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ABSTRACT

Included is a brief description of the characteristics of the ocean, its role as a resource for food and minerals, its composition and its interactions with land and air. The role of atomic physics in oceanographic exploration is illustrated by the use of nuclear reactors to power surface and submarine research vessels and the design and use of techniques based on isotopes. Descriptions of techniques such as neutron activation analysis and deep water isotopic current analysis are included. The analysis of plankton to measure man-made radiation in the ocean is described. Nuclear devices used to preserve sea food and desalinate sea water are discussed. Some non-radiation oceanographic projects are described. Suggested readings and a film list are appended. (AL)

The *ATOM* and the *OCEAN*

U.S. ATOMIC ENERGY COMMISSION / Division of Technical Information

SE 009 799

The Understanding the Atom Series

Nuclear Energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

Edward J. Brunenkant

Edward J. Brunenkant, Director
Division of Technical Information

The *ATOM* and the *OCEAN*

by E. W. Seabrook Hull

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Division of Technical Information

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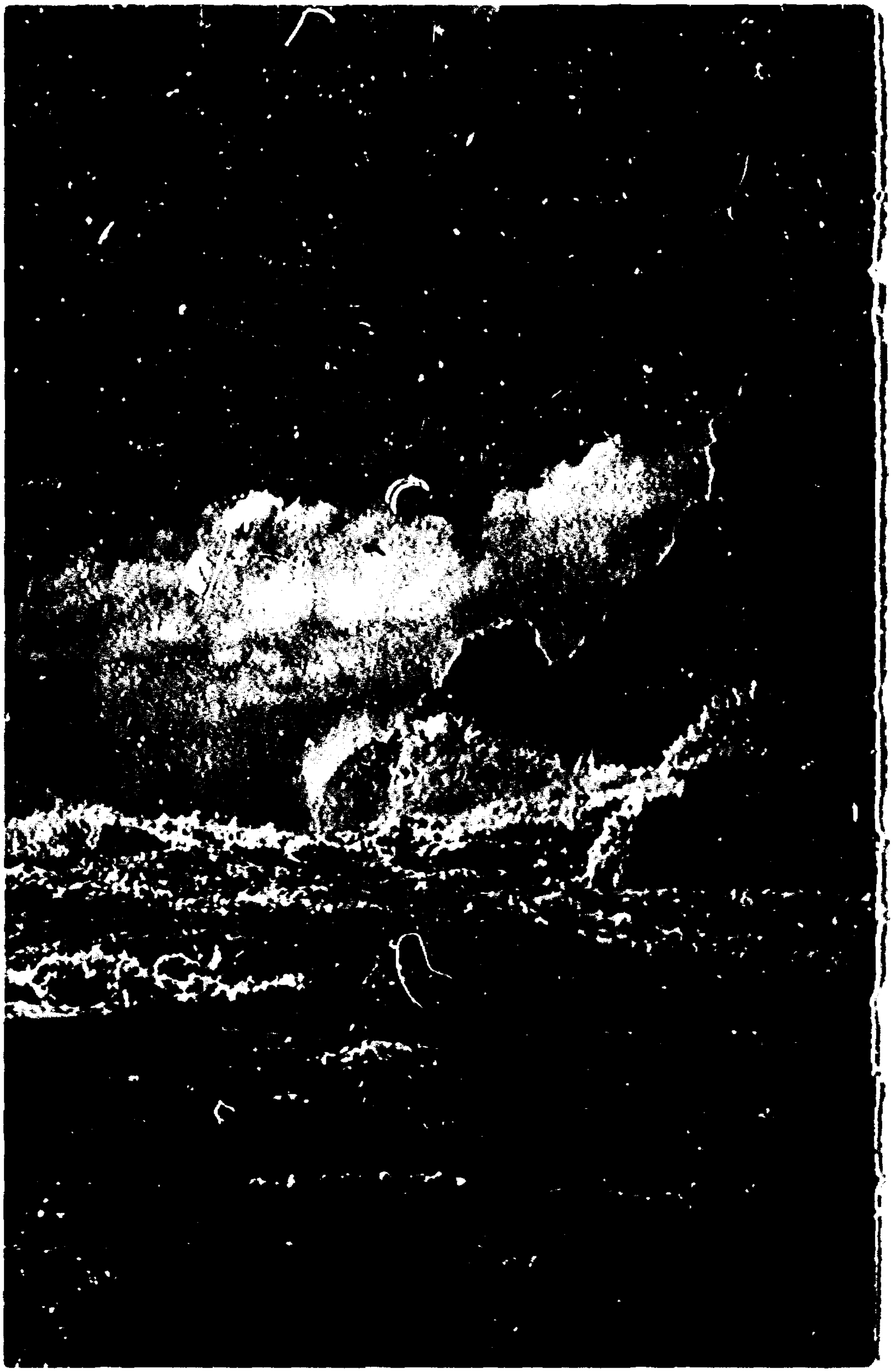


The *ATOM* and the *OCEAN*

By E. W. SEABROOK HULL

SEEKING ANSWERS

Historians of the future will record that man almost simultaneously unlocked the secret f atomic energy and ventured into new domains beneath the closed doors of the world ocean, in one of the greatest exploration endeavors of all time.

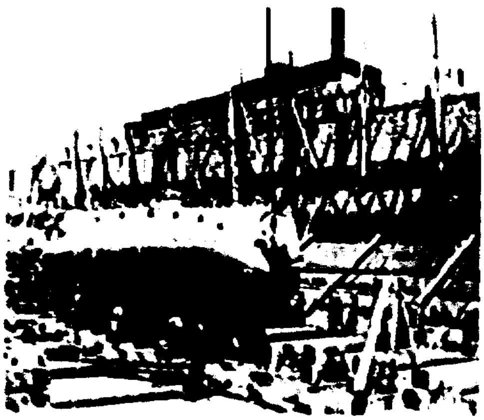
History may also show how these two efforts to benefit mankind became closely interthreaded—how nuclear energy, in its many forms and applications, played a major role in the efforts to explore and exploit "the other three-quarters" of our planet, and moreover, how the very development of a nuclear technology enforced our need to know more about the sea around us.

Nuclear energy is a fundamental physical phenomenon, like the actions of the wheel, the lever, or the inclined plane. Like chemical combustion or electricity, it is but another means for men to do useful work, whether that work be in the interests of science, commerce, recreation, or war. To this extent, nuclear energy is universal, as applicable in the sea as it is on land or in outer space. Wherever man goes and whatever he does, he requires energy to get him there and energy for his work or play when he arrives. Some of the places he now seeks to pioneer are hard to investigate by anyone encumbered with bulky traditional energy sources—coal, fuel oil, or storage batteries. The ocean in its full three-dimensional scope is one of these places.

The atom is the most concentrated source of energy, and one of the most diverse. Thus, not only are we able to do familiar things better with nuclear energy (the nuclear-powered submarine is a dramatic example), but we are also able to do things never before possible (such as studying the diffusion of dissolved salts in the open ocean or extending the useful life of seafoods through irradiation).

Nuclear energy has at last enabled us to realize the predictions of Jules Verne's adventure tale, *Twenty Thousand Leagues Under the Sea*, and to build a true submarine—a craft whose submerged existence is limited only by the physiological and psychological endurance of its human crew. This fact in itself has added greatly to our need to learn much more about the ocean, for the sea is an opaque and strange environment in which the deadly game of hunt-and-be-hunted will be won by whoever knows the ocean best.

The very fact that we have nuclear energy means we have nuclear wastes; many of these inevitably find their way into the ocean, as all things do. We need to know more about the watery world before we can safely allow this inflow to continue.



In 1900 the U. S. Navy commissioned its first submarine, the USS Holland, *which was built by John P. Holland. It is shown in dry dock at Perth Amboy, New Jersey, in 1898. On the right is the USS* Plunger, *named after an early John Holland submarine, which is an example of the Navy's present fleet of nuclear submarines.*

In the waters of the seven seas are enough deuterium and tritium to power tomorrow's thermonuclear power plants* for millions of years. These rare, heavy varieties of hydrogen, enormously abundant in the vastness of the sea, comprise an energy source without limit for all nations, which need only develop the technological ability to extract them and put them to work.

Energy for Exploration

For this exploration, men need to put instruments, navigation beacons (see figures on pages 46 and 47), and other devices on the deep ocean floor, where they must operate for long periods of time unattended and with no external source of power. Radioisotope-powered generators, capitalizing on the energy of disintegrating radioactive atoms, are almost the only devices capable of fulfilling these requirements.† Man also wants to do productive work under the ocean, such as drilling sea floor oil wells, mining, and salvaging for profit some of the tens of thousands of cargoes lost at sea during thousands of years of ocean commerce. Eventually, he even wants to farm the ocean floor.

An artist draws (using pencil and frosted plastic sheet) the position of objects in the wreck of a 7th century Byzantine ship 120 feet down in the Aegean Sea. Nuclear power will permit historians of the future to remain underwater for long periods exploring shipwrecks or old cities far below the surface.

All these activities require energy—energy in an environment where most sources cannot be applied. Above all,

*For a description of how these will work, see *Controlled Nuclear Fusion*, another booklet in this series.

†These devices, which will be frequently mentioned later in these pages, are described in detail in a companion booklet *Power from Radioisotopes*.

man wants to go down himself to explore, to work, and perhaps to direct nuclear-powered robots to do even more work. This means that small, manned, nonmilitary submersibles will be needed—vessels whose endurance should not be limited by the short life of traditional power sources, but should draw on the fissioning atomic nucleus, harnessed in small reactors.*

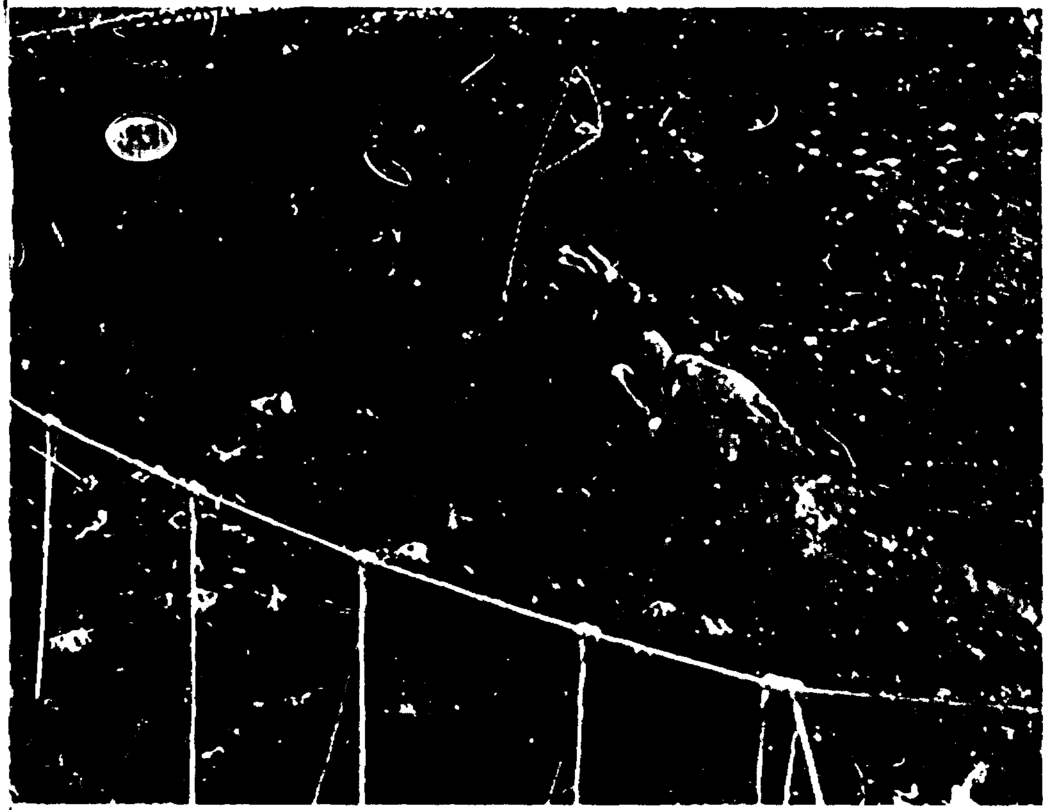
To work effectively in any environment, we must first know and understand it. This is the job of science. In the quest for knowledge and understanding of the ocean, nuclear energy provides scientists with better instruments to put down into the depths and wholly new techniques for the direct study of the many oceanic processes.

