasonic testing. These tests measure wall thickness of steel pipe and other structural members to detect discontinuities and identify flooded members on structures.

Underwater Welding and Cutting

Divers who perform wet or dry welding must be trained and tested to a formal standard. Underwater cutting requires a high degree of technical proficiency to be performed safely, and companies train and test for this in-house (fig. 56).



Courtesy of Brian Derby

Figure 56. Diver starting underwater cut using exothermic burning rods

Rigging

Dive companies have to train and test divers to a nationally recognized standard for proper and safe rigging techniques (fig. 57).

Courtesy of Epic Diving and Marine Services LLC

Figure 57. Rigging

Life Support Technician

LSTs are trained extensively in the mixing and handling of gases and techniques for hyperbaric life support. They must fulfill classroom and field experience requirements and take assessments to be certified through the ADCI.

Diving Supervisor

In addition to other requirements, dive supervisors must also take written tests and qualify through minimum standards and experience. The three different levels of diving supervisor require further training and assessment. Surface-Supplied Air Diving Supervisor, Mixed-Gas Diving Supervisor, and Bell/Saturation Supervisor certification cards are issued by the ADCI after candidates fulfill the necessary requirements.

To summarize—

- In classroom diving, instruction includes:
  - diving physics
  - diving physiology
  - decompression tables
  - industrial and offshore safety
  - diving medicine
- Practical training involves:
  - hyperbaric chamber operations
  - rigging
  - seamanship
  - diving equipment, maintenance, and function
  - underwater work and tools
  - cutting and welding
- Dive instructors must train divers by nationally recognized techniques.

Diving Regulations and Standards

In this chapter:

- Federal agencies and organizations that regulate divers
- Privatized organizations that regulate divers

Inland and offshore commercial diving operations are federally regulated in the United States by two agencies:

- The United States Coast Guard (USCG) regulates offshore diving.
- The Occupation Safety and Health Administration (OSHA) governs inland and coastal diving operations.

These agencies reflect the minimum mandated standards, are similar in content, and often identical. They outline minimum requirements for personnel, equipment, operations, diving mode procedures, testing and inspections of diving equipment, and recordkeeping.

- The USCG Regulation is titled 46 CFR Part 197 Subchapter V-Marine Occupational Safety and Health Standards Subpart B-Commercial Diving Operations. CFR 197 applies to commercial diving operations taking place on the outer continental shelf or from vessels required to have a certificate of inspection issued by the USCG such as mobile offshore drilling units (MODUs). This regulation excludes any diving operation solely for scientific research, public safety, and search and rescue.
- OSHA's 29 CFR Part 1910, Subpart T Commercial Diving Standard is generally applied to inland diving operations.

Organizations that regulate diving:
- OSHA
- ADCI
- ANSI
- USCG
- IMO
- NB23
- IMCA

Generally, commercial oilfield diving operations are governed under the USCG regulations.

- The Association of Diving Contractors International (ADCI) is an organization of commercial diving contractors and associated companies that promotes the safety of commercial divers and other personnel involved in underwater work. It has published the *Consensus Standards for Commercial Diving Operations* as a supplement for government regulations and safe practices for diving operations. The ADCI standards reflect a collective operating philosophy of the member companies. It meets or exceeds the current U.S. federal regulations and adheres to industry standards and practices that are acknowledged as minimum standards that all diving operations should use in performing work.

Several other organizations have regulations that apply to commercial diving and diving equipment:

Diving Chambers or Pressure Vessels for Human Occupancy (PVHO) are regulated by industry, national, and international standards and regulations. Much of the equipment used in commercial diving is specialized and rules have been generated to mitigate risk and improve safety. Any person carrying out offshore diving operations should establish whether there are any national regulations that apply in the area where diving will take place, remembering that a number of countries have regulations that apply to diving taking place anywhere in the world from vessels registered in that country (the flag state).

There may also be international regulations, codes or standards that diving contractors have to comply with. The following list is an example of the most common organizations and standards encountered when planning and executing a diving project.

