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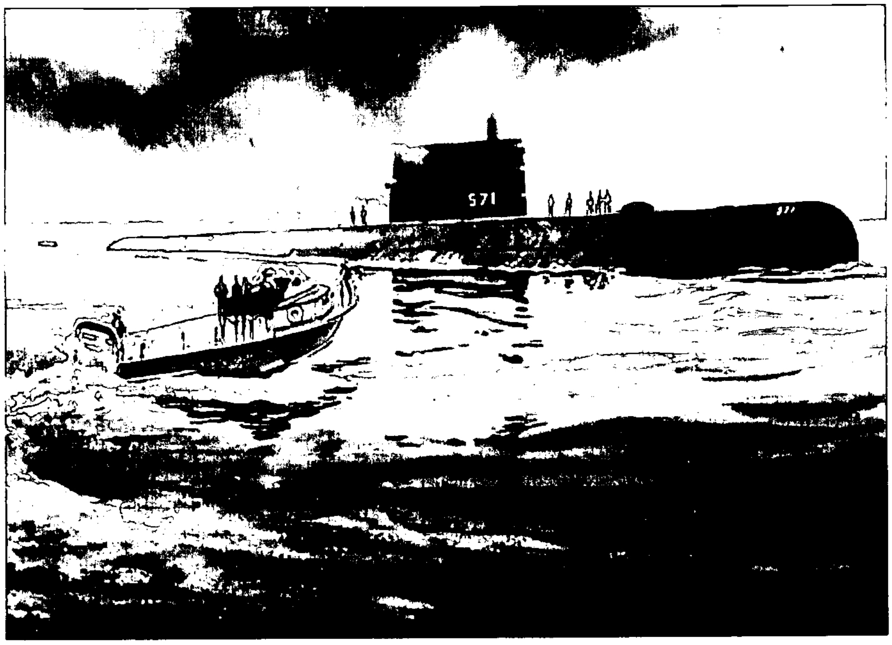
ABSTRACT

This resource guide for science and social studies classes explores the world of U.S. Navy submarines and other submersibles. The guide consists of background information on the history and development of submarines and a list of cross-curricular activities to challenge, educate, and entertain students. Students learn the inherent challenges that complicate travel and survival undersea through activities that teach about submarine design and operation within an historical context. Each activity is intended to expand student understanding of the history, science, and technology of submarines. The guide packet is intended for students in grades 5-8. Contains a 22-item bibliography for teachers. (BT)



Dive! Dive!

An Introduction to the History and Technology of Submarines

DEPARTMENT OF THE NAVY -- NAVAL HISTORICAL CENTER
805 KIDDER BREESE SE -- WASHINGTON NAVY YARD
WASHINGTON DC 20374-5060

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2 July 2001

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An Introduction to the History and Technology of Submarines

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Dive, Dive!
An Introduction to the History and Technology of Submarines

Teachers

DIVE! DIVE! An Introduction to the History and Technology of Submarines is a resource guide for science and social studies classes that explores the world of U.S. Navy submarines and other submersibles. The guide consists of background information on the history and development of submarines and a list of cross-curricular activities to challenge, educate, and entertain students.

Students learn the inherent challenges that complicate travel and survival undersea through various activities that teach about submarine design and operation within an historical context. Each activity is intended to expand students understanding of the history, science, and technology of submarines. This packet is intended for students in grades 5-8. As the teacher, you may pick and choose which lessons are most appropriate for your individual classes.

We have provided a few lesson plans for you to print out, however the entire packet may be obtained when calling the museum to schedule a group tour. Please call Sheila Brennan at (202) 433-6826 if you have any questions or comments regarding this curriculum packet. The curriculum packet includes (items in blue/underlined are available on-line):

Introductory Materials:

- Submarine Development, A Short History
- Elements of Submarine Operation

Lesson Plans/Activities:

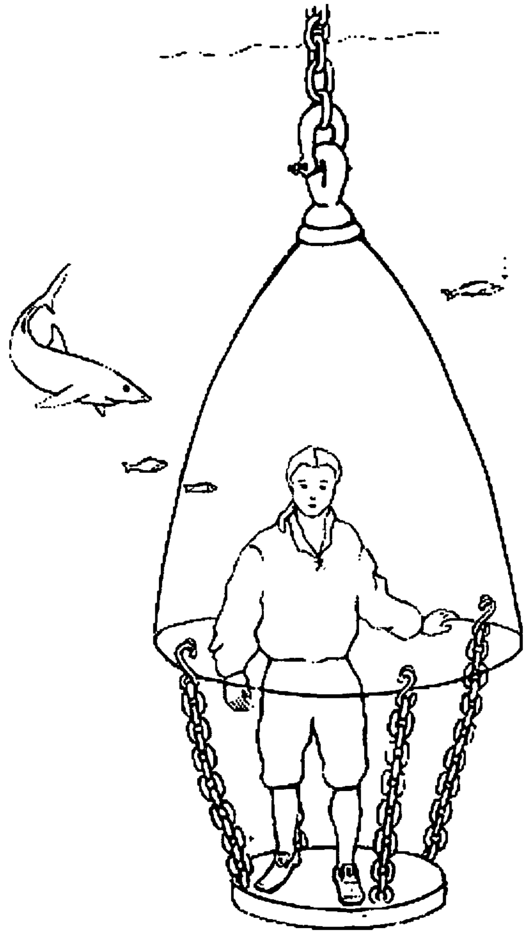
- Build your Own Submarine
- Math Under Pressure
- Gray Lady Down
- Making Fresh Water: Distillation

Resources:

- Bibliography for teachers of all levels

DEVELOPMENT
A SHORT HISTORY

Underwater exploration has fascinated people for thousands of years, yet submarine travel did not become common until the mid-twentieth century. The ancient Athenians used divers in secret military operations, and a legend maintains that Alexander the Great descended into the sea in a primitive diving bell. Many talented and curious people dabbled with submersible boat designs, but achieved limited success. It was not until 1900, when the U.S. Navy commissioned its first submarine. This essay will discuss a few key developments in the history of American submarines.