For example, take the role of radioisotope tracers: For the first time, these telltale atoms permit us to study the metabolism of tiny plankters, the often microscopic drifting creatures of the sea that in their incredible abundance form the base of the entire marine food chain, including fish eaten by humans. Even fallout isotopes from nuclear tests enable us to trace important physical oceanographic events, such as the ponderous process known as overturning, which transports oxygen-rich surface water to the deeps and nutrient-rich bottom water to the surface. Radioisotope tracers also provide a tool for studying the mechanics of littoral transport, which continually tears down some beaches and builds up others. They also enable us to determine if oceanic processes are likely to concentrate fallout particles and deliver them in dangerous doses through the food chain to our dinner tables.†

By using other nuclear energy technology, we are better able to ascertain the age and composition of deep ocean sediments and the rate at which they are deposited, how a tsunami (tidal wave) propagates across vast distances, how tides operate in the open ocean, where the brown shrimp of the Carolina coast go every fall, and the migration patterns of tuna, swordfish, and other valuable food fish.

*See *Nuclear Reactors*, another booklet in this series, for a description of the fission process and how reactors operate.

†For a full discussion of other aspects of this topic, see *Fallout from Nuclear Tests*, another booklet in this series.



Navy men preparing for undersea research by feeding Tuffy, a friendly porpoise, which later carried messages for them during the "Man-In-The-Sea" experiment. (Also see photos page 12.)

These are just a few of the answers we seek from the world ocean —answers important for more productive fisheries, more accurate long-range weather forecasting, possible control of hurricanes and typhoons, pollution control, safer and more economical shipping, better recreation, and numerous other matters that bear on our health, well-being, and day-to-day lives.

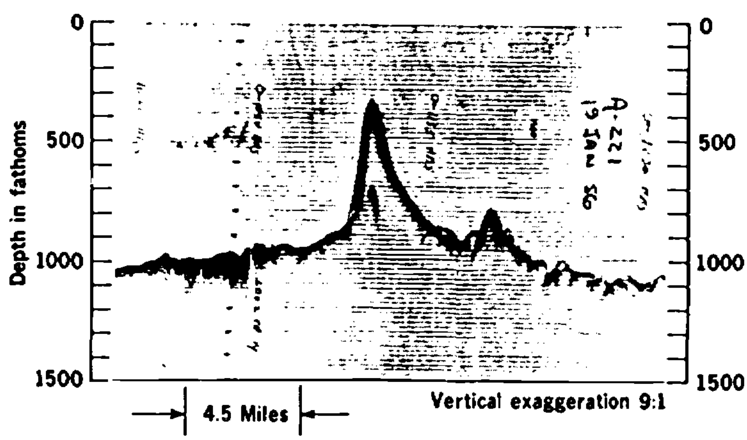
On all these endeavors the ocean exerts a major influence. And in each, atomic energy is helping assemble and interpret answers.

THE WORLD OCEAN

But what of this environment into which, armed with the atom, we plunge with such enthusiasm and expectations? A portrait is in order, which must be brief, for not all the books ever written about the sea have yet described it fully.

The world ocean covers 70.8% of our planet. It contains 324,000,000 cubic miles of seawater. Living in it are upwards of a million different species of plants and animals. They range from one-celled organisms that can only be seen with a microscope to the largest creature ever to have lived on this earth—the giant blue (or sulfur-bottom) whale, captured specimens of which have exceeded 90 feet in length and 100 tons in weight.

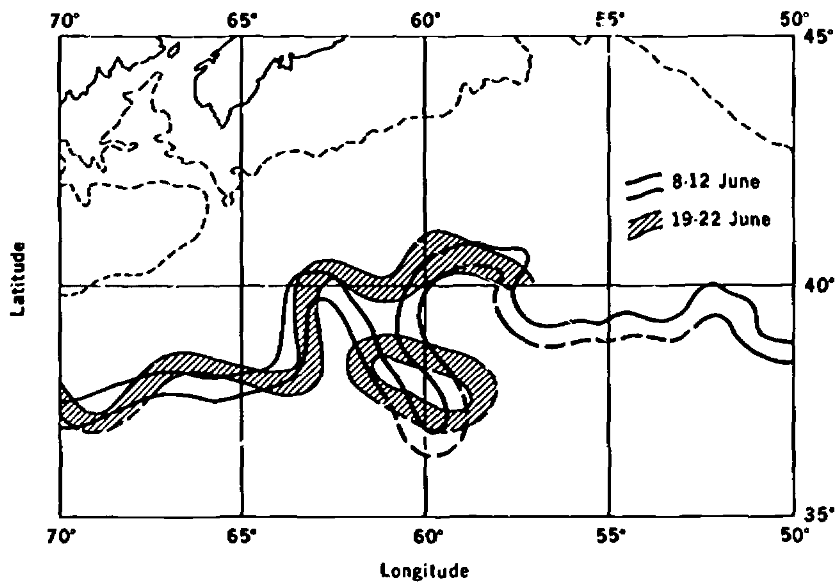
The ocean's depth ranges from 600 feet or less above continental shelves to more than 35,000 feet at the Marianas Trench. The mean depth is 12,451 feet. Sea bottom topography includes wide plains, the world's longest mountain range, steeply rising individual truncated peaks called *guyots* (pronounced gee-ohs), gentle slopes, narrow canyons, and precipitous escarpments. Mountains higher than Everest rise from the ocean floor and never pierce the surface.



Underwater mountain traced by the Woods Hole Oceanographic Institution echo sounder in the Caribbean area. Depth is determined by the time it takes the sound emitted by the instrument to go to the bottom and return to the surface.

Ocean Movements

The ocean is constantly in motion —not just in the waves and tides that characterize its surface but in great currents that swirl between continents, moving (among other things) great quantities of heat from one part of the world to



Six ships checking the Gulf Stream's course through the Atlantic Ocean over a 2-week period found the variations shown above. The infrared film photograph shows the edge of the Gulf Stream. The visible line between the Gulf Stream, which is on the right, and Labrador water is made by Sargassum weed concentrated at the interface.

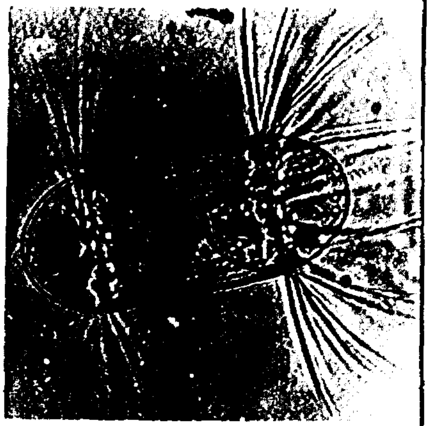
another. Beneath these surface currents are others, deeply hidden, that flow as often as not in an entirely different direction from the surface course.

These enormous "rivers"—quite unconstant, sometimes shifting, often branching and eddying in a manner that defies explanation and prediction—occasionally create disastrous results. One example is El Niño, the periodic catastrophe that plagues the west coast of South America. This coast normally is caressed by the cold, rich Humboldt Current. Usually the Humboldt hugs the shore and extends 200 to 300 miles out to sea. It is rich in life. It fosters the largest commercial fishery in the world and is the home of one of the mightiest game fish on record, the black marlin. The droppings of marine birds that feed from its waters are responsible for the fertilizer (guano) exports that undergird the Chilean, Peruvian, and Ecuadorian economies.

Every few years, however, the Humboldt disappears. It moves out from shore or simply sinks, and a flow of warm, exhausted surface water known as El Niño takes its place. Simultaneously, torrential rains assault the coast. Fishes and birds die by the millions. Commercial fisheries are closed. The beaches reek with death. El Niño is a stark demonstration of man's dependence on the sea and why he must learn more about it.

There are other motions in the restless sea. The water masses are constantly "turning over" in a cycle that may take hundreds of years, yet is essential to bring oxygen down to the creatures of the deeps, and nutrients (fertilizers) up from the sea floor to the surface. Here the floating phytoplankton (the plants of the sea) build through photosynthesis the organic material that will start the nutrient cycle all over again. Enormous tonnages of these tiny sea plants, rather than being rooted in the soil, are separated from solid earth by up to several vertical miles of saltwater. Sometimes, too, there is a more rapid surge of deep water to the surface, a process known as upwelling.

Internal waves, far below the surface, develop between water masses that have different densities and between which there is relative motion. These waves are much like the wind-driven waves on the surface, though much



A dividing cell of the diatom Corethron hystrix. *Diatoms, one-celled photosynthetic plants, are the primary producers of organic matter in fresh waters.*

bigger: Internal waves may have heights of 300 feet or more and be 6 miles or more in length!

Among other motions of the sea there are landslides, or turbidity currents, which are great boiling mixes of mud, rock, sand, and water rushing down submarine mountainsides at speeds of a mile a minute. They destroy everything in their paths and spread clouds of debris over the abyssal plains like a sandstorm, producing fanlike deposits radiating far out from the base of the slope. And there are tsunamis, or seismic sea waves—popularly misnamed "tidal waves"—that transmit energy from undersea earthquakes or volcanic eruptions. At sea, these waves are only a few inches high,

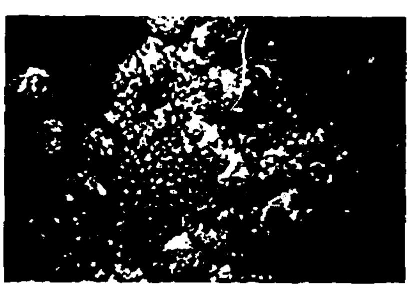
Ocean currents feed sand from nearby beaches into this "sandfall", which is about 30 feet high, in a submarine canyon off Baja California.

but they may travel great distances at 500 miles an hour. As they approach the shoaling waters of a coast, they are slowed to about 30 miles an hour and build up great surface waves capable of destroying harbor and coastal installations.

A Mix of Elements

The sea is a chemistry, too. Over 60 elements have been discovered in measurable amounts in solution or in suspension in the ocean. Many of these are in the form of salts, making seawater a highly efficient electrolyte, and a most corrosive fluid. The study of corrosion and techniques for combatting it is a continuous one in which nuclear energy already has a principal role.

Because the sea is so much a chemistry, it is a potential source of minerals for the world's growing industrial appetite. All of our magnesium and most of our bromine already are extracted directly from seawater. Oil and sulfur are mined from the sea floor or beneath it, as are coal (United Kingdom and Japan), iron ore (Japan), tin (Thailand and United Kingdom), diamonds (Southwest Africa), and gold (Alaska). In the layered sediments that cover the ocean-basin floors to depths of thousands of feet, geologists believe there also may be found some missing chapters of earth history.



Nodules such as these containing manganese cover millions of undersea acres on the ocean floor. Many nodules are rich in nickel, cobalt, zirconium, and copper. Metallurgists are seeking ways to recover the metals from these deposits.

The ocean, by and large, is an opaque fluid through which light travels only a few hundred feet and most other radiant energy not much more than a few yards; yet through this same fluid, sound waves, by contrast, have been transmitted and received over distances of many thousand miles.

The Sea's Interfaces

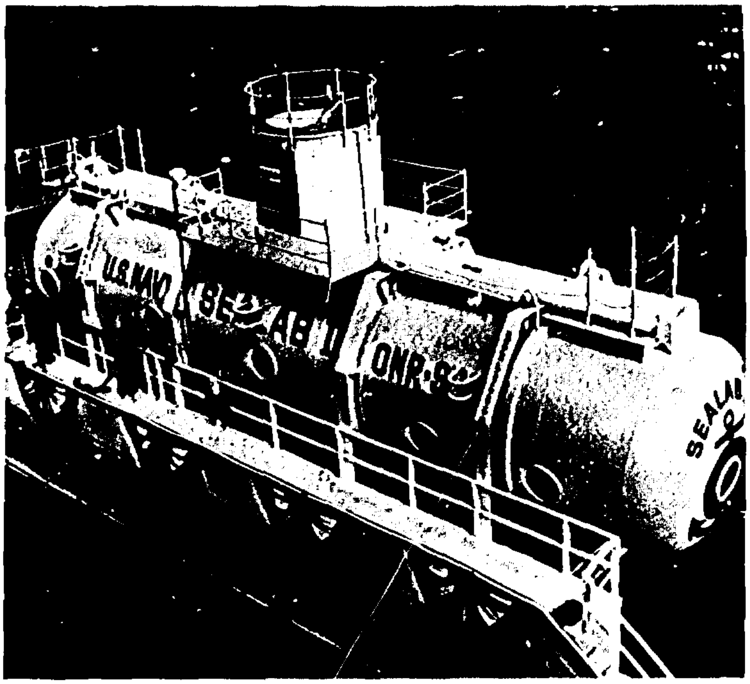
What of the interfaces of the sea? Above three-quarters of the globe, water and air are in constant contact, continually exchanging heat and moisture. This is a major factor in the making of weather and climate. The sea constantly feeds electricity into the atmosphere, primarily through the electron-scrubbing action of tiny popping bubbles at the sea surface. It also lifts tiny crystals of salt and the remains of microscopic sea creatures into the air. Perhaps these are the nuclei on which moisture condenses to trigger hurricanes, since it is the latent heat of vaporization of air, made over-moist by long travel over the tropical sea, that provides a hurricane's energy.