- ANSI—ASME/PVHO-1 Safety Standard for Pressure Vessels for Human Occupancy
- Association of Diving Contractors International (ADCI) Consensus Standards for Commercial Diving Operations
- United States Coast Guard (USCG) 46 CFR Part 197 USCG rules for Commercial Diving Operations
- Occupational Safety and Health Administration (OSHA) 1910 OSHA rules for Commercial Diving

- IMO (International Maritime Organization) Code of Safety for Diving Systems a.536(13)
  - IACS (International Association of Classing Societies)
  - ABS (American Bureau of Shipping)
  - DNV (Det Norske Veritas)
  - Lloyds Registry
  - Bureau Veritas (BV)
  - Germanischer Lloyd (GL)
- National Board of Boiler and Pressure Vessel Inspectors ANSI-NB23
- IMCA (Internation Marine Contractors Association) Internation Code of Practice for Offshore Diving

---

To summarize—

- The two federal agencies regulating divers are:
  - United States Coast Guard—governs offshore divers
  - OSHA—regulates inland coastal diving operations
- Several different organizations exist to protect the standards of diving, including the Association of Diving Contractors and Pressure Vessels for Human Occupancy.

Appendix

Figure Credits

All images are copyrighted and may not be reprinted, reproduced, or used in any way without the express written permission of the owner.

Figure	Owner	Web site
Cover Grit blasting	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
Inside Wet bell	Photo by Brian Derby	www.epiccompanies.com
1 The first design of compressed air tanks was introduced by W.H. James of England in 1825.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
2 Futuristic underwater workstations such as this one were conceptualized in the 1960s and 1970s.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
3 Working environments for a a diver are usually between 45°F and 60°F.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
4 The absorption of light rays by water.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
5 Intelligibility tests run with helium unscramblers.	The University of Texas at Austin, PETEX	www.utexas.edu/ce/petex
6 Diver preparing to enter the water from a barge	Photo by Robert Sanchez	www.epiccompanies.com
7 While working deep under water, human tissues are sensitive to increased pressures.	Photo by Robert Sanchez	www.epiccompanies.com
8 Diver entering deck chamber for surface decompression	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
9 Diver preparing for dive	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com

Figure		Owner	Web site
10	Dressing diver on the surface	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
11	Two-diver communications unit	Copyright © Amron Internatl. All rights reserved.	www.amronintl.com
12	Divers umbilical providing breathing gas, video, and communications support while setting down line to send and receive tools from topside.	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
13	Chambers such as these are used offshore during diving operations for surface decompression and recompression treatment.	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
14	Diving stage	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
15	Mixed-gas diving control panel operator in dive control van	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
16	Wet bell	Photo by Brian Derby	www.epiccompanies.com
17	Portable saturation diving system	Photo by Robert Sanchez	www.epiccompanies.com
18	Saturation diving controls	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
19	Diving bell locked on trunking	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
20	Diving bell in use	Photo by Robert Sanchez	www.epiccompanies.com
21	Saturation diving control console	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
22	Inside living area of a saturation diving system	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
23	Diver exiting deck chamber	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
24	Hyberbaric rescue chamber	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
25	Today, advances in camera capabilities allow divers to capture details of work performed deep under water.	Photo by Brian Derby	www.epiccompanies.com

Figure		Owner	Web site
26	A remotely operated vehicle (ROV) with headlights on and samplers begins its descent.	Public Domain. 2007:Exploring the Inner Space of the Celebes Sea, National Oceanic and Atmospheric Administration (NOAA)	www.oceanexplorer.noaa.gov
27	Divers often work in tandem with ROVs in a variety of subsurface research projects.	Copyright © Canada Space Agency. All rights reserved.	www. asc-csa.gc.ca
28	Diver removing marine growth from a node with a rig axe to prepare for visual inspection.	Photo by Brian Derby	www.epiccompanies.com
29	Construction and repair work requires long periods deep under water.	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
30	Utility DSV	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
31	Four-point anchor vessel	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
32	Dynamically positioned dive support vessel	Copyright © Adams Offshore. All rights reserved.	www.adamsoffshore.net
33	Spud barge	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
34	A pipelay barge held by a dynamic positioning system	Copyright © Gulfstream Natural Gas System, LLC. All rights reserved.	www.gulfstreamgas.com
35	Two views of jet sled dredging gear lowered on top of the pipe-line used to help excavate the soil from around the pipeline	Copyright © Epic Diving and Marine Services LLC *also* Photo by Brian Derby	www.epiccompanies.com
36	Derrick barge used for installing or removing offshore platforms	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
37	Derrick barge lifting with portion of platform (surface-gas diving equipment in background)	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
38	Typical crane block to perform lifts on a derrick barge	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
39a	Lift boats are self-powered.	Photo by Brian Derby	www.epiccompanies.com
39b	Lift boats provide a stable platform in water.	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com