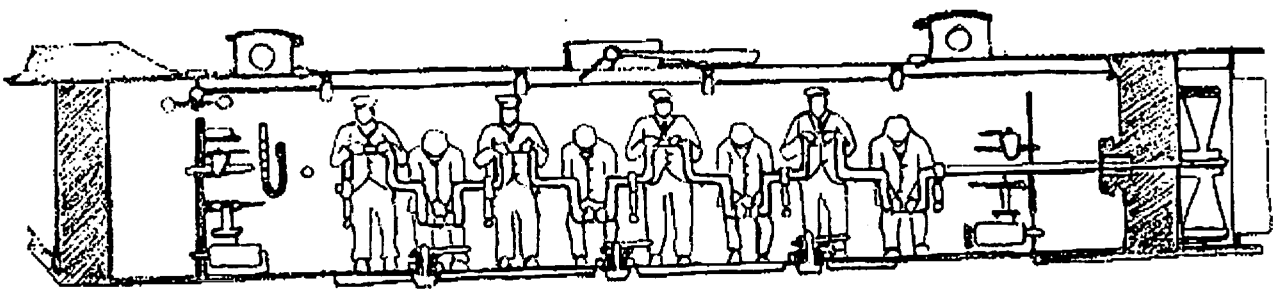
Diving Bell

The first American submarine was designed before the Revolutionary War by David Bushnell, a young inventor from Connecticut. He designed and built a one-man submersible vessel that he called *Turtle*. Bushnell's *Turtle* featured a hand-cranked screw-like oar that moved the boat forward and back underwater, air pipes that brought fresh air into the boat, ballast tanks that took on water to dive and emptied to ascend, and a primitive torpedo to attack enemy ships.

Encouraged by George Washington and Thomas Jefferson, Bushnell adapted his vessel to use against the British during the war. *Turtle* was sent to New York harbor in September 1776 to surprise the British ships blockading the city. *Turtle*'s pilot Ezra Lee crept up on HMS *Asia* and attempted to attach explosives to the side of the wooden ship, but failed to do so before losing control of the boat. Lee escaped, but tried again to attack the British one month later without success. Despite *Turtle*'s failures, Bushnell proved that a boat could be used for underwater surprise attacks.

Between the American Revolution and the Civil War many individuals experimented with submarine technology, including American Robert Fulton, an innovator and promoter of the steam engine. In 1800, Fulton completed his version of a submarine, *Nautilus*. Fulton's design introduced elements that may be found in modern submarines, such as adjustable diving planes for easy vertical maneuvering underwater, a dual system of propulsion, and a compressed air system that allowed the crew about four hours of underwater travel.

As naval surface ships continued to develop throughout the nineteenth century, submarines were still considered experimental and unsafe for the U.S. Navy. However, during the Civil War, both Union and Confederate forces experimented with submarines. One such experiment was *H.L. Hunley* named for its financier Horace L. Hunley. His boat sank twice in training missions killing 11 crew members, including Hunley himself. Despite these tragedies, *Hunley* was called to battle on February 17, 1864.



H.L. *Hunley*

Powered by nine men working a hand-cranked propeller, *Hunley* set out underwater to attack U.S.S. *Housatonic* in Charleston Harbor. *Hunley*'s crew used its spar torpedo to attack and sink *Housatonic*. *Hunley* became the first submarine ever to sink an enemy ship, however, *Hunley* never surfaced again, losing her entire crew. The submarine's potential as a surprise attack vessel finally was realized, but the problem of working safely underwater remained unresolved.

THE FIRST SUCCESSFUL AMERICAN SUBMARINE

Ten years after the end of the Civil War, Irish-born John Holland began designing and building submarines in the United States. Holland submitted his first submarine design to the U.S. Navy in 1875, which at the time was dismissed as impractical. Seeing this rejection as a challenge, Holland quickly went back to the drawing board to redesign and improve on the construction of these underwater boats.

By 1888, the U.S. Navy recognized the potential for submarines in its fleet and held a design competition for a new underwater vessel. Holland won the competition and began building the submarine *Pluger* five years later. After experiencing difficulties with *Plunger*, Holland began work on another submarine that he named *Holland VI.*

John Holland

For his sixth submarine, Holland introduced a new method of propulsion using a gasoline engine. Holland designed a small, lightweight gasoline engine that turned a propeller while the boat cruised on the surface. The engine ran a generator, a machine that produces electricity, to charge batteries necessary to run an electric motor during underwater operations. Holland's efforts proved successful and he was able to persuade the Navy in April of 1900 to purchase this submarine. It was added to the fleet as USS *Holland* (SS-1)six months later.

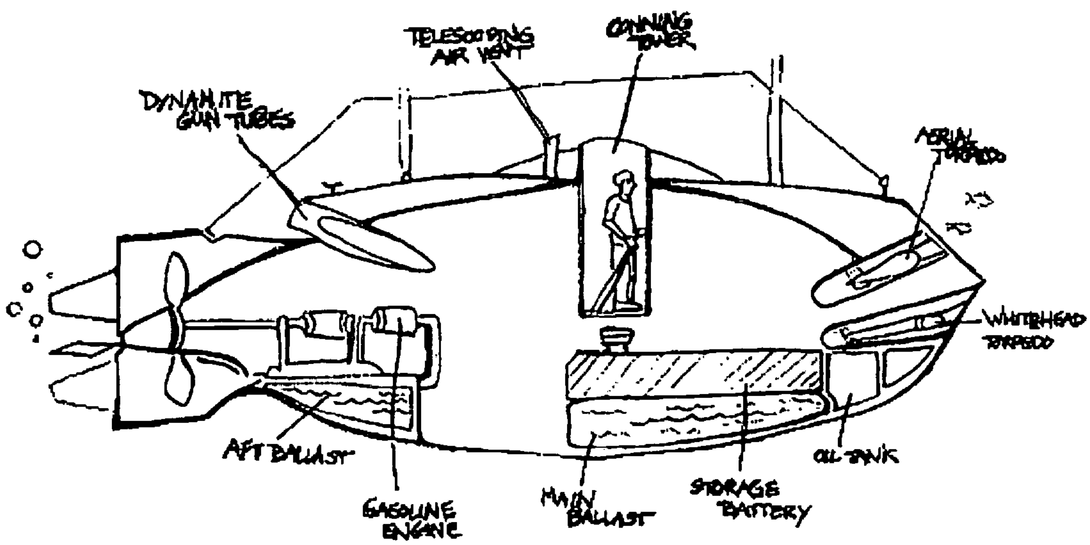


Diagram of USS *Holland*

IMPROVED PROPULSION

Although the gasoline engine worked well on paper, the engine had flaws. Gasoline is highly flammable and unstable. Using this fuel in a confined environment, such as the submarine, endangered the crew. Another danger were the batteries that ran the electric motor during underwater travel. They were heavy, bulky, terribly inefficient, and potentially explosive. Finding a safer means of propulsion was needed if the submarine was ever to submerge for long periods of time.