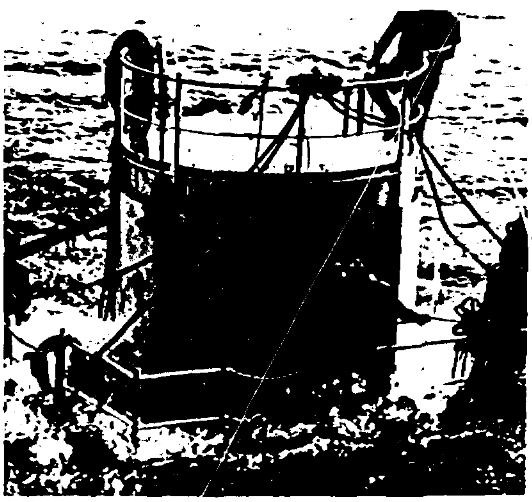
Along its land edges, the sea is constantly working on the shore—sometimes gently, sometimes violently—breaking down rock cliffs, opening bays and harbors, closing channels and inlets, smashing breakwaters and seawalls, and moving sand up and down and to and from beaches.

The Sea's Resources

In summary, then, the ocean, the largest single geographical feature of our planet, is infinitely varied and infinitely complex. We are learning it bears on our day-to-day living in ways we never suspected. It is the largest resource of food for our exploding population, the largest resource of minerals with which to support the world's burgeoning industries, the largest resource of energy, and, of course, it is the largest supply of water. It is mankind's largest dumping ground for the wastes of cities and industries. It is the source of much pleasure and recreation.

Men already have lived experimentally for weeks at a time on the bottom of the ocean. Both sea floor laboratories and military bases are being planned or, in a few cases, installed. Sea floor mining complexes are in the conceptual design stage. It is only a matter of time before recreational "aquotels" are built safely below the sea's restless surface. Private sports submarines are an actual, though costly, reality. It is not inconceivable that in the not-too-distant future human beings may overflow the land into complete, self-sufficient communities below the oceans.





In 1965 the U. S. Navy conducted a 45-day experiment in its "Man-In-The-Sea" program in which 10 aquanauts lived and worked 205 feet below the surface of the sea off La Jolla, California. Their undersea base was Sealab II shown at her christening above and during final checkout before descent. The aquanauts conducted experimental salvage operations, marine research, and underwent a series of physiological and human performance tests.

NUCLEAR ENERGY'S ROLE

The role of nuclear energy in the study, exploration, and utilization of the world ocean is best defined by citing the specific oceanographic interests of the U. S. Atomic Energy Commission (AEC): Development of better instruments and devices for work and study in the ocean, development of ever-stronger national sea power, conversion of seawater to fresh water, possible modification of ocean boundaries, purely scientific studies to advance knowledge, and, indirectly at least, improving the state of oceanographic engineering. Among the technological products of the nuclear age are radionuclides, neutron sources and other radiation sources, radioisotope heat and electric generators, and nuclear reactors. All these are applied to ocean-related endeavors.

Several divisions of the AEC have important oceanic interests. These range from pure oceanographic research to development of specific instruments, nuclear reactors, radioisotopic power sources, and other devices for use in or under the ocean. The AEC also conducts extensive marine environmental studies to monitor the effects or ensure the safety of specific projects involving nuclear energy. A statistical summary of specific AEC programs in oceanography is shown in Table I on page 14.

Radionuclides in the Sea

Before we can follow the atom down into the sea, we must understand something about the potentials, both good and bad, of this incursion of one of our most advanced technologies into one of earth's least understood environments. This adventurous probing has ramifications for studying both man-produced radioactivity in the sea and the ocean itself as an uncontaminated environment.

Radionuclides (radioactive atoms) can find their way into the sea from natural radiation sources or from nuclear energy operations undertaken by the United States and other countries since 1945. Specific man-made sources in the past may have included nuclear weapons tested in the atmosphere and under water, the cooling water and wastes

TABLE I

AEC OCEANOGRAPHY PROGRAM	1968 Expenditures Estimate
Research Activities	
Division of Biology and Medicine Studies of uptake, concentration, distribution and effects of radioisotopes on marine life, of geochemical cycling of elements, and of geophysical diffusion and transport.	$ 4,000,000
Division of Research Geological dating of corals and other marine and terrestrial materials.	25,000
Division of Isotopes Development Radioisotope applications to devices for marine systems, such as current meters, analysis and recovery of sedimentary minerals, and underwater sound transmission.	190,000
Division of Reactor Development and Technology Studies of factors affecting dissolution and dispersal of accidentally released radionuclides, and site evaluations.	197,000
Division of Space Nuclear Systems Nuclear power sources for aerospace applications.	275,000
Division of Military Applications Ocean environmental observation and prediction.	850,000
Total—Research Activities	5,537,000
Engineering Activities	
Division of Reactor Development and Technology Radioisotope and reactor power development.	5,900,000
Division of Naval Reactors Deep submergence research vehicle.	1,320,000
Total—Engineering Activities	7,220,000
Total—AEC Oceanographic Activities	12,767,000

The Nansen bottle, shown being attached to a hydrographic wire, is one of the standard tools of oceanology. When a bottle reaches a desired depth, a sliding weight tips it upside down to collect seawater samples. Thermometers on the sides of the bottles record temperature. The device was designed by the Norwegian oceanographer and explorer, Fridtjof Nansen. (See photo on page 56.)

of nuclear reactors, laboratories and nuclear-powered ships, containers of radioactive waste disposed of at sea*, radioisotope energy devices, and intentional injection of radioisotope tracers for scientific research. In the future, they may also include reentry from space of upper-stage nuclear rockets or satellite-borne nuclear energy sources.

In order to evaluate the effects of these materials in the ocean environment, it is necessary to know many things. Just how much radiation is introduced? In what form? Where geographically? How are these radionuclides dispersed or concentrated physically, chemically, biologically, and geologically? What is the net result in each case now, and what will it be many years hence?

These questions are not answered easily. There is, as yet, no satisfactory laboratory substitute for the open ocean. Research for the most part must be conducted at sea, where tests and measurements are difficult at best, and where results therefore are often suspect. Further, if we are to study the effects of man-induced changes in a natural environment, it would have been advantageous to have known the nature of that environment before the

*For a full discussion of this topic, and the safety measures taken by the AEC in connection with it, see *Radioactive Wastes*, another booklet in this series.

Table II CONCENTRATION AND AMOUNTS OF 42 OF THE ELEMENTS IN SEAWATER

Element	Concentration (mg/l)	Amount of element in seawater (tons mile^3)	Total amount in the oceans (tons)
Chlorine	19,000.0	89.5×10^6	29.3×10^{15}
Sodium	10,500.0	49.5×10^6	16.3×10^{15}
Magnesium	1,350.0	6.4×10^6	2.1×10^{15}
Sulphur	885.0	4.2×10^6	1.4×10^{15}
Calcium	400.0	1.9×10^6	0.6×10^{15}
Potassium	380.0	1.8×10^6	0.6×10^{15}
Bromine	65.0	306,000	0.1×10^{15}
Carbon	28.0	132,000	0.04×10^{15}
Strontium	8.0	38,000	$12,000 \times 10^9$
Boron	4.6	23,000	$7,100 \times 10^9$
Silicon	3.0	14,000	$4,700 \times 10^9$
Lithium	0.17	800	260×10^9
Rubidium	0.12	570	190×10^9
Phosphorus	0.07	330	110×10^9
Iodine	0.06	280	93×10^9
Barium	0.03	140	47×10^9
Indium	0.02	94	31×10^9
Zinc	0.01	47	16×10^9
Iron	0.01	47	16×10^9
Aluminum	0.01	47	16×10^9
Molybdenum	0.01	47	16×10^9
Selenium	0.004	19	6×10^9
Tin	0.003	14	5×10^9
Copper	0.003	14	5×10^9
Arsenic	0.003	14	5×10^9
Uranium	0.003	14	5×10^9
Nickel	0.002	9	3×10^9
Vanadium	0.002	9	3×10^9
Manganese	0.002	9	3×10^9
Antimony	0.0005	2	0.8×10^9
Cobalt	0.0005	2	0.8×10^9
Caesium	0.0005	2	0.8×10^9
Cerium	0.0004	2	0.6×10^9
Silver	0.0003	1	5×10^8
Cadmium	0.0001	0.5	150×10^6
Tungsten	0.0001	0.5	150×10^6
Chromium	0.00005	0.2	78×10^6
Thorium	0.00005	0.2	78×10^6
Lead	0.00003	0.1	46×10^6
Mercury	0.00003	0.1	46×10^6
Gold	0.000004	0.02	6×10^6
Radium	1×10^{-10}	5×10^{-7}	150

Adapted from *The Mineral Resources of the Sea*, by John L. Mero, American Elsevier Publishing Company, New York, 1964.

changes were introduced—which, by and large, in the case of the ocean we do not. So we must start with a contaminated environment and try to separate what we have put there ourselves from what would have been there anyway. It isn't an easy task to make the physical and biological observations that will make this distinction.

Many sea creatures are efficient, selective concentrators of "trace elements", which occur in seawater only in minute portions. These elements are difficult enough to detect qualitatively and all but impossible to analyze quantitatively. Yet among the elements the sea's plants and animals concentrate are the very materials with which we are apt to be most concerned: Strontium, cesium, cerium, ruthenium, cobalt, iodine, phosphorus, zinc, manganese, iron, chromium, and others. Radioisotopes* of all these elements occur as by-products of human nuclear activities. Many concentrating organisms are microscopic in size and are frequently impossible to raise in captivity. It is apparent that we are faced with a research program of considerable challenge and proportion.

We need to know *how* each marine species concentrates. Is it from the food it eats, by absorption from the water, or both? Does it concentrate an element by continuous accumulation, or is there a constant turnover of the material in the organism's system? (In the first case, once the creature became radioactive it would remain so throughout its life or until the radioactivity decayed. In the second case, however, the radioactivity might be a transient condition, assuming the creature could find its way into uncontaminated water and were able to flush itself.) Obviously, both the cycling time of the radioisotope in the organism and its radioactive half-life† must be taken into account.

Even if we should manage to identify all the marine concentrators and gain some insight into their metabolic processes, this would be only a first step. For example, one tiny form of planktonic protozoan, *acantharia*, con-

*Radioisotopes, unstable forms of ordinary atoms, are distinguishable by reason of their radioactivity, not by their biological or chemical activity.

†The time in which half of the atoms in a quantity of radioactive material lose their radioactivity.

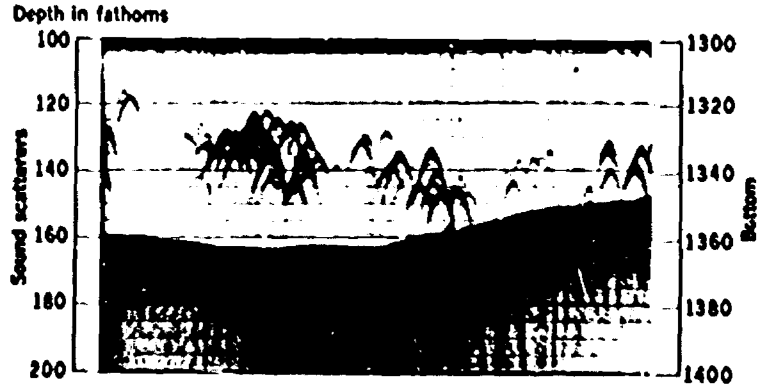
centrates up to 15% of its own weight of strontium, including the radioisotope strontium-90. It is eaten by larger zooplankton (animals), such as copepods, which are eaten by little fish, which, in turn, are eaten by bigger fish, etc. Somewhere along this food chain, perhaps, a fish will come along that is favored for human dinner tables. How much strontium-90 has *that* fish accumulated through swallowing its prey and by absorption from the water? Is the radioactivity in its scales, bones, viscera, and other usually uneaten portions, or in its flesh?