Figure		Owner	Web site
40	Diver preparing for magnetic particle testing of a weld on a node	Photo by Brian Derby	www.epiccompanies.com
41	Concrete mats	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
42	End connectors slip onto the end of a pipeline and are secured in place using a type of gripping mechanism.	Photo by Robert Sanchez	www.epiccompanies.com
43	Preparing to launch pipeline spool piece down to diver	Photo by Robert Sanchez	www.epiccompanies.com
44	Spool piece entering the water	Photo by Robert Sanchez	www.epiccompanies.com
45	Hydraulic impact wrenches draw the flanges together evenly.	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
46	Bolt tensioners tighten large-diameter flanges.	Photo by Robert Sanchez	www.epiccompanies.com
47	New hot-tap technology in progress	Copyright © Subsea 7. All rights reserveed.	www.subsea7.com
48	Hot tap on deck	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
49	This diver remains under water	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
50	This diver remains underwater for long periods while rigging a derrick barge sling to a platform during a salvage project.	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com
51	Diver using underwater buring gear to cut a horizontal member on a platform.	Photo by Brian Derby	www.epiccompanies.com
52	A guillotine saw is used to cut material under water.	Photo by Robert Sanchez	www.epiccompanies.com
53	Hydraulic shears	Photo by Robert Sanchez	www.epiccompanies.com
54	Wet welding	Photo by Robert Sanchez	www.epiccompanies.com
55	Underwater burning package	Photo by Brian Derby	www.epiccompanies.com
56	Grit blasting a weld for inspection requires specialized training and certifications.	Photo by Brian Derby	www.epiccompanies.com
57	Diver starting underwater cut using exothermic burning rods.	Photo by Brian Derby	www.epiccompanies.com
58	Rigging	Copyright © Epic Diving and Marine Services LLC. All rights reserved.	www.epiccompanies.com

Glossary

▼
▼
▼

A

absolute pressure *n*: total pressure measured from an absolute vacuum. It equals the sum of the gauge pressure and the atmospheric pressure. Expressed in pounds per square inch.

ACFM (acfm) *abbr*: actual cubic feet per minute. Refers to the actual volume of gas supplied to a diver, bell, etc. at ambient pressure.

air diving *n*: diving in which a diver uses a normal atmospheric mixture of oxygen and nitrogen as a breathing medium. It is limited to depths less than 190 feet (58 metres) because of the dangers of nitrogen narcosis; however, dives with bottom times of 30 minutes or less may be conducted to a maximum of 220 feet (67 metres).

ambient pressure *n:* the surrounding pressure at depth (actual or simulated, in a hyperbaric chamber) to which the diver, bell, etc. is subjected.

atmosphere (atm) *n*: a unit of pressure equal to the atmospheric pressure at sea level, 14.7 pounds per square inch (101.325 kilopascals).

atmospheres absolute *n pl*: total pressure at a depth underwater, expressed as multiples of normal atmospheric pressure.

atmospheric pressure *n*: the pressure exerted by the weight of the atmosphere. At sea level, the pressure is approximately 14.7 pounds per square inch (101 kilopascals), often referred to as 1 atmosphere. Also called barometric pressure.