Around the same time Holland was creating his submarines, German scientist Rudolf Diesel developed an excellent substitute for the gasoline engine. Diesel's engine used a fuel that was more stable than gasoline and could be stored safely. The engine also did not need an electric spark to ignite the fuel, adding another element of safety. These advantages, plus improved fuel economy, granted submarines with Diesel engines longer and safer cruises on the surface. While underwater, batteries were still necessary to provide power. After 1909, Diesel engines would be used in American submarines for nearly 50 years.

THE NUCLEAR- POWERED SUBMARINE

Despite the success of diesel-powered submarines, the quest for a single power source continued. The concept of nuclear power was discovered by German scientists in the 1930's. Upon learning of this idea, American physicist Ross Gunn visualized the potential for nuclear-powered submarines and Phillip Abelson first sketched an image of one. The most recognized proponent of nuclear-powered submarines in the U.S. Navy was Admiral Hyman G. Rickover.

Rickover managed a research team that converted the concepts of nuclear power into working submarines. Nuclear power uses atoms, the smallest particles of an element, to produce an enormous amount of energy. That energy allows the power plants on submarines to super heat water and create steam. The steam then powers a giant turbine which turns the sub's propeller. Those small nuclear power plants on submarines could supply the necessary power for these boats to travel up to 500,000 miles and to stay underwater almost indefinitely without refueling.

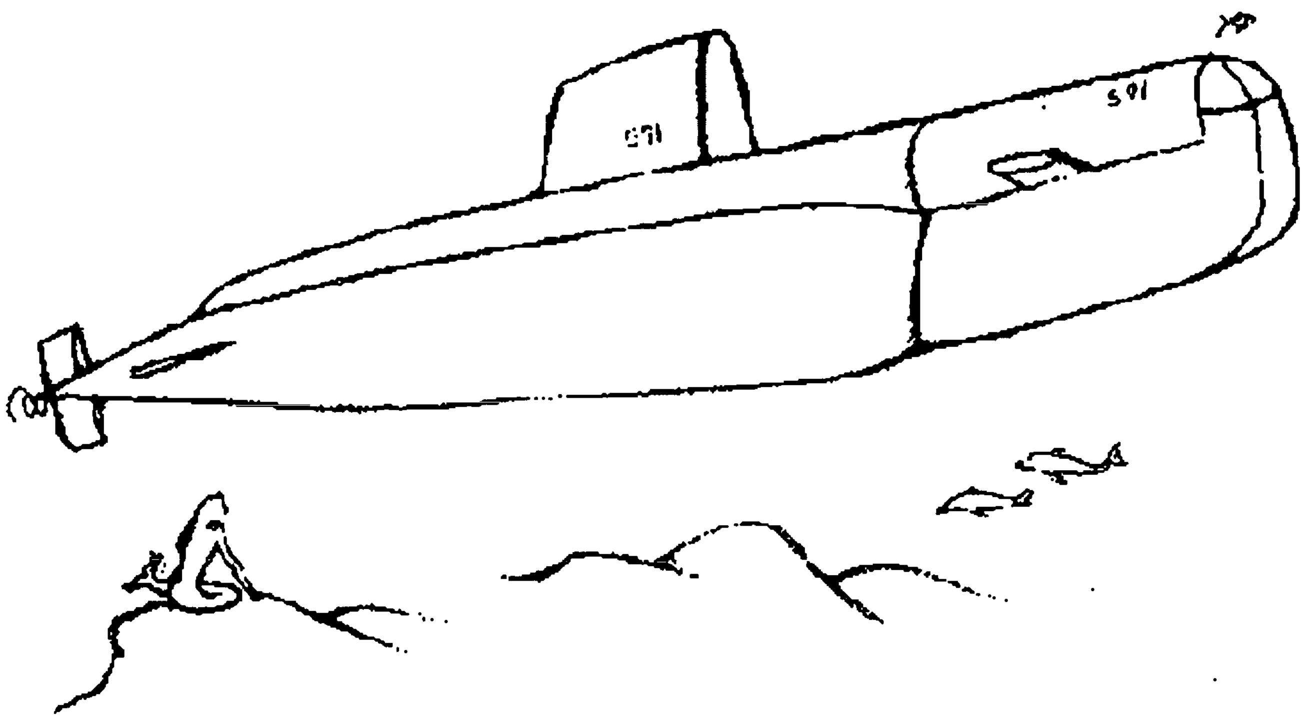
Rickover convinced the Navy and the Atomic Energy Commission that nuclear power was the ideal propulsion method for submarines. On January 17, 1955, the first nuclear-powered submarine, USS *Nautilus* (SSN-571) went to sea. On her first voyage, *Nautilus* traveled completely submerged in the Atlantic for more than 1,300 miles. In 1958, she traveled under the polar ice cap and reached the North Pole.

Today's fleet of American nuclear submarines is able to spend up to six months on submerged patrol. Submarines have two complete crews. When a boat returns from a lengthy cruise, the crews rotate. Since the vessel is refueled only once or twice over its lifetime, there is no need to "stop for gas. " However, subs still need to stop to restock food and supplies.

THE FUTURE OF SUBMARINES

Changes in world politics and further adaptations of sea, land, and space technologies are creating new challenges for submarines in the 21st century. In the future, some submarines may contain no crew at all, but merely computer technology that talks to satellites and transfers information to distant military bases for analysis.

Submarines now are an essential part of the U.S. Navy, which would not have been possible without the ingenuity and vision of the innovators described in this essay.



Elements of Submarine Operation

DETECTION

A submarine's effectiveness depends on its ability to remain submerged and undetected. From this position beneath the surface, a sub can search, track, and attack using the element of surprise. The element of surprise has always been the submarine's greatest asset and is still considered its most powerful weapon. When surfaced, however, submarines are quite vulnerable, since modern subs operate more slowly and have less armament than surface ships. By surfacing, submarines surrender their invisibility.