It is probable, though as yet by no means proven, that among the million or so oceanic species of plant and animal life, there are concentrators of virtually all the 60 or more elements found in seawater. To identify and study them is an enormous undertaking, which is often possible only by using radioisotopes as tools.

And what of the immediate and genetic effects of radiation on each species? Studies of reef fish in the nuclear testing area in the Marshall Islands have shown that radioiodine in the water caused thyroid gland damage long after the amount of radioiodine remaining in the water was too low to be detected. Studies of salmon in the Columbia River have shown some physiological variations between those fish whose eggs and young were reared in radioactive waters and those that were not, though these variations have not been determined to be statistically significant or different from variations caused by other contaminants.

Studies are being made of the reproductive efficiency and patterns of sea creatures in a radiation-contaminated environment, compared with those in an uncontaminated environment, to learn such things as the numbers, survival rates, and sex ratios of the offspring, and any genetic abnormalities or mutations. Many more studies are needed. Always, the task is made difficult by insufficient detailed knowledge of the original natural environment, the limitations of laboratory experiments, and the mechanics of trying to follow the reproductive cycles of free-floating or swimming organisms in any statistically meaningful manner through successive generations.

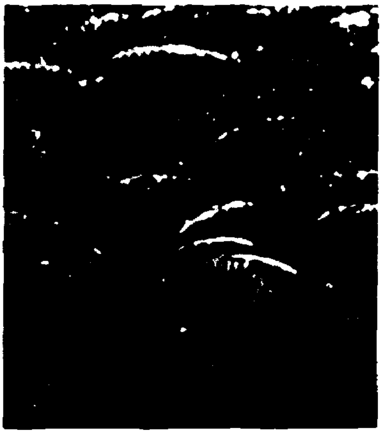
One obviously important kind of research deals with the rate, pattern, and means by which radionuclides are distributed into the sea from a point source, such as the mouth of a river or a nuclear test site. Transport and diffusion of radioactivity can be, and are, influenced by physical, chemical, biological, or geological means, separately or all at once. This has led the AEC to support scientific studies of currents, upwelling, downwelling, convergence, diffusion, mixing rates, air-sea interactions, chemical and geological processes in the sea, and the horizontal and vertical migrations of sea life.



This sound instrument record reveals the layers of planktonic sound scatterers on the continental slope east of New England. Each peak originates from an individual group of organisms.

In much of the ocean there is an acoustic "floor", known as the *deep scattering layer* (because of what it does to sound waves), which is believed to consist primarily of zooplankton. Every 24 hours the layer migrates up and down through several hundred feet of water. At night the countless small animals graze in the rich sea-plant pastures near the surface; during daylight, back at the lower level, they undoubtedly are heavily fed upon by larger animals. Over a period of time, the layer accounts for considerable vertical transport of materials. (See figure above.) Other life forms may move materials still farther down, or, in some instances, back up—as when the sperm whale descends to the depths to fight and best a giant squid, and then returns to the surface to eat it.

Constantly drifting downward is a great volume of material—the dead bodies, skeletons, excrement, and other waste from sea life at all depths. As it sinks there is a constant exchange of matter between it and the surrounding water through chemical, physical, and biological processes. Eventually, the molecules of material added to the bottom sediments may be returned to the water mass by bacteriological action or the eating and living habits of sea floor animals.

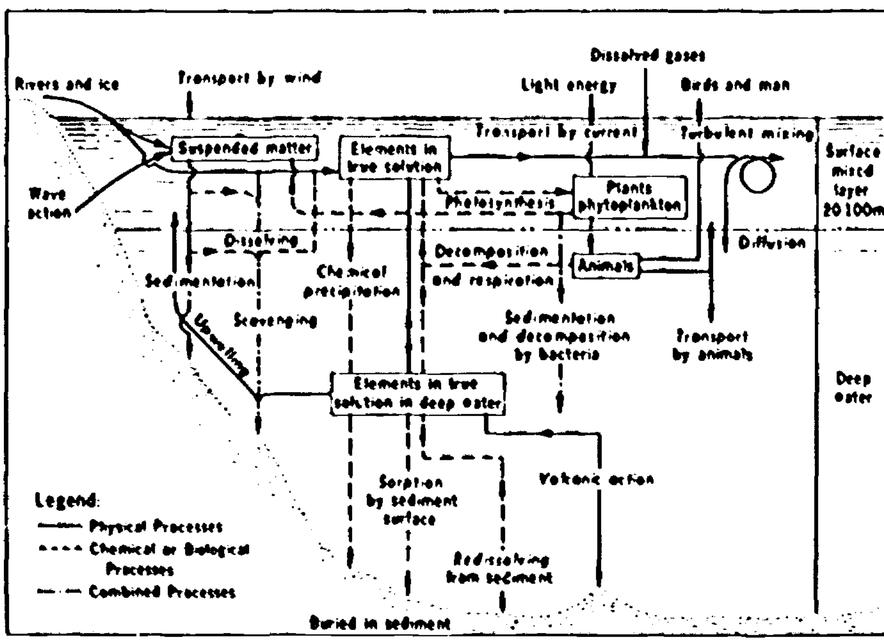


A school of skipjack tuna photographed from an underwater observation chamber on the research vessel Charles H. Gilbert.

Biological transport works in other ways, too. Most pelagic (free-swimming) fish are great travelers. They account for a tremendous movement of material, namely themselves, from one place to another. Tuna, swordfish, whales, porpoises, and sea birds may travel thousands of miles in a single year. Such migrations may serve, variously, as mechanisms for either dispersal or concentration of elements or nutrients. The anadromous (river-ascending) fishes, such as salmon, herring, sturgeon, and shad, concentrate in freshwater streams in untold numbers to spawn. After hatching, the young seek the ocean and scatter widely until they, too, feel the urge to return to the rivers and lakes whence they came, to spawn and die there as did their ancestors.

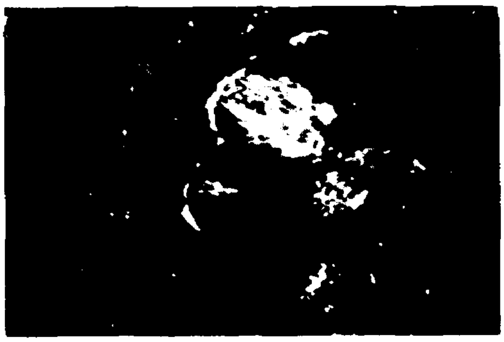
Ocean currents may transport concentrations of radionuclides essentially undiluted for thousands of miles. Surface currents move at speeds of up to five knots (nautical miles per hour). Normally current waters do not mix readily with the water mass through which they pass.

Because of the slowness of vertical circulation in the ocean, radionuclides deposited on the surface of the ocean may take a thousand years to reach the bottom. But the vertical transport sometimes is much more rapid: When the wind piles too much water against a coastline, the resultant downwelling (sinking) may move radionuclides suddenly into the deeper ocean. Or, conversely, when the wind and the rotation of the earth combine to force the surface water *away* from the coast, deep water may suddenly rise to replace it, a process known as upwelling.



Mechanisms of nutrient turnover in the sea.

Some recent evidence indicates that the passage of a hurricane across the ocean drives surface water out from the storm center in all directions. This, too, produces upwelling. If radionuclides fall on the Arctic ice pack or on the Greenland or Antarctic ice caps, it may be years before they are released to the sea. In more or less stable conditions at sea, radionuclides may remain trapped above the thermocline (a layer of sharp temperature change usually less than 100 meters below the surface) for a considerable period. Then a severe storm may destroy the thermocline and mix the waters to much greater depths.



Winds of 100 knots (about 115 mph) whip high waves in the Caribbean Sea east of Guadeloupe Island during a hurricane.

The process of diffusion in the ocean is not well understood, due both to the difficulty of the measurements that have to be made and to the variety of other factors affecting both vertical and horizontal transport of materials. Here again, however, the existence of radionuclides, introduced artificially at a known time and place, is materially aiding these investigations by making a particular water mass detectable and traceable.

In chemical oceanography the AEC is concerned with the fact that in some instances our society is introducing elements, ions, and compounds that have not been naturally found in the sea, as well as natural materials in greater concentration than is normal. These may combine with other materials in the sea, changing into new forms or substances, or removing them from solution entirely. Any change in the chemical composition of the ocean is quite likely to have biological effects, some of which may prove detrimental to man.

A disturbance of the chemical balance of the sea is thought to be responsible, at least in part, for the periodic, disastrous plankton "blooms" known as "red tides". Such a sudden, explosive overpopulation of plankton is a natural phenomenon, but one that can be triggered by man-made pollution. When it occurs, plankton multiply so rapidly that the oxygen in the water is depleted and many fish die from suffocation.

Fortunately, nuclear energy operations account for an extremely small portion of the chemical contamination of the sea, when contrasted with the tremendous volume of poisons dumped daily into it in the form of other industrial and municipal waste and agricultural pesticides.

Research Projects

The AEC supports oceanographic research conducted by its own laboratories and by other federal agencies, as well as by non-government research scientists. The Environmental Sciences Branch of the Division of Biology and Medicine has begun the long and complex task of unraveling the mystery of the fate of radionuclides in the ocean. Valuable techniques have been developed for the intentional injection of radioisotopes into the sea for specific research. Scientists are now able to conduct investigations that were never before possible. In some instances, traditional scientific concepts and theories have been shattered, or at least severely shaken, by new evidence gathered by radioisotope techniques.

Since 70% of the earth's surface is water, at least 70% of the radioactive debris lofted into the stratosphere during atmospheric nuclear weapons tests falls into the ocean. An additional small proportion finds its way into the sea as the run-off from the land. In the case of tests at sea, the majority of radiation immediately falls into the water nearby. For this reason, the ocean around the sites in the Marshall Islands where U. S. tests were conducted has provided a unique opportunity to study the effect of large concentrations of radionuclides. Particularly significant studies have been conducted of the absorption of radionuclides by plants and animals living on nearby reefs and islands, and of both lateral and vertical diffusion rates of elements in the open ocean.*

The 1954 nuclear test at Eniwetok Atoll produced heavier-than-expected local radioactive fallout. Since then, both

* For more details of these studies, see *Atoms, Nature, and Man*, a companion booklet in this series.

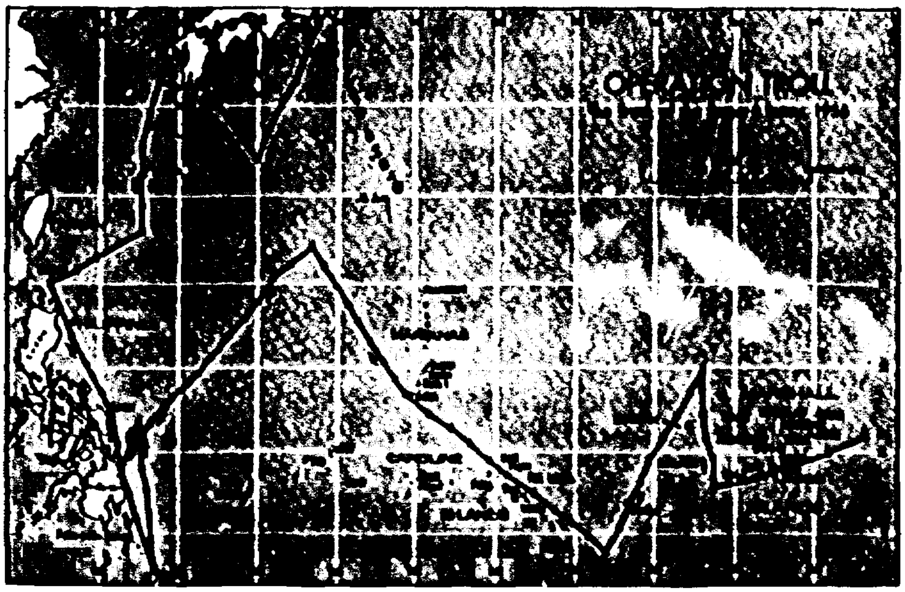
Autoradiograph of a plankton sample collected from a Pacific lagoon a week after a 1952 nuclear test, showing concentration of radioisotopes (bright areas).