B

bell *n:* an enclosed compartment, pressurized (closed bell) or un-pressurized (open bell), which allows the diver to be transported to and from the underwater work area and which may be used as a temporary refuge during diving operations. A Class-I bell is an open bell. A Class-II bell is fitted with a lower hatch and can be closed.

bends *n*: a highly painful and potentially fatal condition in which air or other breathable gases come out of solution in the bloodstream and cause distress or death. So named because the bending joints of the body are most often affected. Also called decompression sickness. See *decompression sickness.*

BIBS *abbr:* built-in breathing system. A breathing gas system built into all deck chambers and SDC's by which emergency breathing gas or a treatment gas can be supplied to the diver through an oral-nasal mask or hood.

bottom time *n*: the total amount of time, measured in minutes, from the time a diver leaves the surface until he or she begins the ascent. Also called working time.

bounce dive *n*: a rapid dive with a very short bottom time to minimize decompression time.

breathing bag *n*: part of the semi-closed circuit breathing apparatus, used to mix gas and ensure low breathing resistance.

breathing system *n*: device or apparatus for delivering respirable breathing mixture.

bursting pressure *n:* the pressure at which a pressure containment device would fail structurally.

buoyancy *n*: the apparent loss of weight of an object immersed in a fluid. If the object is floating, the immersed portion displaces a volume of fluid the weight of which is equal to the weight of the object.

C

carbon dioxide excess *n*: see *hypercapnia*.

Certified Commercial Diver *n:* an individual who has applied for and been awarded a certification card or other document recognized to reflect the formal training, field experience, on-the-job performance, and capabilities, of the individual.

closed circuit *n*: 1. a life-support system in which the gas is recycled continually while the carbon dioxide is removed and oxygen added periodically. 2. a television installation in which the signal is transmitted by wire to a limited number of receivers.

CNS *abbr:* central nervous system.

compressor *n*: a machine that raises air or other gases to a pressure above one atmosphere.

cylinder *n:* a pressure vessel for the storage of gases.

D

DDC *abbr*: deck decompression chamber.

deck decompression chamber (DDC) *n*: a chamber in which excessive pressure can gradually be reduced to atmospheric pressure. It is especially equipped to help divers complete their decompression schedules and may also be used to treat diving casualties. One or more of the compartments may be installed on the deck of a work boat or barge.

decompression *n*: releasing from pressure or compression following a specific decompression table or procedure during ascent; ascending in the water or experiencing decreasing pressure in the chamber.

decompression schedule *n:* a time-depth profile with a specific bottom time and depth, whose application is calculated to reduce the pressure on a diver safely.

decompression sickness *n*: a condition resulting from the formation of gas bubbles in a diver's blood or tissues during ascent. Failure to rid tissues of the inert gas may cause a wide variety of symptoms, including pain, nausea, paralysis, unconsciousness, temporary blindness, and even death. Also called the bends.

decompression table *n*: a set of decompression schedules computed on a common protocol.

deepsea dress *n*: see *standard dress.*

demand regulator *n*: the part of the open-circuit diving system that allows a diver to expel all used air directly into the water and avoid rebreathing exhaled carbon dioxide. The regulator reduces the air pressure in the tanks to a diver's ambient pressure so that he or she can breathe the air with no resistance. Also called open-circuit regulator.

density *n*: the mass or weight of a substance per unit volume. For instance, the density of a drilling mud may be 10 pounds per gallon, 74.8 pounds/cubic foot, or 1,198 kilograms/cubic metre. Specific gravity, relative density, and API gravity are other units of density.

depth *n*: 1. the distance to which a well is drilled, stipulated in a drilling contract as contract depth. Total depth is the depth after drilling is finished. 2. on offshore drilling rigs, the distance from the baseline of a rig or ship to the uppermost continuous deck. 3. the maximum pressure that a diver attains during a dive, expressed in feet (metres) of seawater.

diffusion *n*: 1. the spontaneous movement and scattering of particles of liquids, gases, or solids. 2. the migration of dissolved substances from an area of high concentration to an area of low concentration.

diver-carried reserve breathing gas *n*: a diver-carried supply of air or mixed gas to allow the diver to reach the surface, or another source of breathing gas, or to be reached by a stand-by-diver. Also called EGS (Emergency Gas Supply) or Bail Out Bottle.