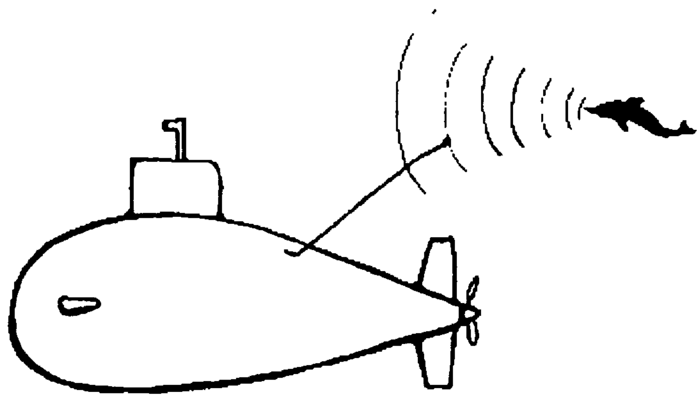
The earliest submersible vessels operated blindly under the sea. Until the twentieth century the only way for a sub to see was by surfacing, thus revealing herself to surrounding vessels. Since 1903, naval submarines have used periscopes at shallow depths (about 60 feet) to get a view of the surrounding sea.

The development of RADAR (Radio, Detection And Ranging) during World War II allowed surface ships to talk with submarines and warn them of impending danger. Radio communication was established with a retractable antenna from the sub that rose above the surface. In order for this to work, the submarine had to come close to the surface. Another danger was that the radio transmissions could be detected and tracked, threatening to reveal the sub's location. It wasn't until the introduction of SONAR (Sound Navigation And Ranging) that submarines were able to capitalize on their stealth.

STEALTH

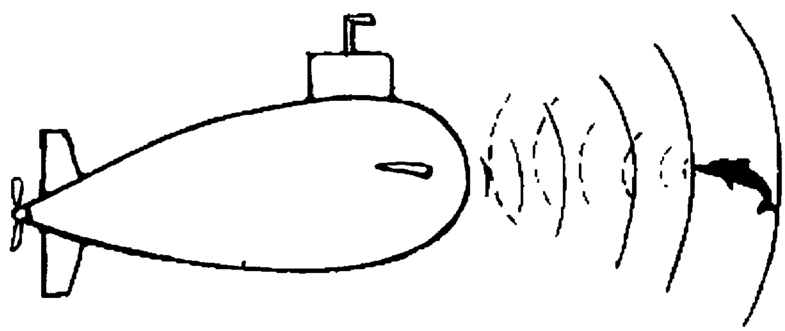
In order to go undetected, submarines needed something that concealed them from other boats or ships. SONAR offered submarines stealth. SONAR is a system that uses sound waves traveling through water to search for objects or geographic obstacles. There are two types of SONAR, passive and active.

PASSIVE SONAR picks up sounds using electronic listening equipment.



A target can be detected by the noise it makes from its machinery, the propeller, or the sound of the water passing around the vessel as it travels.

ACTIVE SONAR produces and emits a burst of sound or a "ping."



This is reflected back when it hits an object and is registered as a "blip "on a screen. Active SONAR sends and receives sound transmissions. There is a danger that enemy SONAR will detect the ping.

SONAR is very important to submarines because it lets them see what is around them, without coming close to the surface. Submariners must listen carefully, because SONAR can pick up other sounds made by their own sub or sea creatures. When a sub is listening for a target, it also must be very quiet. Submariners even wear tennis shoes when underway to silence their footsteps!

To increase stealth, submariners take advantage of how sound waves act in ocean water. The speed of sound in seawater is greatly determined by temperature, pressure, and salinity. These three factors vary in different locations and bend the sound waves accordingly. Because SONAR depends on receiving sounds signals, the way sound waves bend determines what can be picked up by SONAR. Submariners can find places between the bending sound waves of active enemy SONAR called shadow zones. There, subs can hide and watch the enemy without being detected.

MANEUVERABILITY

Modern control systems enable a submarine to operate much like an airplane, but subs fly in a sea of water. Similar to a plane's wings and tail, a sub's hull-mounted hydroplanes allow the boat to ascend or descend several hundred feet per minute. Like planes, submarines must consider the topography of their surroundings. Underwater mountains and valleys, just like the continental ones, limit the maneuverability of submarines. SONAR is used actively to detect underwater obstacles and increase mobility.

HABITABILITY

Living conditions on a submarine are unique because the crew works, eats, and sleeps in a confined space that is beneath the sea. Through the 1920s, submarine crews were packed into tight spaces with equipment, machinery, weapons, and provisions. Berthing spaces (sleeping areas), heads (bathrooms), and community areas were intertwined within the subs' limited space, making life aboard exceedingly unpleasant and unhealthy. Food and body odors, combined with gasoline vapors and carbon dioxide, contaminated the limited amount of breathable air in the submarine.

Since World War II, the Navy significantly improved the environment onboard their submarines. Improvements in the air quality of subs was perhaps the most important change. The Navy learned from the mining industry how to filter out deadly carbon dioxide while the boat was submerged. Carbon Dioxide accumulated at a rate of one cubic foot per crew member per hour. With better ventilation systems, the air quality greatly improved.

Maintaining a constant source of drinkable water also was a problem. Modern submarines now carry distillation plants to make fresh water from salty seawater. Living conditions continued to improve when the Navy separated the eating, sleeping, and sanitary accommodations, and added lockers and storage facilities to cope with the lack of space on the submarine. Today, the habitability of a submarine is assured by equipment that makes fresh air and water, filtration systems that eliminate toxic vapors, and new designs that improve space management.