American and Japanese scientists have studied water-mass movement rates, using the fallout radionuclides strontium-90 and cesium-137 themselves as tracer elements. These nuclides produced in the test have been detected at depths down to 7000 meters in the far northwestern Pacific in the vicinity of Japan.

If this results from simple eddy diffusion, as some scientists believe, it is a case of diffusion at a very high rate. Other scientists suggest that other factors may have contributed to the vertical transport of the radionuclides to these depths. Still others believe that the strontium-90 and cesium-137 might not have originated with the U. S. Pacific tests at all, but rather with Russian tests in the Arctic taking place at about the same time. They propose the theory that a syphoning effect in the Bering Strait causes a current to flow out of the Arctic Ocean and down under the surface waters of the western Pacific. In support of this, Japanese researchers cite a dissolved oxygen content where these measurements were made that is different from that of other deep water in the area. If this theory should be proved correct, it would be the first indication that such a current exists.

Similar investigations have been conducted of the variations in depth of strontium-90 concentration in the Atlantic Ocean. In February 1962, when fallout from 1961 nuclear tests was high, tests south of Greenland showed that mixing of fallout was fairly rapid through the top 800 meters of water. At greater depths a colder, saltier layer of water contained only about half as much strontium-90, confirming other evidence that interchange between water masses of different physical and chemical properties is comparatively low.

Work such as this has emphasized the difficulty in making meaningful measurements of man-made radiation in the ocean. One problem is to separate the artificially produced radiation from the natural radiation, namely that from potassium-40 (which accounts for 97% of oceanic radiation) and from the radionuclides, such as tritium, carbon-14, beryllium-7, beryllium-10, aluminum-26, and silicon-32, created in the stratosphere naturally by cosmic-ray bombardment.



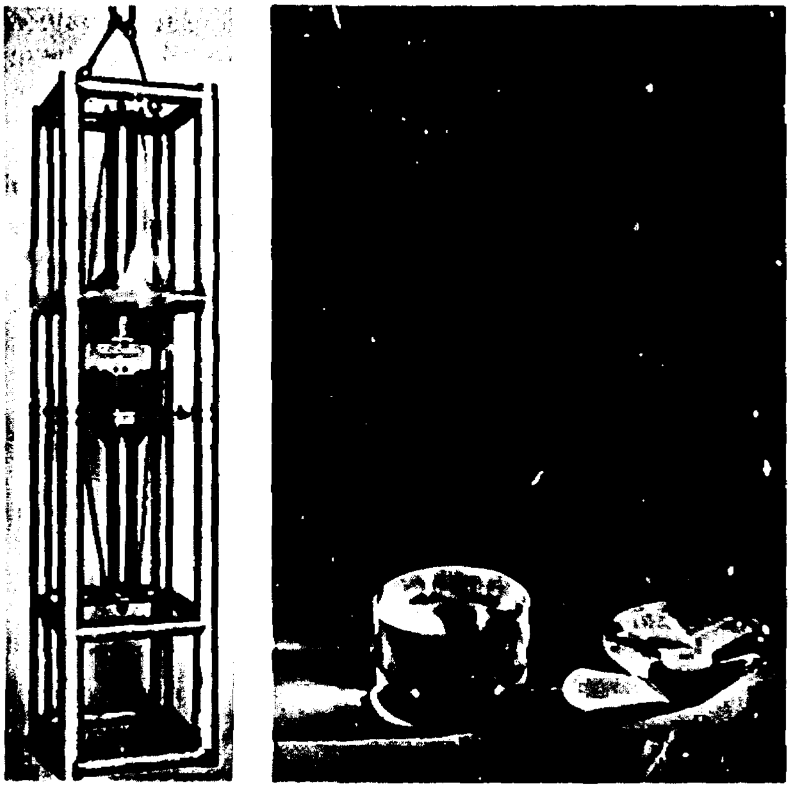
In 1955 a scientific team aboard the U. S. Coast Guard vessel Roger B. Taney *conducted a survey of ocean fallout in the western Pacific. They collected marine organisms and water samples at various depths on their 17,500-mile, 7-week journey.*

Another problem is the sheer physical size of the water sample required to get any measurements at all. Up to now there has been no truly effective radiation counter that can be lowered over the side of a ship to the desired depth. It is often necessary to collect a sample of many gallons at great depths and return it to the surface without its being mixed by any of the intervening water. This is difficult at best, and only rather primitive methods have been developed. None is more than partly satisfactory. A standard system is to lower a large, collapsed polyethylene bag to the desired depth, open it, fill it, and close it again, all by remote control, and then gingerly and hopefully return it to the surface. Results do not always agree among samples taken at the same location by different methods or by different scientists. There is still no universal agreement among scientists as to the quantitative validity of any of the measurements, although as more and better data are gathered there tends to be a greater concurrence.

Fifty-gallon sampler ready to be lowered over the side of the research vessel Atlantis II *in the North Atlantic. Such devices are used to obtain samples at fixed intervals from the sea surface to the bottom. The water is analyzed for radioisotopic content.*

Recently, under an AEC contract, a detector for direct measurements of gamma radiation* in the deep ocean was developed for the Institute of Marine Sciences, University

*Gamma rays are high-energy electromagnetic radiation, similar to X rays, originating in the nuclei of radioactive atoms.

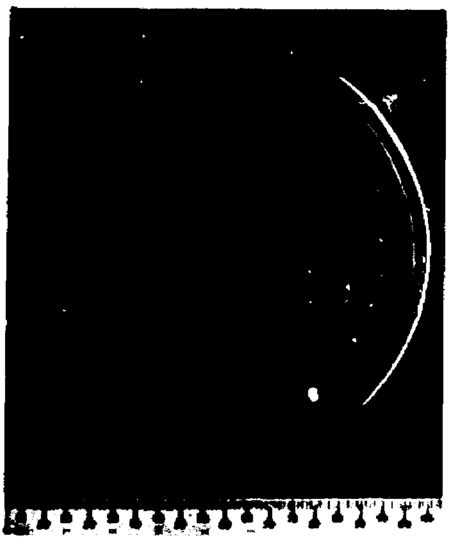


Scintillation counter for use in the deep ocean, showing constituent parts (right). The plastic discs are the radiation detectors.

of Miami, by the Franklin GNO Corp. (See figure above.) This unit incorporates two of the largest plastic scintillation counters* ever used in the ocean — each is 16 inches in diameter by 12 inches thick. This apparatus may permit direct qualitative and quantitative measurement of radiation at great depths by techniques that will be eminently more satisfactory than water sampling. Already tests with the detector have disclosed the existence of cosmic-ray effects at much greater depths than heretofore known.

*Instruments that detect and measure radiation by recording the number of light flashes or scintillations produced by the radiation in plastic or other sensitive materials.

Biologists from Woods Hole Oceanographic Institution in Massachusetts for the first time have been able to measure the rate of excretion of physiologically important fallout radionuclides by several species of zooplankton — *pteropods*, *pyrasomas*, *copepods*, and *euphausids*. Radioactive zinc and iodine, it was learned, are excreted as soluble ions, while iron and manganese appear as solid particles. However, the extent to which the intake and excretion of radionuclides and the vertical migration of zooplankton contribute quantitatively to the transport of radioactivity across the thermocline (and into the ocean deeps) still can only be guessed.



Zooplankton, mostly copepods, collected with automatic underwater sampling equipment on board the nuclear submarine Seadragon *while cruising under the Arctic ice.*

Other plankton research at Woods Hole uses radioactive carbon-14 and phosphorus-32 as tracers to evaluate rates of growth and nutrient assimilation by algae (floating green plants). These investigations have revealed that the presence or absence of minute quantities of nutrient minerals in seawater affects the rate at which the algae produce oxygen by the process of photosynthesis. Since the energy of all living things — including man — is also made available by photosynthesis, and since most of the photosynthesis on earth is performed by algae afloat in the oceans, it is apparent that this research is of more than academic interest. Algae, the original energy-fixers of the "meadows of the sea", are also the original food source for the billions of aquatic animals, and may some day prove a source of food for a mushrooming human population.

In a project with more immediate application, extensive biological and environmental studies of the Eniwetok Atoll area in the Pacific were conducted prior to the first nuclear testing there in 1948, and these studies have continued ever since. Early in the test series the Japanese, who were at first concerned with the possible contamination of their traditional marine food supplies, were invited

This shell of the giant clam Tridacna gigas *shows the position of a layer of strontium-90 absorbed in 1958 (black line) and in 1956 (white line). The inside of the shell (light layers) was deposited in 1964 when the clam was collected at Bikini Atoll by scientists from the University of Washington, Seattle.*

to participate in these studies. Fisheries radiological monitoring installations were established in Japan and the U. S. (The latter was established by the AEC and administered by the U. S. Food and Drug Administration.) Neither station encountered any radiological contamination of tuna or other food fish, and the American unit has now been closed.

Groups that have cooperated with the AEC in marine radiobiological research are the University of Hawaii, University of Connecticut, Virginia Fisheries Laboratory, University of Washington, U. S. Office of Naval Research, and U. S. Bureau of Commercial Fisheries.

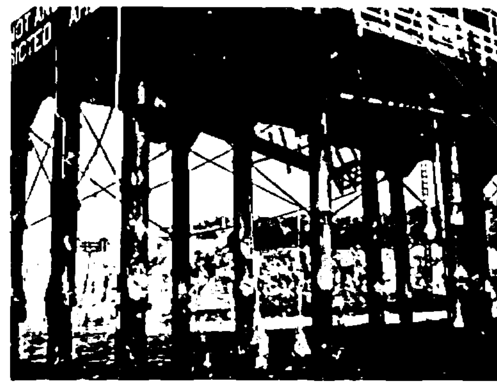
At the Bureau of Commercial Fisheries Radiobiological Laboratory in Beaufort, North Carolina, a cooperative effort of the AEC and the BCF is concerned with learning the effects of radioactive wastes on one of America's most valuable marine resources—the tidal marshlands and estuaries that are essential to the continued well-being of some of our important commercial fisheries.

Table III RADIOISOTOPES THAT MIGHT BE FOUND IN AN ESTUARINE ENVIRONMENT

Isotope	Half-life
Iodine-131	8.05 days
Barium-140—Lanthanum-140	12.8 days—40 hours
Cesium-141	32.5 days
Ruthenium-103—Rhodium-103	40 days—57 minutes
Zirconium-95—Niobium-95	65 days—35 days
Zinc-65	245 days
Cerium-144	285 days
Manganese-54	314 days
Ruthenium-106—Rhodium-106	1 year—30 seconds
Cesium-137	30 years
Potassium-40	1.3×10^9 years

(Reprinted from *Radiobiological Laboratory Annual Report*, April,1, 1964, page 50.)

The project has determined that radionuclides are removed from waters in an estuarine environment by several physical, chemical, and biological means. For example, radionuclides are absorbed in river-bed sediments at a rate varying directly with sediment particle size. Mollusks, such as clams, marsh mussels, oysters, and scallops, not only assimilate radionuclides selectively, but do so in sufficient quantity and with sufficient reliability to be useful as indicators of the quantity of the isotopes present. Clams and mussels are indicators for cerium-144 and ruthenium-106, scallops for manganese-54, and oysters for zinc-65 (most of which winds up in the oyster's edible portions). It was learned that scallops assimilate more radioactivity than any other mollusk. Of the total radioactivity, manganese-54 accounts for 60%: The scallop's kidney contains

On the left are mussels collected near the Columbia River in an environment containing abnormal amounts of zinc-65. On the right are mussels suspended in seawater in research to determine how fast they lose their zinc-65 radioactivity. (Photograph taken at low tide.)

100 times as much manganese-54 as any of the other tissues and 300 times as much as the muscle, the only part of the scallop usually eaten in this country.

In a surprising unintended result, it was determined that one acre of oyster beds, comprising 300,000 individual oysters, may filter out the radionuclides from approximately 10,000 cubic meters (18 cubic miles) of water per week!