diver-worn equipment *n*: that equipment required for the safety and well-being of the diver, worn or attached to the diver while underwater.

dive station *n*: the site from which diving operations are directly controlled. This site shall also include any auxiliary or peripheral equipment necessary to the conduct of the diving operation.

diving bell *n*: a cylindrical or spherical compartment used to transport a diver or dive team to and from an underwater work site. (see *bell* and *submersible decompression chamber*, *SDC*.)

diving operations *n*: any work operation requiring some type of diving or work underwater that involves planned human exposure to increased pressures to perform the job.

dive supervisor *n*: the dive supervisor, or designated dive superintendent, having complete responsibility for the safety of the diving operation including the responsibility for the safety and health of all diving personnel.

drilling rig *n*: see *rig*.

dry suit *n*: a diving suit designed to exclude water from the surface of the body.

dry welding *n*: arc, gas, or plasma welding performed in an underwater habitat with a gas environment at ambient pressure.

F

face mask *n*: a mask made of a rubber frame surrounding a clear, flat lens used, to seal all or a portion of a diver's face from the underwater environment.

fathom *n*: a measure of ocean depth equal to 6 feet or 2 metres.

fins *n*: semi-rigid, paddlelike extensions worn on the feet to increase propulsion power while swimming.

flotation vest *n*: most commonly by sport divers to overcome the buoyancy effect of water and keep them afloat in the proper position. Carbon dioxide cartridges inside the vest are fired when inflation is necessary.

free air space *n*: any of the cavities in the human body that contain air and are normally connected to the atmosphere, including lungs, sinuses, and middle ear.

FSW (fsw) *abbr:* a foot of seawater 1. A unit of pressure at sea level generally defined as representing the pressure exerted by a foot of seawater having a specific gravity of 1.027, and is equal to approximately 0.445 pounds per square inch.

G

gas embolism *n:* a condition caused by expanding gases which have been taken into and retained in the lungs while breathing under pressure, being forced into the bloodstream or other tissues during ascent or decompression.

gauge pressure *n*: 1. the amount of pressure exerted on the interior walls of a vessel by the fluid contained in it (as indicated by a pressure gauge). It is expressed in pounds per square inch gauge or in kilopascals. Gauge pressure plus atmospheric pressure equals absolute pressure. 2. pressure measured relative to atmospheric pressure considered as zero.

H

harness *n*: the combination of straps and fasteners used to attach equipment and umbilical to the diver which can be utilized as a lifting point to remove the diver from the water in the event of an emergency.

helium unscrambler *n*: an electronic device designed to render intelligible the words spoken in a helium hyperbaric environment. Also called *unscrambler*, *speech unscrambler*.

helmet *n*: a protective enclosure for a diver's entire head. It is part of the lifesupport system and also contains a communications system.

high-pressure nervous syndrome(HPNS) *n*: a group of symptoms including a lack of coordination, tremors of the extremities, disorientation, nausea, dizziness, and brief lapses of consciousness occurring at depths of 500 feet (152 metres) or deeper.

HPNS *abbr*: high-pressure nervous syndrome.

hypercapnia *n*: excessive amount of carbon dioxide in the blood, often resulting from an excessive carbon dioxide partial pressure in a diver's breathing supply. Also called carbon dioxide excess.

hypothermia *n*: profound loss of body heat.

I

inert gas *n*: the part of a breathing medium, such as helium, that serves as a transport for oxygen and is not used by the body as a life-support agent. Its purpose is to dilute the flow of oxygen to the lungs, thereby preventing oxygen toxicity.

L

lifeline *n*: a line attached to a diver's helmet by which he or she is lowered and raised in the water.

life-support technician (LST) *n*: responsible for safe operation of hyperbaric system chambers who reports to Diving Supervisor. *LST/Rack Operator*.

lightweight gear *n*: all diving equipment less complex than the standard dress. This equipment employs face masks or helmets, protective clothing, and swim fins or boots.

liveboating *n*: the practice of supporting a diver from a vessel which is underway.