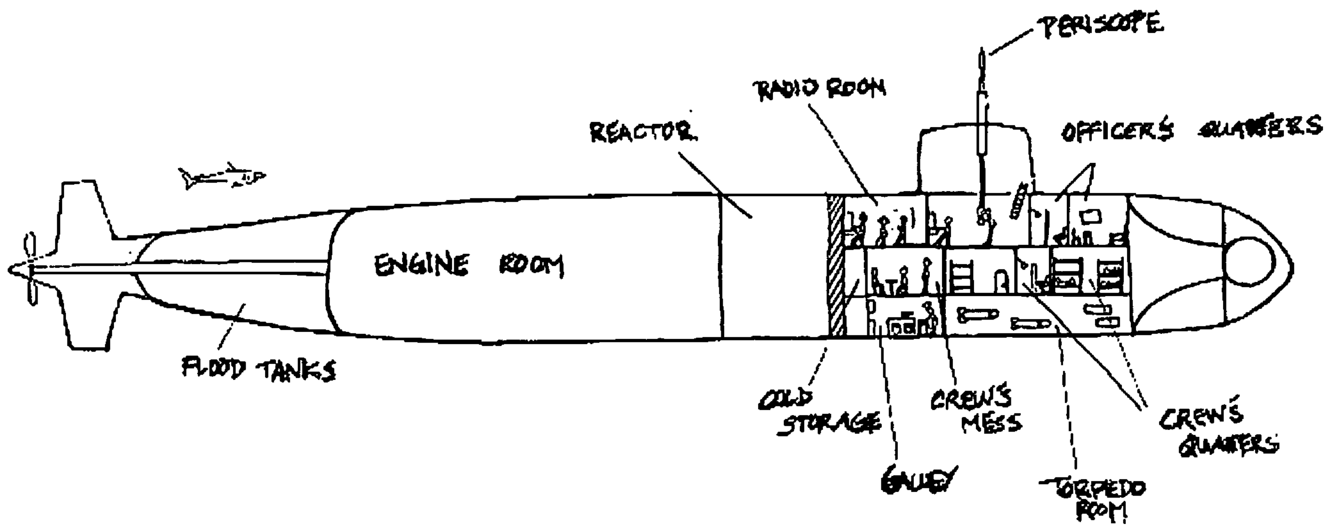


Diagram of Nuclear sub interior

SPEED

While design helps improve the habitability of a submarine, it also improves its speed. Combined with stealth, speed is one of the modern submarine's greatest assets. Early submersibles were meant to cruise on the surface and submerge only for short periods. Because of anti-submarine warfare, modern subs need speed under water to escape attack. Although the actual top speed of American naval vessels is a secret, modern submarines travel faster than 30 knots underwater.

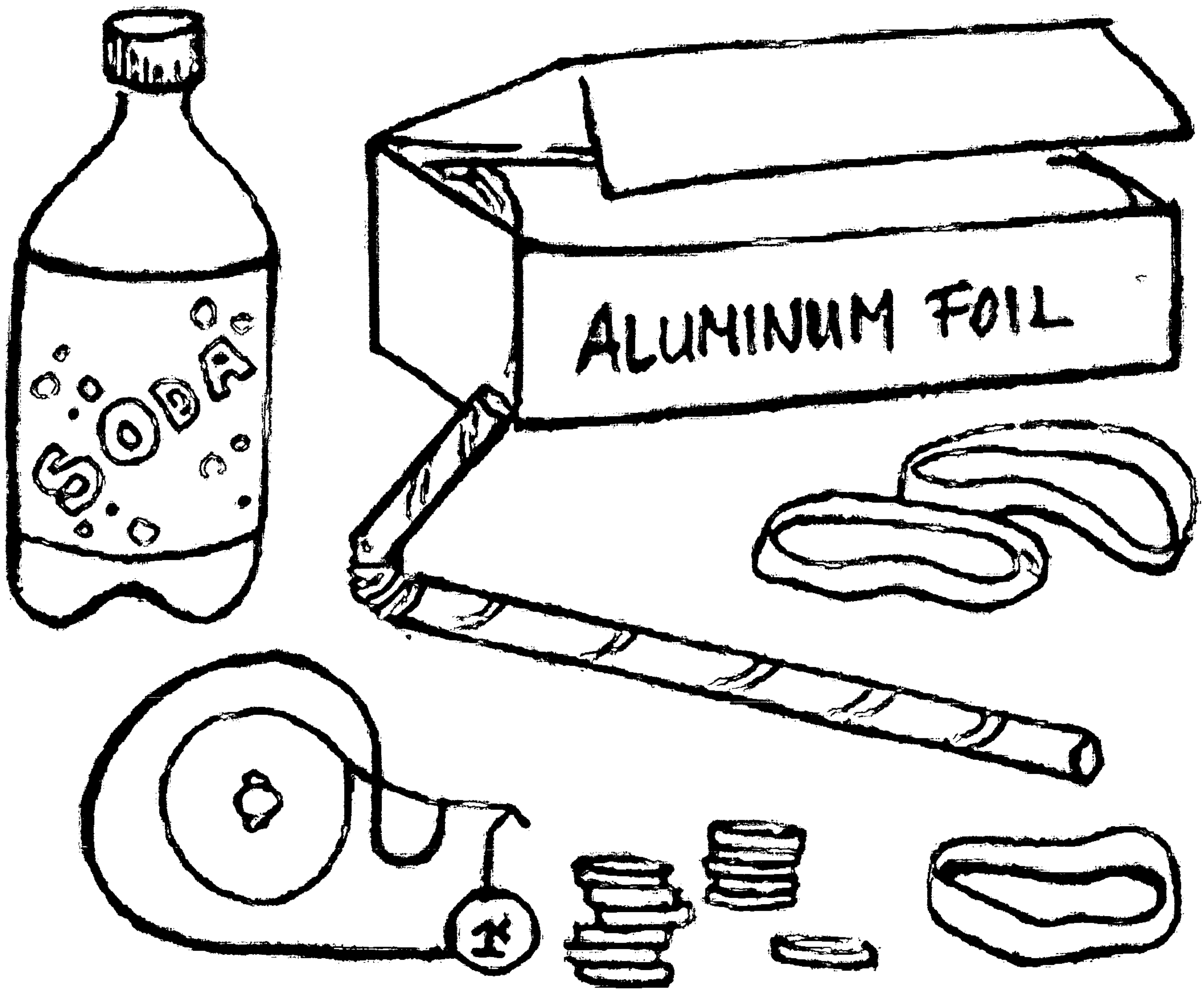
Submarines are carefully designed to enhance their speed. They have become more fish-like in shape, or hydrodynamic. As the speed increases, the fins of these metal "fish" automatically adjust their position to help the sub control its depth so the boat may slice silently through the sea.

CONCLUSION

By the mid-20th century, nuclear power became a truly efficient propulsion system for submarines. After years of experimenting, it became clear that nuclear power held the answer to propulsion, habitability, and strategic problems that plagued earlier boats. By removing the necessity to surface for air replenishment and battery recharge, nuclear energy made submarine operations faster, healthier, and quieter.

BUILD AND MANEUVER A SUBMARINE
Lesson Plan

OBJECTIVE: Students learn the basic of principle of buoyancy and how submarines use it to dive and ascend in water.