The Radiological Laboratory scientists also have found that plankton are high concentrators of both chromium-51 and zinc-65, and that zinc apparently is an essential nutrient for all marine organisms. Some plants and animals appear to reach a peak of radionuclide accumulation quickly, which then tapers off even though the radiation concentration in the water is unchanged.

While the AEC's oceanographic research budgets have not been large, they have contributed materially to knowledge of the oceanic environment. AEC-sponsored research at Scripps Institution of Oceanography has determined by a process known as neutron activation analysis* that the concentration of rare earth elements in Pacific Ocean

*A method involving use of nuclear reactors or accelerators for identifying extremely small amounts of material. See *Neutron Activation Analysis*, a companion booklet in this series.

waters appears to be only about one hundredth of the level previously reported. By analysis of naturally occurring radioisotopes, they have also discovered that it takes from one million to 100 million years for lithium, potassium, barium, strontium, and similar elements introduced into the ocean from rivers to be deposited in the bottom sediments. Aluminum, iron, and titanium are deposited in from 100 to 1000 years. They have also found that sedimentation occurs in the South Pacific at a rate of from 0.3 to 0.6 millimeter per thousand years, in the North Pacific at a rate several times that figure, and in the basins on either side of the Mid-Atlantic Ridge at a rate of several millimeters per thousand years.

The University of Miami has successfully developed two methods for determining the ages of successive layers of deep ocean sediments based on the relative abundances of natural radioelements, and thereby has established a chronology of climatic changes during the last 200,000 years during which the sediments were laid down.

The U. S. is not alone in its use of nuclear energy as a tool of science. The United Kingdom has carried out radiological studies of the marine environment for many years, particularly concentrating on the effects of radionuclides from nuclear power plants on the sea immediately contiguous to the British Isles. Both the European Atomic Energy Community and the International Atomic Energy Agency also encouraged marine radiological studies. Many laboratories and government agencies in Europe, North and South America, Africa, and the Middle East and Far East have well-established and productive programs under way.

Scientists in many parts of the world have used both natural and intentionally injected radiation to study the coastwise movement of beach materials. British experimenters, for example, activate sand with scandium-46 and are thus able to follow its movement for up to four months. Pebbles (shingle) coated with barium-140 and lanthanun-140 are also used as tracers and are good for 6 weeks. Scientists at the University of California trace naturally occurring radioisotopes of thorium, which may be introduced from deposits of thorium sands along river banks. These studies are of immediate practical importance, for each year the ocean moves billions of cubic yards of sand, gravel, shingle, and rock to and from beaches and along shores. This action destroys recreational beaches, fills channels, blocks off harbors, and in general rearranges the terrain, often at considerable cost and inconvenience to mariners and other people who use the coast.

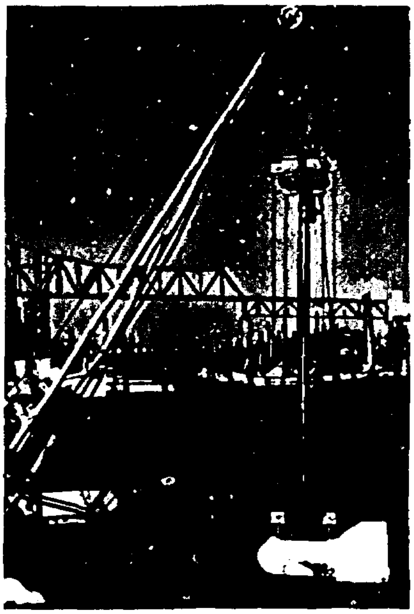
In another use of radioisotopes in marine research, studies at the AEC's Oak Ridge National Laboratory in Tennessee have revealed radioactivity in the scales of fish taken from waters affected by the laboratory's radioactive waste effluent. It was suggested that this phenomenon might be put to use as a tagging technique in fish-migration studies, and scientists are now working on a method using cesium-134 introduced into the fishes' natural diet.

Some of the most extensive studies of a marine environment ever conducted are those by the AEC, the Bureau of Commercial Fisheries, and the University of Washington in the Columbia River system and the nearby Pacific Ocean.

Isaacs-Kidd midwater trawl collects samples of oceanic animals off the Oregon Coast. These animals are then radioanalyzed to compare the quantity of radioisotopes associated with animals from various depths. The recorder at the trawl mouth indicates the volume of water filtered.

Operations at the AEC's giant Hanford facilities some 300 miles upstream from the ocean result in the release of small amounts of radioactivity to the river and also in raising the river-water temperature. This downstream research is to determine any effects of these changes, including any that might be detrimental to man. The research encompasses studies of the variations and distributions of the freshwater "plume"—the outflow from the rivermouth—extending into the nearby Pacific, sediment analyses, studies of the population dynamics of phytoplankton, and the transport of radionuclides through the food chain.

As so often happens with basic programs, this research has produced immediate benefits. New resources of marketable oceanic fish were discovered by the scientists at depths never before fished commercially (from the edge of the continental shelf to depths of 500 fathoms and greater). Similarly, commercial quantities of one species of crab have been discovered in the deeper ocean. Other findings indicate that crab populations may have seasonal up-and-down migrations that vary according to sex. It appears, in



This core sampler is used to obtain stream bed samples up to 5 feet long in the Columbia River. The samples are then analyzed for radioisotope content.

fact, that, except while mating and as juveniles, the male and female crab populations lead separate lives. This information is important both for more efficient fisheries and for improved conservation of the crab as a food resource.

The AEC is, in short, concerned with virtually every facet of basic oceanography, and with study of the sea as a whole, for radionuclides, like their nonradioactive counterparts, can and do become involved in every phase of the vast and complex ocean ecology. In the process of pursuing its research interests, it also provides oceanographers with a whole new family of tools for study. Let us now see how atomic instruments contribute to the growing knowledge of the sea.

Oceanographic Instruments

The ocean is both a complex and a harsh environment and its study has always demanded that designers of seaworthy instruments and sampling devices be both ingenious and experienced in shipboard requirements. Until recently,

This radioisotope powered swimsuit heater uses plutonium-238 to produce 420 watts of heat. Water, heated by the decay of ^{238}Pu, is pumped through plastic veins partially visible in the undergarment. The cylinder under the diver's arm contains 4 capsules of ^{238}Pu, and a battery-pump assembly is contained in the box at his feet. After preliminary tests at the Naval Medical Research Institute in Bethesda, Maryland, the unit will be used in Sealab III, the Navy's underwater research laboratory. The heater was developed by the AEC Division of Isotopes Development.

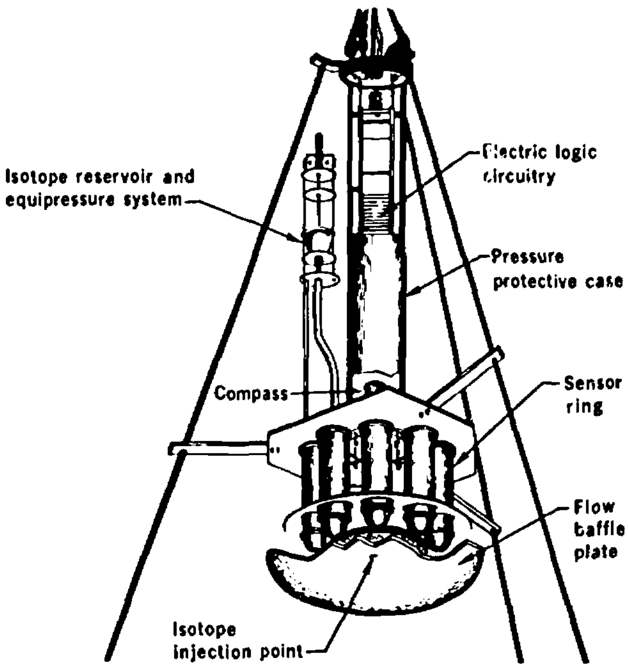
these devices tended to be rugged and simple, if not indeed crude. More refined, electronic instrumentation has begun to appear in recent years, but most designs still fail to pass the test of use at sea. Even among those that do pass, there is persistent difficulty in separating desired information-carrying signals from background and system-induced "noise". This has been a specific problem with current meters designed to be moored in the open ocean and also with one quite sophisticated gamma-ray detector.

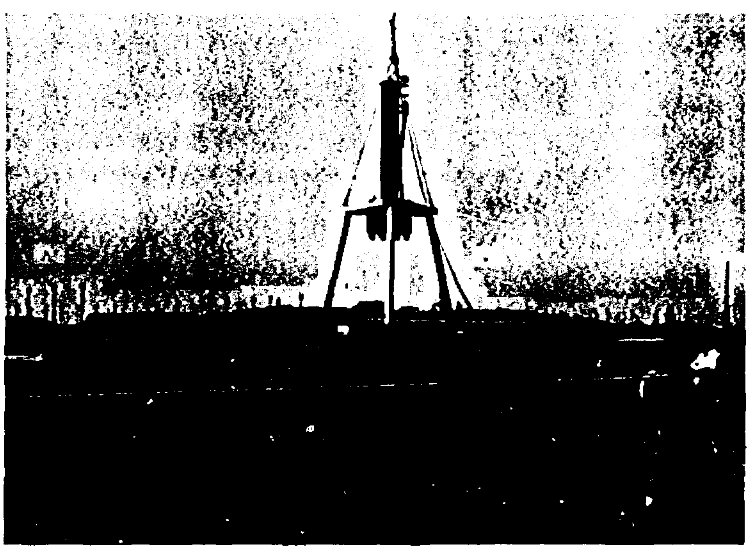
To meet the clear need for improved devices, as well as to support its own research and increase utilization of nuclear materials and techniques, the AEC Division of Isotopes Development encourages the development of oceanographic instrumentation. This comparatively young technology already has produced exciting results. The future may be even more revealing as nuclear energy is applied more and more to the study, exploration, and exploitation of the ocean.

Instruments that have been developed under the AEC program include a current meter, a dissolved-oxygen-content analyzer, and a sediment-density meter. A new, fast method for determining the mineral content of geological samples also has been perfected.

The **DEEP WATER ISOTOPIC CURRENT ANALYZER** (DWICA) was developed under a contract with William H. Johnson Laboratories, Inc. It relies on radioisotope drift time over a fixed course to measure seawater flow rates ranging from 0.002 to 10.0 knots. The device embodies 12 radiation sensors spaced equally in a circle around a radioisotope-injection nozzle. Current direction can be determined to within 15 degrees. The mass of tracer isotope injected is very small—less than 10 picograms* per injection—and the instrument can store enough tracer material to operate for a year. The tracer can be injected automatically at intervals from 2 to 20 minutes, depending on the current. The device sits on the sea floor, where its orientation to magnetic north can be determined within 2.5 degrees.

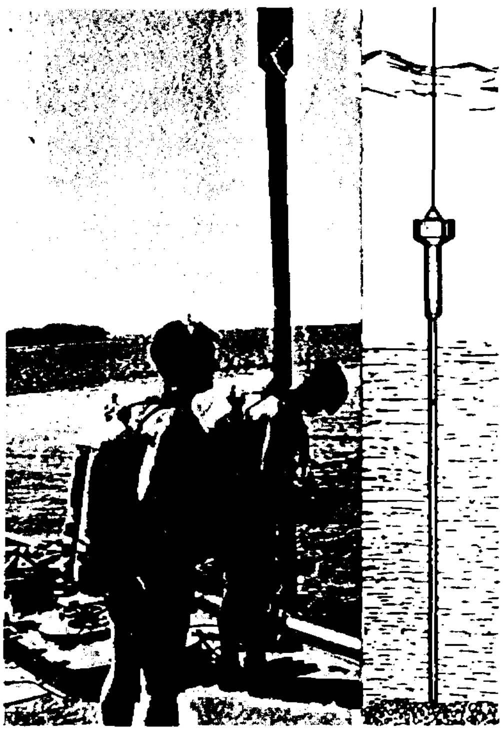
*A picogram is one trillionth (10^{-12}) of a gram.





The Deep Water Isotopic Current Analyzer.

A SEDIMENT DENSITY PROBE, developed under an AEC contract by Lane-Wells Company, employs gamma-ray absorption and backscatter properties* to determine the density of the sediments at the bottom of lakes, rivers, or the ocean, without the necessity of returning a sediment sample to the surface. It is expected that it can be modified to sense the water content of the sediments. These determinations are valuable not only for research, but also for activity that requires structures on the ocean floor, such as petroleum exploration and naval operations.