M

Master *n*: normally considered to be the Person in Charge of a marine vessel.

M.A.W.P. *abbr:* Maximum Allowable Working Pressure.

Maximum Working Pressure *n:* the maximum pressure to which a pressure containment device can be exposed under operating conditions (usually the pressure setting of the pressure relief device).

mixed-gas diving *n:* a diving technique in which the diver is supplied with a gas mixture other than air for respiration.

N

niggles *n:* a general feeling of itchiness or sensation of skin irritation related to decompression sickness.

nitrogen narcosis *n*: the intoxicating or narcotic effect of gaseous nitrogen experienced by a diver breathing air at greater than 100 feet (30 metres) of depth. The effect increases with depth, impairing a diver's ability to think and act effectively.

no-decompression diving *n:* diving which involves depths and times shallow and short enough so that the ascent can be made to the surface without water stops or subsequent chamber decompression.

O

open-circuit diving system *n*: a diving lifesupport system in which the diver's exhalation is vented completely to the water

opencircuit regulator *n*: see *demand regulator.*

overbottom pressure *n:* that pressure above ambient, at which a breathing gas supply must be supplied to the helmet/mask so that the diver will have a sufficient supply of gas.

oxygen toxicity *n:* a medical emergency resulting in convulsions and unconsciousness if gone unchecked; caused by breathing a high partial pressure of oxygen under pressure.

P

partial pressure *n:* that portion of the total gas pressure exerted by a particular constituent of the breathing mixture.

person in charge (PIC) *n:* in relation to the craft/barge/structure, includes the captain or any other person made responsible by the owner for the vessel or facility, its operation, and the safety, health, and welfare of those on board.

pneumofathometer *n:* a depth measuring device consisting of an open-end hose fixed to the diver, with the surface end connected to a gas supply and pressure gauge (usually marked in fsw). Gauge measures pressure required to discharge water to depth of diver. Also known as kluge, pneumo.

pressure *n*: the force that a fluid (liquid or gas) exerts uniformly in all directions within a vessel, pipe, hole in the ground, and so forth, such as that exerted against the inner wall of a tank or that exerted on the bottom of the wellbore by a fluid. Pressure is expressed in terms of force exerted per unit of area, as pounds per square inch or in kilopascals.

pressurize *v*: to increase the internal pressure of a closed vessel.

psi *abbr:* pounds per square inch. An expression of pressure, for example, one atmosphere equals 14.7 psi.

psia *abbr*: pounds per square inch absolute. See *absolute pressure*.

psig *abbr*: pounds per square inch gauge.

PVHO *abbr:* Pressure Vessel for Human Occupancy. see *deck decompression chamber*.

R

recompression *n*: increasing the ambient pressure on a diver for the primary purpose of treating decompression sickness.

recompression chamber *n*: see *deck decompression chamber*.

refracted *n*: deflected from a straight path undergone by a light ray or energy wave in passing from one medium to another in which the wave velocity is different, such as the bending of light rays when passing from air into water.

rig *n*: the derrick or mast, drawworks, and attendant surface equipment of a drilling or workover unit.

S

saturation *n*: a state of being filled or permeated to capacity. Sometimes used to mean the degree or percentage of saturation (e.g., the saturation of the pore space in a formation or the saturation of gas in a liquid, both in reality meaning the extent of saturation).

saturation diving *n:* procedures in accordance with which a diver is continuously subjected to an ambient pressure greater than atmospheric pressure so that his body tissues and blood become saturated with the constituent elements of the breathing gas. Once the diver's body becomes saturated, he can remain within a specified zone for an unlimited time without incurring any additional decompression obligation.

scrubber *n*: 1. a vessel through which fluids are passed to remove dirt, other foreign matter, or an undesired component of the fluid. 2. a unit that removes carbon dioxide from the diver's breathing medium by chemical absorption.

scuba *n*: self-contained underwater breathing apparatus.