MATERIALS:

- Build a Submarine activity sheet
- empty 16 or 20 oz. plastic soda bottle with hole in cap (the hole should be big enough to pass a flexible straw through)
- three wide rubber bands

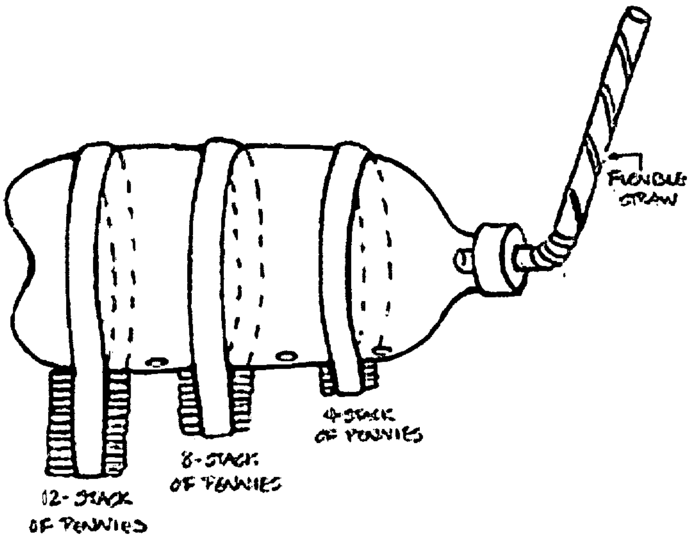
- 24 pennies
- aluminum foil
- adhesive tape
- flexible straw
- large tub of water

PROCEDURE: See activity sheet

BUILD AND MANEUVER A SUBMARINE
Activity Sheet

PROCEDURE:

1. Cut three holes in side of the soda bottle.



2. Stack the pennies into three piles containing 4, 8, and 12 pennies.

3. Carefully wrap stacks of pennies with foil.

4. Place a rubber band around the plastic bottle and slide it next to the closest hole. Position the other rubber bands next to the two remaining holes.

5. Place the four-penny stack under the rubber band closest to the bottle's top.

6. Place the eight-penny stack under the middle rubber band, next to the middle hole.

7. Place the 12-penny stack under the last rubber band (NOTE: The weights should be next to the holes NOT over them.)

8. Push the shorter end of the straw (about 1 inch) through the hole in the bottle's cap. Reattach the bottle cap to the bottle. Keep the flex section outside and bent upwards. Tape straw securely into place in bottle cap.

9. Lower the "submarine" into the water. Do not let long end of straw take in water.

10. Observe the action of the "sub" and record your observations.

11. When the sub stops sinking, blow into the straw.

12. Observe the action of the sub and record your observations.

QUESTIONS:

1. What makes your submarine sink?

2. What makes it surface?

3. You learned the basic properties that make submersibles dive and surface. What is your model missing that U.S. Navy submarines have to navigate underwater? Think of your sub as an underwater plane.

MATH UNDER PRESSURE

Lesson Plan

OBJECTIVE: Students calculate air and water pressure and discuss the effects of pressure on people and things underwater.

MATERIALS:

- Math Under Pressure activity sheet
- Pressure graph
- Teacher answer sheet
- Calculators as desired

PROCEDURE:

1. Brainstorm with students about how air and water pressure affects their lives, such as in airplanes, while swimming/diving, blowing up a balloon, etc.
2. Pass out copies of "Math Under Pressure" activity sheet and pressure graph to students.
3. Review answers with students.
4. Break students into teams to develop other atmosphere problems for their classmates.

MATH UNDER PRESSURE

Activity Sheet

BACKGROUND:

Pressure is all around us. Although submarines are designed and tested to be safe underwater, the problems of increasing water pressure affect them as they submerge.

Pressure increases rapidly underwater. To help understand the effect of water and air pressure on our bodies, scientists have developed a measuring system . For every 33 feet of depth, pressure increases 14.7 pounds per square inch , or one "atmosphere." As a diver or submarine gets deeper, each atmosphere adds another 14.7 pounds per square inch to the pressure exerted on them. The weight of the air at the surface must also be added when figuring underwater pressure. At the surface of the water, air weighs 14.7 pounds per square inch (psi).

Use the attached graph, and what you know about air and water pressure to answer these questions.

1. John has dropped a quarter into a swimming pool. To get it back, he must dive to the bottom of the 11' section of the pool.

How many pounds per square inch of pressure will he be under before he dives into the water?____________________________.

How will that number change as he swims to the bottom of the pool? WHY?

____________________________.

2. A cliff diver in Acapulco dives from a 200-foot cliff into the ocean. He is moving so fast that his body plunges to a depth where the pressure on his body is just over 44 pounds per square inch.

How far underwater is he? ____________________.

How many atmospheres are pressing on him? ____________________________________.

3. A submarine is planning to make a test dive to a depth of 2,425 feet.

How many atmospheres is that?____________________________.

What do you think will happen to the sub if its construction can't take the pressure?