The Sediment Density Probe. The drawing shows the complete probe.

The unit consists of a rocket-like tube 26 feet long and about 4 inches in diameter, containing a gamma-ray-emitting cesium-137 source, a lead shield, and a radiation detector. The device is lowered over the side of a ship and

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*For an explanation [illegible] work, see *Radioisotopes in In*[illegible] this series.

allowed to penetrate the sediment. Once in place, the gamma ray source, shield, and detector move together up and down, inside the probe, for a distance of 11 feet, stopping every 24 inches for 4 minutes to take a measurement. Gamma rays are absorbed in any material through which they pass, according to its density. A low radiation count at the detector indicates a high-density sediment: More radiation is absorbed and less is reflected back to the detector. Conversely, a high count indicates low density. Data are recorded on special cold-resistant film. A number of different sediment measurements can be made in several locations before the unit must be returned to the surface.

OXYGEN ANALYZER The amount of dissolved oxygen in any part of the ocean is a basic quantity that must be determined before some kinds of research can be undertaken. For example, oxygen concentration is important in determining the life-support capability of seawater and in

Oxygen analyzer equipment includes the deep-sea probe (large device, center, including a special Geiger counter, the electronic assembly, a pump, and power supplies), cable for transmission of Geiger counter signals (back), and portable scaler (left). The latter is also shown aboard a research vessel (inset) during tests made at sea.

measuring deep-water mixing. In the past this measurement has had to be determined by laborious chemical methods that may subject the water sample to contamination by exposure to atmospheric oxygen. Under an AEC contract, the Research Triangle Institute has developed a dissolved oxygen analyzer that relies on the quantitative oxidation by dissolved oxygen of thallium metal containing a known ratio of radioactive thallium-204.

The seawater sample passes through a column lined with thallium. The thallium is oxydized and goes into solution. It then passes between two facing pancake-shaped radiation counters that record the level of beta radiation from the thallium-204. Since the rate of oxidation, and therefore the rate of release of the thallium to solution, is proportional to the amount of dissolved oxygen in the water, it is simple to calibrate the device to show oxygen content. The system is sensitive enough to detect one part of oxygen in 10 billion of water. And, the device can be towed and take readings at depths of up to one mile, an added advantage that obviates the chances of surface-air contamination.

NEUTRON ACTIVATION ANALYSIS Nuclear energy is contributing to the more accurate and more rapid analysis of minerals in the sea in at least two different ways. The first employs neutron activation analysis, which we have already mentioned. This method is valuable not only in analyzing sediments cored from the ocean floor, but also in the detection and quantitative analysis of trace elements in the water. Knowledge of the role of all natural constituents in the ocean is essential to an understanding of the complex interrelationships of the ocean environment, as we have seen. Identification of trace elements also is a necessary preliminary to determining the effects of purposely introduced radionuclides. Collection of the minute quantities of trace elements is very difficult at best. Once they have been collected and concentrated, neutron activation analysis provides a means for their identification and measurement.

X-RAY FLUORESCENCE is another technique, used to identify the mineral content of ore or sediment. This system was developed (for the purpose of spotting gold being smuggled through Customs) by Tracerlab Division of Laboratory for Electronics, Inc. (LFE), under an AEC contract. Similar equipment was developed simultaneously in England for use by prospectors, geologists and mining engineers. It now may be used at sea in analyzing samples from the sea floor. As is often the case with isotope-based devices, its operation is really quite simple. When excited by radiation from an isotope (or any other radiation source), each element produces its own unique pattern of X-ray fluorescence, that is, it radiates characteristic X rays. By varying filters and measuring the count rate, oceanographers can detect and measure materials, such as tin, copper, lead, and zinc. The British unit is completely transistorized, battery powered, and weighs only 16.5 pounds.

RHODAMINE-B DYE The AEC also has improved oceanographic research in ways that do not involve the use of nuclear energy. Some years ago under the joint sponsorship of the AEC Division of Reactor Development and Technology and the Division of Biology and Medicine, the Waterlift Division of Cleveland Pneumatic Tool Company developed instrumentation and techniques for detecting the presence of the red dye, rhodamine-B, in concentrations as low as one-tenth part per billion. This method is now widely used both for groundwater studies and in the study of currents, diffusion, and pollution in rivers, lakes, and the ocean. In many cases, rhodamine-B is a better tracer in water than radioisotopes, due to the greater ease with which it is detected.

Environmental Safety Studies

The AEC Division of Reactor Development and Technology has supported extensive environmental studies to assess the safety of isotopic power sources (to be discussed later) in oceanic environments. One of the most important of these is being conducted by the Naval Radiological Defense Laboratory at an ocean environmental testing complex near San Clemente Island off the coast of California, which includes a shore installation and a floating ocean platform. These studies are to determine seawater corrosion of containment alloys and fuel solubility in seawater; the dispersion of the fuel in the ocean; the effect of the radioactive material on marine life; and the radiation hazard to man, when all significant exposure pathways are considered.

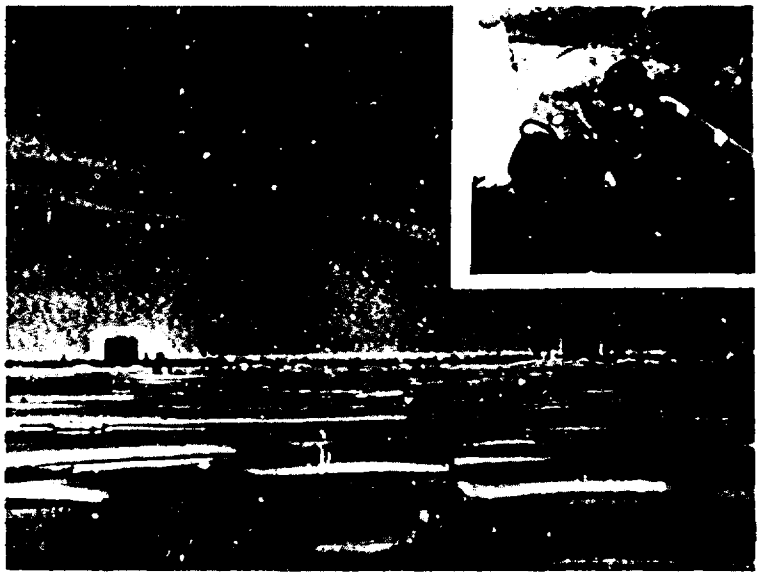
In another study the Chesapeake Bay Institute of Johns Hopkins University investigated potential hazards that might result if radioactive materials were released off the Atlantic Coast. Five areas along the Continental Shelf were examined in detail for environmental factors such as vertical diffusion. The same Institute made environmental and physical dispersion studies off Cape Kennedy, Florida, to predict the fate of any radioactive materials that might be released in aborted launchings of nuclear rockets or nuclear auxiliary power devices for space uses. Fluorescent dye was released into offshore, surf zone, and inshore locations; the diffusion was observed, sampled, and compared with existing diffusion theory. Mathematical models have been developed that can now be used to predict the rate and extent of diffusion in the Cape Kennedy area in the event of any radioactivity release from aborted test flights.

Similar studies have been carried out near the space launching site at Point Arguello, California, by the Scripps Institution of Oceanography. These included collection of data on dispersion, marine sediments, and the biological uptake of radioactive plutonium, polonium, cesium, and strontium.

The Atom at Work in the Sea

NUCLEAR REACTOR PROPULSION

The transformation in undersea warfare tactics and national defense strategy effected by the introduction of nuclear-powered submarines is now well known. Navy submarines employing the latest reactors and fuel elements can stay at sea for more than 3 years without refueling. *Polaris* submarines on patrol remain submerged for 60 to 70 days. The nuclear submarine *Triton*, tracing Magellan's route of 400 years earlier, traveled 36,000 miles under water, moving around the world in 83 days and 10 hours.



USS Seadragon *and* Skate *sit nose to nose on top of the world after under-ice voyages from the Atlantic and Pacific Oceans to the North Pole. In the inset a frogman from the* Seadragon *swims under the Arctic ice in one of the first photographs made beneath the North Pole.*

Under-ice transits of the Arctic Ocean by nuclear submarines are now commonplace. These feats all are possible because of the nuclear reactors and propulsion systems developed by the AEC Division of Naval Reactors, which also developed the propulsion plants for the Navy's nuclear surface vessels.*

DEEP SUBMERGENCE RESEARCH VEHICLE On April 18, 1965, President Johnson announced that the Atomic Energy Commission and Department of the Navy were undertaking development of a nuclear-powered deep submergence research and engineering vehicle. This manned vehicle, designated the NR-1, will have vastly greater endurance than any other yet developed or planned, because of its

*For a discussion of proposed nuclear merchant submarines, see *Nuclear Power and Merchant Shipping*, another booklet in this series.

nuclear power. Its development will provide the basis for future nuclear-powered oceanographic research vehicles of even greater versatility and depth capability.

The NR-1 will be able to move at maximum speed for periods of time limited only by the amount of food and supplies it carries. With a crew of five and two scientists, the vehicle will be able to make detailed studies of the ocean bottom, temperature, currents, and other phenomena for military, commercial, and scientific uses. The nuclear propulsion plant will give it great independence from surface support ships and essentially unlimited endurance for exploration.

The submarine will have viewing ports for visual observation of its surroundings and of the ocean bottom. A remote grapple will permit collection of marine samples and other objects. The NR-1 is expected to be capable of exploring areas of the Continental Shelf, which appears to contain the most accessible wealth in mineral and food resources in the seas. Exploratory charting of this kind may help the United States in establishing sovereignty over parts of the Continental Shelf; a ship with its depth capability can explore an ocean-bottom area several times larger than the United States.

The reactor plant for the vehicle is being designed by the General Electric Company's Knolls Atomic Power Laboratory, Schenectady, New York. The remainder of the propulsion plant is being designed by the Electric Boat Division, General Dynamics Corporation, Groton, Connecticut.

Scientists are already beginning to implant small sea floor laboratories. In the future, when large permanent undersea installations for scientific investigation, mining, or fish farming become a reality, nuclear reactors like the one designed for research submersibles or the one already in use in Antarctica and other remote locations* will serve as their power plants.

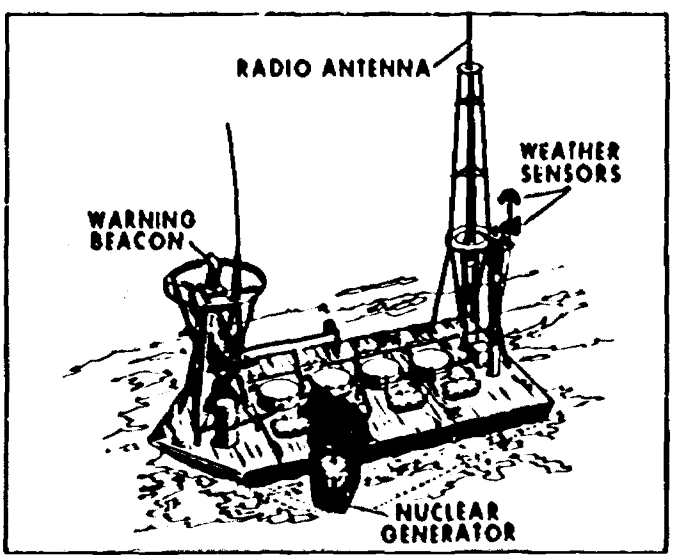
*These are described in *Power Reactors in Small Packages*, another booklet in this series.

ISOTOPIC POWER SOURCES

The ocean is a logistically remote environment, in the sense that conventional combustible fuels can't be used underwater unless supplied with their own sources of oxygen. It is usually extremely costly to take anything heavy or bulky into the deep ocean. Even if the two essential components of combustion—fuel and oxygen—could be delivered economically to an undersea base or craft, the extreme back pressure of the depths would present serious exhaust problems. Yet deep beneath the sea is just where we now propose to do large amounts of work requiring huge supplies of reliable energy. The lack of reliable and extended duration power sources is perhaps one of the most critical requirements for expansion of underwater and marine technology. For example, the pressing need for measurements of atmospheric and oceanic data to support scientific, commercial, and military operations will in the future require literally hundreds of oceanographic and meteorological buoys deployed throughout the world to take simultaneous measurements and time-series observations at specific sites.