SDC *abbr:* a submersible decompression chamber. A pressurized bell in which the divers can be transferred to the underwater work site and return to the surface under pressure.

seafloor *n*: the bottom of the ocean; the seabed.

semi-closed circuit *n*: a diving lifesupport system in which the gas is partially vented and the remainder is recycled, purified, and reoxygenated.

specific heat *n*: the amount of heat required to cause a unit increase in temperature in a unit mass of a substance, expressed as numerically equal to the number of calories needed to raise the temperature of 1 gram of a substance by 1°C.

squeeze *n:* a lack of equalization between parts of the body or between the body and equipment. Extreme cases can cause severe injury or death.

standard dress *n*: diving equipment consisting of brass diving helmet, breastplate, heavy dry suit, weighted boots, weighted belt, hose, compressor, and communications.

standby diver *n:* another qualified diver at the dive location who in a state of readiness to go to the assistance of the diver in the water.

surface decompression *n*: a process used by divers to eliminate inert gases from the tissues, whereby they breathe high partial pressures of oxygen while resting after a dive to reduce the risk of getting decompression sickness.

surface-supplied air diving *n:* a diving mode in which the diver in the water is supplied from the dive location with compressed air for breathing.

surface-supplied diving *n:* a diving mode in which the diver receives his breathing gas from a supply on the surface.

T

tender *n*: 1. the barge anchored alongside a relatively small offshore drilling platform. It usually contains living quarters, storage space, and the mud system. 2. a shipment of oil presented by a shipper to a pipeline for movement. 3. the person responsible for tending to a diver's needs.

tethered diving *n*: diving in which an umbilical hose is used to connect a diver to the gas supply.

treatment tables *n:* a depth, time, and breathing gas profile designed to treat a diver for gas embolism or decompression sickness.

U

umbilical *n:* a hose bundle that supplies a lifeline, breathing gas, communications, power, and heat as appropriate to the diving mode or conditions. Underwater television camera, etc. cabling can also be carried as a component part of the umbilical.

unlimited duration excursion tables *n:* two tables for use with saturation excursion diving which limit upward and downward excursions, and provide a zone in which the diver can move freely without regard to the number of excursions or their duration without incurring a decompression penalty.

V

volume tank *n:* a pressure vessel connected to the outlet of a gas supply and used as a gas reservoir.

W

weight belt *n:* a belt worn by a diver to achieve desired buoyancy.

wet suit *n*: a diving suit, usually made of neoprene material, designed to provide thermal insulation for a diver's body. A small amount of water enters the suit, is warmed by body heat, and protects divers for a short time.

wet welding *n*: underwater welding performed without the use of a protective habitat.

working pressure *n:* the pressure to which a pressure containment device is exposed under normal operating conditions.

work site *n:* an underwater location where work is performed.

Review Questions
LESSONS IN ROTARY DRILLING
Unit V, Lesson 5: Diving and Equipment

Fill in the Blanks

Fill in the blanks with the appropriate word or phrase.

1. Although his theory was later proved to be inaccurate, Haldane believed a diver would not need to decompress if he went no deeper than __________ feet.
2. Jacques Cousteau introduced the AquaLung scuba system, which became popular because of its ____ regulator.
3. Archimedes' principle states that a body is buoyed up by a force equal to the ____________ _______________________ of the water it displaces.
4. A depth of 33 feet of sea water can be expressed in atmospheres absolute as _________.
5. Atmospheric pressure is _______________________ pounds per square inch at sea level.
6. Boyle's law states that at constant temperature, the volume of a confined gas is __________________________ proportional to the absolute pressure exerted upon it.
7. Charles's law states that at constant pressure, the volume of a confined gas is ____________ _____________________proportional to its absolute temperature.
8. The refraction of light underwater makes objects appear ______________________ (smaller, larger) to a diver.
9. Spaces in the body like lungs, sinuses, and middle ear are known as ____________________ __________________.
10. Holding one's breath during ascent can cause an _____________________________.
11. Nitrogen narcosis is caused by the partial pressure of nitrogen being too __________________ (low, high) in the diver's breathing mixture.
12. One of the lightest gases known, __________________________, is used as a substitute for nitrogen in dives of great depth.