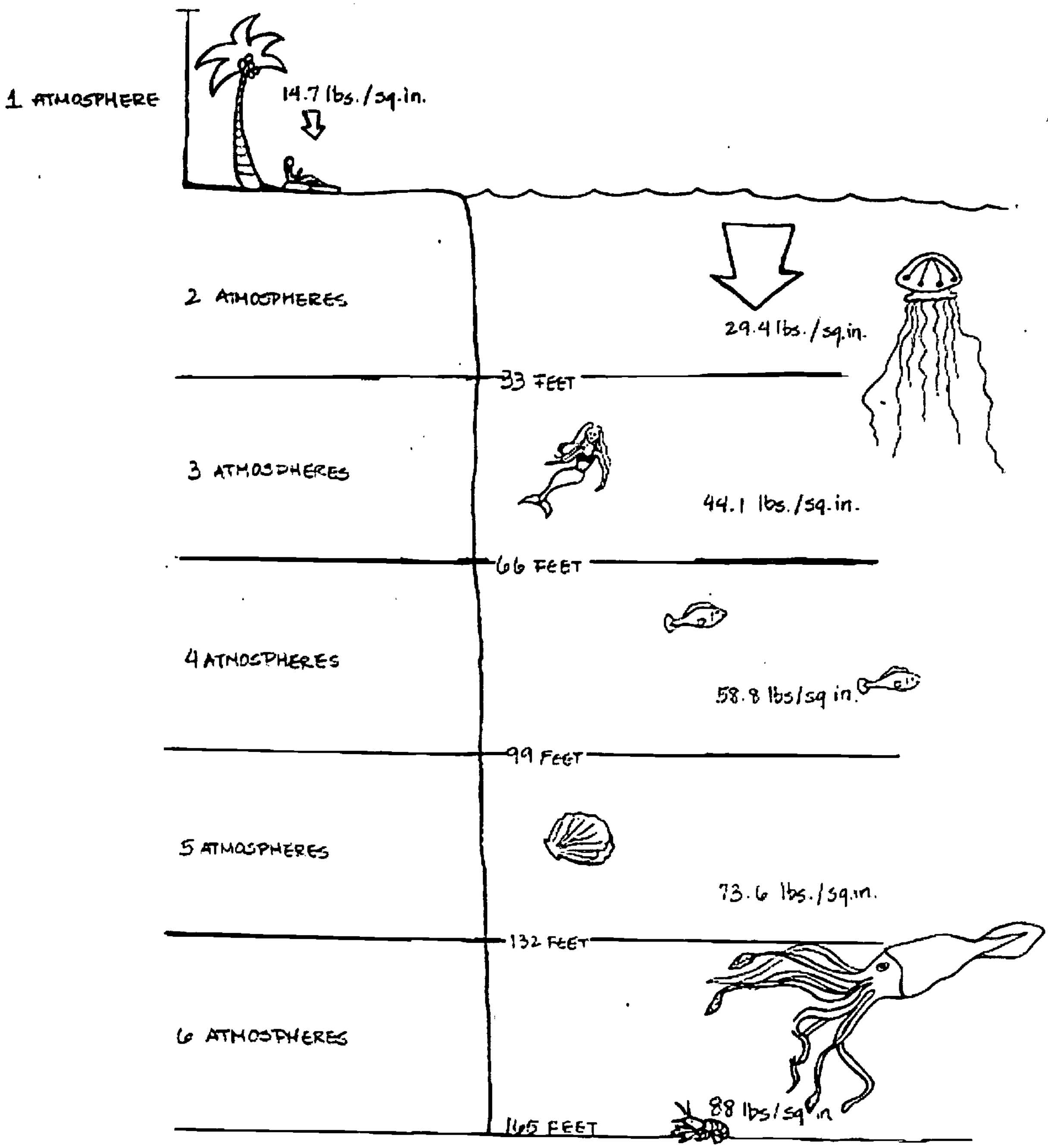
____.

4. During a U.S. Navy exercise at sea, two submarines are playing hide-and-seek to test their invisibility. At first, the subs dive as deep as they can go, but then each hides in the ocean. Sub #1 stops at a depth where it is affected by 88.3 lbs/sq.in. of pressure. Sub #2 is floating at a depth of 165 feet.

Which is deeper?____________.

Follow Up: Work in small groups to make up "atmosphere" problems to stump your classmates. Be creative!

PRESSURE GRAPH



MATH UNDER PRESSURE

Answer Sheet

1. 14.7 psi
2. pressure will increase
3. the deeper he dives, the greater the pressure on him.
4. 66 feet
5. 3
6. 74.48 including 1 atmosphere of surface air pressure
7. It will implode or be crushed.
8. They are at the same depth.

GRAY LADY DOWN

Lesson Plan

OBJECTIVE: Students discover the effects of pressure on objects and humans at extreme ocean depths, and discuss how that affects submarine travel.

MATERIALS:

- Gray Lady Down activity sheet
- *Trieste* photos

PROCEDURE:

1. Brainstorm with the class about what it's like to go to sea on a submarine.
   - How would their lives at sea be different? the same?
   - What would be the best part of living underwater? the worst?
   - How long would they want to stay underwater?
   - How do they think air/water pressure would affect them?
2. Distribute Gray Lady Down activity sheet for students to read.
3. Discuss the differences between the *Thresher* and *Scorpion* tragedies in small groups using the questions at the end of the activity sheet as a guide.
4. Optional: Rent and watch *Gray Lady Down* with your class before doing this activity.

MUSEUM LINK: You and your students may view the bathyscaph *Trieste* and learn more about *Thresher* upon your visit to The Navy Museum.

GRAY LADY DOWN

Activity Sheet

BACKGROUND: One of the most terrible things the crew of any Navy ship can hear is that a sister ship is lost at sea. Based solely on her operating configuration as an undersea vessel, the situation may be the worst for a submarine. Since the exact number and location of American submarines worldwide is secret, the actual code for a lost sub is classified. However, in the 1970s, the phrase "Gray Lady Down" was used as the title of a movie about efforts to rescue a nuclear submarine that was down or unable to return to the surface.

The movie was fiction, but there are two tragic instances of submarine losses under unknown circumstances. In separate incidents, *Thresher* and *Scorpion* went down with no survivors. The hulls were later discovered at depths far beyond those the boats and crew could survive.

There is a certain romance to life at sea and an element of danger in every sea voyage. To preserve and protect crew and material, all Navy vessels must be in close-to-perfect operating condition before they are cleared to get underway. But even then there are no guarantees. Two of the saddest chapters in the history of the U.S. Navy chronicle the unexplained loss of *Thresher* and *Scorpion*, two nuclear submarines on routine assignments.

USS *Thresher*

The mission began as a routine deep-dive test, but the crew of the USS *Skylark* knew something was wrong. Their test submarine had barely reached her assigned test depth when static-filled underwater telephone transmissions from far below told them things were going wrong, very wrong.

On April 10, 1963, the nuclear submarine USS *Thresher* (SSN-593) and submarine rescue ship USS *Skylark* (ASR-20) journeyed to the cold waters 200 miles east of Massachusetts for deep-diving testing. Only fifteen minutes after reaching her test depth, *Thresher* notified *Skylark* that she was "experiencing difficulties." Within moments, *Skylark*'s crew heard a noise "like air rushing into a tank" and then there was silence. Frantic efforts to reestablish contact with the sub failed. *Thresher* was down with all hands, which included a crew of 112 and 17 civilian technicians on board to observe the testing. A hastily arranged search group found only bits of debris and a pair of gloves. After four months of searching, the bathyscaph *Trieste* located broken parts of the sub in over 8,000 feet of water. The photos taken by *Trieste* in August of 1963 are all that is known of *Thresher*'s fatal accident.

USS *Scorpion*

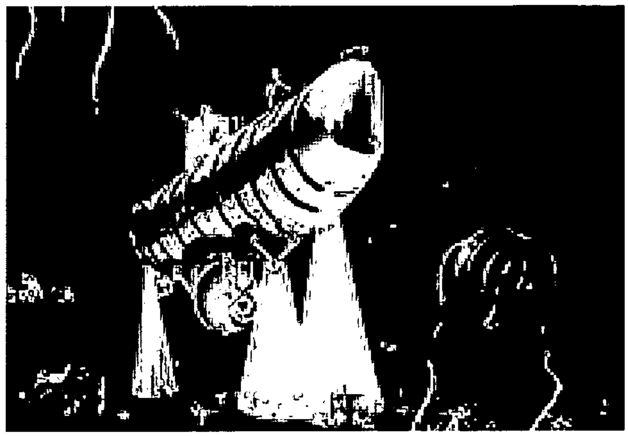
The story of USS *Scorpion* (SSN-589) is a little different, because no observers witnessed this loss. *Scorpion* played a vital role in the development of nuclear submarine warfare tactics by participating in different testing exercises in the 1960's. She was operating with the 6th Fleet in the Mediterranean Sea in May 1968. On May 21, 1968, *Scorpion* with her crew of 99 last reported their position about 50 miles south of the Azores. The sub was reported overdue at Norfolk, VA six days later. In October 1968, the research ship *Mizar*, located *Scorpion*'s splintered hull in 10,000 feet of water 400 miles southwest of the Azores. Although information and pictures collected by the Navy and *Trieste* record the site and wreckage, no reason for the loss has been recorded. There were no survivors.

Discussion Questions

1. How are the two submarine tragedies different? the same?
2. Explain the role of *Trieste*. Why was it important for the Navy to photograph the wreck sites?
3. Think about why the sinking of a nuclear submarine might be particularly dangerous.
4. What other ship wrecks do you know about and how are they different from *Thresher* and *Scorpion*?

Online Library of Selected Images:
-- U.S. NAVY SHIPS --

Bathyscaphe *Trieste* (1958-1963)



Trieste, a deep-diving research bathyscaphe, was launched in 1953 near Naples, Italy, by the Swiss scientist Auguste Piccard. After several years of operations in the Mediterranean, she was purchased by the U.S. Navy. Transported to San Diego, California, in 1958, she conducted tests in the Pacific during the next several years, including a dive to the deepest part of the ocean in January 1960. In 1963, she went to the Atlantic to search for the lost submarine USS *Thresher* (SSN-593). *Trieste* was taken out of service soon after completing that mission and is now on exhibit at the Navy Museum, at the Washington Navy Yard, Washington, DC.

This page features views of *Trieste* in about 1958-59, when she was first obtained by the U.S. Navy, and provides links to other images of her at http://www.history.navy.mil/photos/sh-usn/usnsh-t/trste-b.htm

MAKING FRESH WATER: Distillation

Lesson Plan

This activity requires adult supervision.

OBJECTIVE: Students replicate the process by which submarines distill fresh water from salt water to understand one of the steps required for living underwater in a submarine.

MATERIALS:

- Distillation activity sheet
- 1 heating device, stove or hot plate
- 1 old tea kettle
- 1 metal spoon or jar lid
- Water to fill kettle
- Salt
- Padded glove or pot holder
- 1 clear drinking container

PROCEDURE: See activity sheet

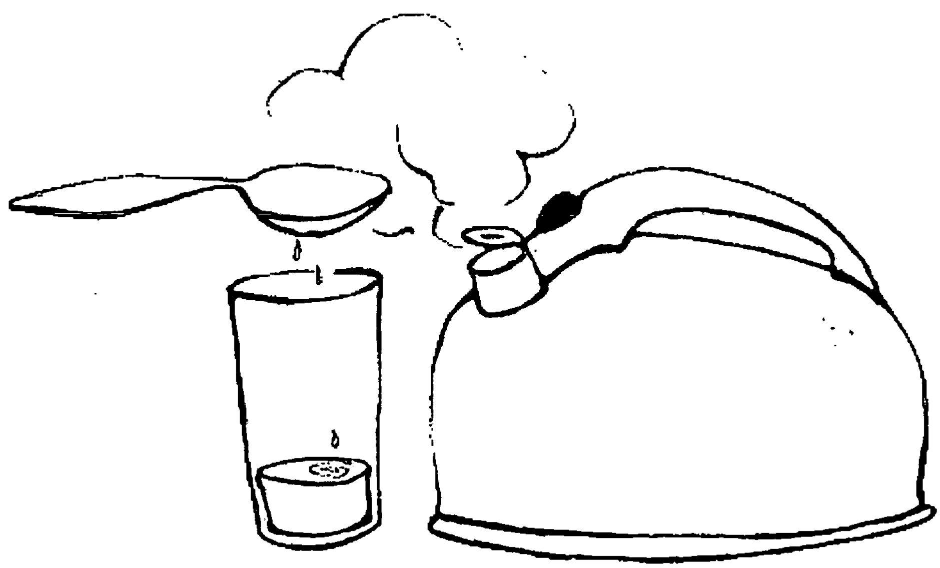
MAKING FRESH WATER: Distillation

Activity Sheet

Submarines do not have enough space to store the amount of fresh water its crew needs for drinking, cooking, bathing and laundry, so it must makes its own. Distilling equipment on board the boat makes fresh water by boiling salty sea water and collecting the steam created as it condenses on cooled surfaces. The condensed steam is fresh water that later is used by the crew. How does this transformation from salt to fresh water occur? This activity will help you understand the process as you distill your own water.

PROCEDURE:

1. Fill kettle with water.
2. Add at least 5 tablespoons (approx.) of salt to the kettle.
3. Place the kettle on the heating device.
4. Turn device to high and boil water until steam begins to escape from the spout.
5. Place a cool metal spoon or lid in front of the escaping steam.
6. Collect the water condensing on the metal by dripping it into the drinking container.
7. Collect about 1 inch of water in the glass and taste it.



QUESTIONS:

1. Is the water still salty?
2. What makes the freshwater separate from the salt?
3. What happens to the salt?

RESOURCES

This resource list has been created for teachers at all grade levels.

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