13. Breathing extremely high partial pressures of oxygen can lead to a reaction known as ___________ ___________ .

14. Decompression sickness, also called _____________ _____________, can occur from incomplete decompression.

15. Medical research concerning the use of helium under high pressure is continuing because of a reaction known as high-pressure _____________________ _________________.

16. The introduction of the ________________ _________________ by Frenchman Jacques Cousteau in 1943 made practical the use of compressed air in a self-contained apparatus.

17. A *reclaim helmet* allows the diver's exhaled gas to return back to the surface through another hose in the umbilical and be scrubbed of ________ and replenished with ___________, stored, and reused.

18. Although the wet suit is popular, the _________________ suit offers divers maximum protection from cold or polluted waters.

19. Deep-sea diving gear is still in use today, but ________________ diving gear offers more mobility and ease of movement for divers working at deep depths.

20. The 1-atmosphere diving suit requires no time for ___________________________, even though it can go to depths of 1,500 feet.

21. The guage that topside uses to determine a divers depth is called a ______________ or ______________.

22. A comfortable living area where pressure is monitored and decompression takes place is called the ______________ __________________ ____________________.

23. _________-_________ ________ _______________ is appropriate from the surface to about 190 fsw.

24. A surface supplied diver's breathing-gas supply is usually delivered from the surface through an _____________ _________________.

25. Divers undergo decompression requirements after a dive both in the water and in a ______ _________________________________.

26. If a diver might have the bends, he or she will enter a recompression chamber with assistance from ________________ ________________.

27. ____________ ____________ ___________ eliminates the problem of nitrogen narcosis at deeper depths by substituting helium as the inert gas in the breathing mixture.

28. A significant increase in diver bottom time can be realized utilizing _______________ ______________ techniques.

29. The _________-__________ ________________ of a saturation system has several functions such as temperature control, CO_2 elimination and humidity control that are regulated and monitored.

30. ___________________ allow divers to __________ __________ __________ to the diving bell or pass between saturation chambers through a small tube with hatches on both sides.

31. Divers in saturation would utilize a ____________ _____________ ___________ for events such as a sinking vessel or platform or a fire that is out of control.

32. ________ ___________ or heavy-lift barges are work platforms used for lifting large components offshore, such as installing or removing offshore platforms.

33. Divers routinely perform the nondestructive testing methods of ______________, __________ ________ _________ and ___________ _________ ___________ commonly during underwater platform inspections.

34. Wet welding and ____________________ welding are two underwater techniques.

35. Dry, hyperbaric welding makes use of a pressurized enclosure known as a _______________ _____________________ __________________.

36. Inland and offshore commercial diving operations are federally regulated in the United States by the ___________ _________ __________ and OSHA.

37. A critical undertaking for diving companies is in-house ______________________.

38. Today, ____________ ____________ _______________ allow divers to tighten flanges for pipeline operations.

39. Underwater burning, or __________ ______________, is often a fast and precise way to cut steel under water.

40. There are many organizations that regulate commercial diving and ________________.

Index

Answers to Review Questions
LESSONS IN ROTARY DRILLING
Unit V, Lesson 5: Diving and Equipment

1. 33
2. demand
3. weight
4. 2 ata
5. 14.7
6. mass, or weight
7. inversely
8. larger
9. free air spaces
10. embolisim
11. high
12. helium
13. oxygen toxicity
14. the bends
15. nervous syndrome
16. demand regulator
17. CO_2, oxygen
18. dry
19. light weight
20. decompression
21. pneumofathometer, pneumo
22. deck decompression chamber
23. surface-supplied air diving
24. umbilical
25. deck decompression chamber
26. diving tender
27. mixed gas diving
28. saturation diving
29. life-support system
30. trunkings, transfer under pressure
31. hyperbaric rescue chambers (HRC)
32. derrick barges
33. ultrasonics, magnetic particle inspection and cathodic potential surveys
34. dry
35. underwater welding habitat
36. U.S. Coast Guard
37. training
38. hydraulic impact wrenches
39. oxy-arc cutting
40. diving equipment