Some of these buoys will support and monitor up to 100 sensors each. These devices record a variety of physical, chemical, and radiological phenomena above, at, or below the surface. Periodically the sensor data will be converted to digital form and stored on magnetic tape for later retrieval by distant shore-based or shipboard radio command, by satellite command (for retransmittal to ground stations), or by physical recovery of the tapes. Individually, each buoy will not require a great deal of energy to operate, but will have to operate reliably over long periods of time. Conventional power sources are being used for the prototype buoys now under development and testing, but these robot ocean platforms in the future will make excellent use of nuclear energy supplied by isotopic power sources.

The SNAP-7D isotope power generator has been operating unattended since January 1964 on a deep-ocean moored buoy in the Gulf of Mexico. This U. S. Navy NOMAD (Navy Oceanographic and Meteorological Automatic Device) buoy is powered by a 60-watt, strontium-90 radioisotope source.


RADIO ANTENNA
WEATHER SENSORS
WARNING BEACON
NUCLEAR GENERATOR

which was developed by the AEC Division of Reactor Development and Technology. This weather station transmits data for 2 minutes and 20 seconds every 3 hours. This data includes air temperature, barometric pressure, and wind velocity and direction. Storm detectors trigger special hourly transmissions during severe weather conditions. The generator operates continuously and charges storage batteries between transmissions. Some power is used to light a navigation beacon to alert passing ships.

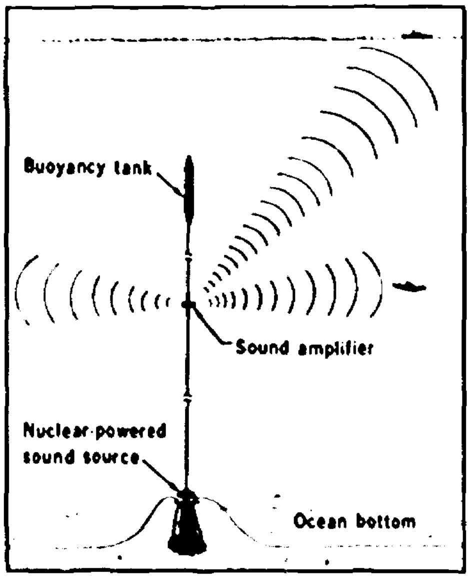
Energy from the heat of radioisotope decay has been used on a "proof-of-principle" basis in several other instances involving ocean or marine technology.

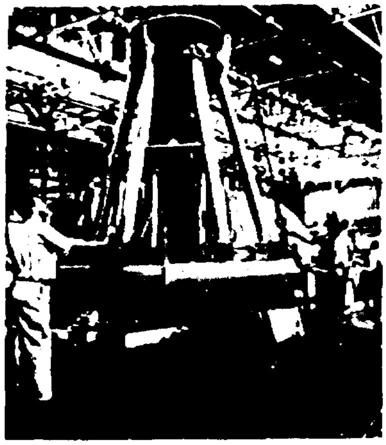
An experimental ^{90}Sr isotope-powered acoustic navigation beacon (SNAP-7E) now rests on the sea floor in 15,000 feet of water near Bermuda. Devices such as these not only will enable nearby surface research or salvage vessels to locate their positions precisely (something very difficult to do at sea) and to return to the same spot, but the beacons also will aid submarine navigation (see page 48).

A U. S. Coast Guard lighthouse located in Chesapeake Bay has been powered by a 60-watt, ^{90}Sr power source, SNAP-7B, for 2 years without maintenance or service. This unit was subsequently relocated for use in another application (described below).

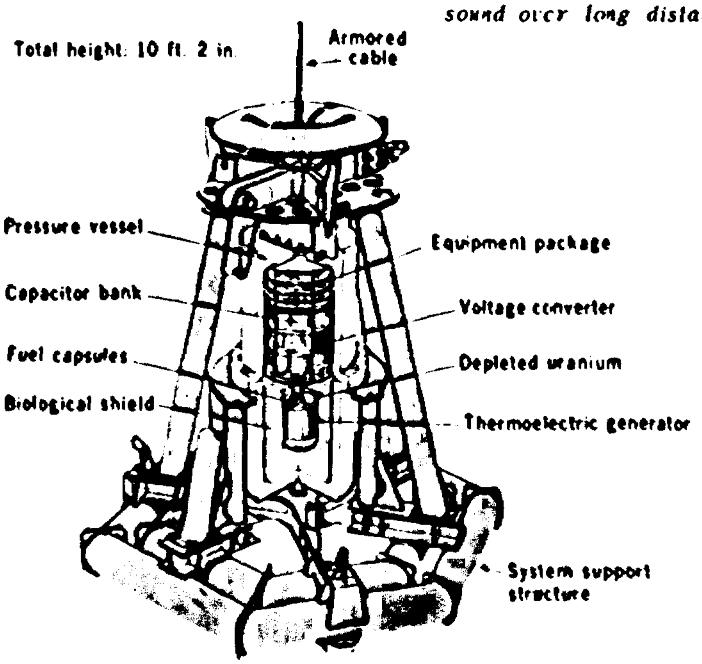
The first commercial use of one of these "atomic batteries" began in 1965 when the SNAP-7B 60-watt generator

On the left is the world's first nuclear-powered weather buoy located in the center of the Gulf of Mexico. This weather station, part of the U. S. Navy's NOMAD system, is on a barge 10 feet × 20 feet, and is anchored in 12,000 feet of water. On the right, engineers prepare to install the SNAP-7D generator.

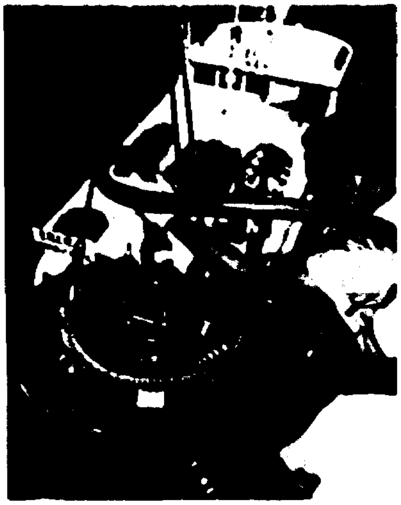


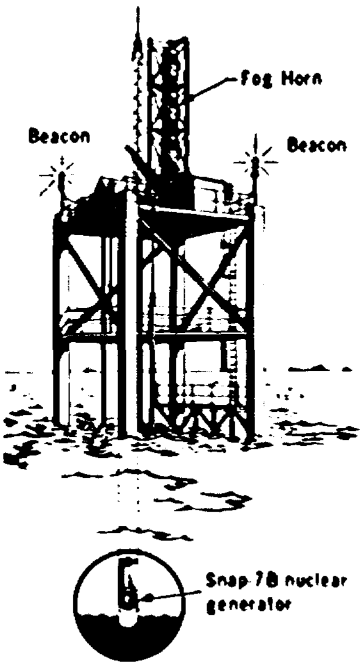


The SNAP-7E isotopic generator powers an undersea acoustic beacon, which produces an acoustic pulse once every 60 seconds. In addition to being a navigation aid, the beacon is used to study the effects of a deep-ocean environment on the transmission of sound over long distances.



Details of the Phillips Petroleum platform, which uses the SNAP-7B nuclear generator. Below the final electrical connection is made from the nuclear generator to the platform's electronic foghorn and two flashing light beacons.





went into operation on an unmanned Phillips Petroleum Company offshore oil platform, 40 miles southeast of Cameron, Louisiana. The generator operates flashing navigational lights and, in bad weather, an electronic foghorn (see page 49). This unit will be tested for 2 years to determine the economic feasibility of routinely using isotopic power devices on a commercial basis.

The radioisotope-powered devices previously described were developed by the AEC under the SNAP-7 Program.* The testing of these units has demonstrated the advisability of developing reliable and unattended nuclear power sources for use in remote environments without compromise to nuclear safety standards. As a result of the success of these tests, a variety of potential oceanographic applications have been identified. A study, conducted by Aerojet-General Corporation in conjunction with Global Marine Exploration Company and Northwest Consultant Oceanographers, Inc., described ocean applications including underwater navigational aids, acoustic beacons, channel markers, cable boosters, weather buoys, offshore oil well controls along with innumerable oceanographic research applications. This study was sponsored by the AEC Division of Isotopes Development.

In order to satisfy the requirements for these and other applications, the AEC has begun developing a series of compact and highly reliable isotope power devices that are designed to be economically competitive with alternative power sources. Currently underway are two specific projects, SNAP-21 and SNAP-23.

SNAP-21 is a two-phase project to develop a series of compact strontium-90 power systems for deep-sea and ocean-bottom uses (20,000-foot depths). The first phase of design and component development on a basic 10-watt system already has been completed, and a second phase development and test effort now under way will extend through 1970. A series of power sources in the 10- and 20-watt range will be available for general purpose deep-ocean application.

*See *Power from Radioisotopes*, a companion booklet in this series, for a more complete discussion of radioisotopes in use.

The SNAP-23 project involves the development of a series of economically attractive strontium-90 power systems for remote terrestrial uses. This project will result in 25-watt, 60-watt, and 100-watt units capable of long-term operation in surface buoys, offshore oil platforms, weather stations, and microwave repeater stations.

In addition to the above, effort is underway by the AEC to develop an isotope-fueled heater that will be used by aquanauts in the Navy's Sealab Program (see page 12). Future activities, now being planned, will involve the development of large isotope power sources (1 – 10 electric kilowatts) and small nuclear reactors (50 – 100 kilowatts) for use in manned and unmanned deep-ocean platforms.

Ocean Engineering

Considerable engineering experience has been derived from the work of federal agencies in development of the largest taut-moored instrumented buoy system ever deployed in the deep ocean. Developed by Ocean Science & Engineering, Inc., it is useful in observation and prediction of environmental changes.

The system embodies substantial advances in design. It incorporates, among other features, an acoustically commanded underwater winch for adjustment of the mooring depth after the buoy is deployed, and for recovering a 16,000-pound submerged data-recording instrument canister. This buoy system can survive being moored in up to 18,000-foot depths of the open ocean for upward of 30 days.

The very first deep-ocean, taut-moored buoy system was developed for the government in 1954, and has since become an important tool for oceanographers and others who seek stable instrument platforms at sea. The buoys have the advantage of minimizing horizontal movement due to currents, winds, and waves.

The National Marine Consultants Division of Interstate Electronics Corporation has developed for the government a system for measuring the propagation of seismic sea waves (tsunamis).

Work of these sorts contributes materially to reliable ocean engineering. And the measurements made by these sophisticated instruments contribute to our knowledge of ocean fluid dynamics and wave mechanics.

Corrosion is a huge, ever-present problem plaguing oceanographic engineers, ship designers, mariners, operators of desalination plants, petroleum companies with offshore facilities, and, in fact, everyone who places structures in salt water to do useful work. While the basic mechanisms of corrosion are known, there are many detailed aspects that are not: For example, the precise role of bacteriological slimes in causing corrosion on supposedly protected structures. Radioisotope tracers now are helping engineers follow the chemical, physical, and biological actions in corrosion processes.

Fresh Water from Seawater

In 1960 the chairman of the board of a large U. S. corporation made a fundamental policy decision for his company: Since the greatest critical need of man in the next decade would be fresh water, his company would begin working to produce large volumes of fresh water —including the development of methods for desalting seawater. His pioneering analysis proved to be prophetic.

Throughout the world, more people are using more water for more purposes than ever before. Many areas of the world, including some that are densely populated, have been parched since the dawn of history. In others where water was once abundant, not only are natural sources being depleted faster than they are replaced, but many rivers and lakes have been so polluted that they can now scarcely be used.

The world's greatest resource of water is the ocean, but energy is required to remove the salt from it and make it potable or even useful for agriculture and industry. The energy produced by nuclear reactors is considered economical in the large quantities that soon will be required.

The AEC and the Office of Saline Water of the Department of the Interior, after a preliminary study, have joined with the Metropolitan Water District of Southern California and the electric utility firms serving the area,

Plans to construct a nuclear desalting plant in California were announced in August 1966 by (from left) AEC Commissioner James T. Ramey, Secretary of the Interior Stewart L. Udall, Mayor Samuel Yorty of Los Angeles, and Joseph Jensen, Board Chairman of the Metropolitan Water District of Southern California.

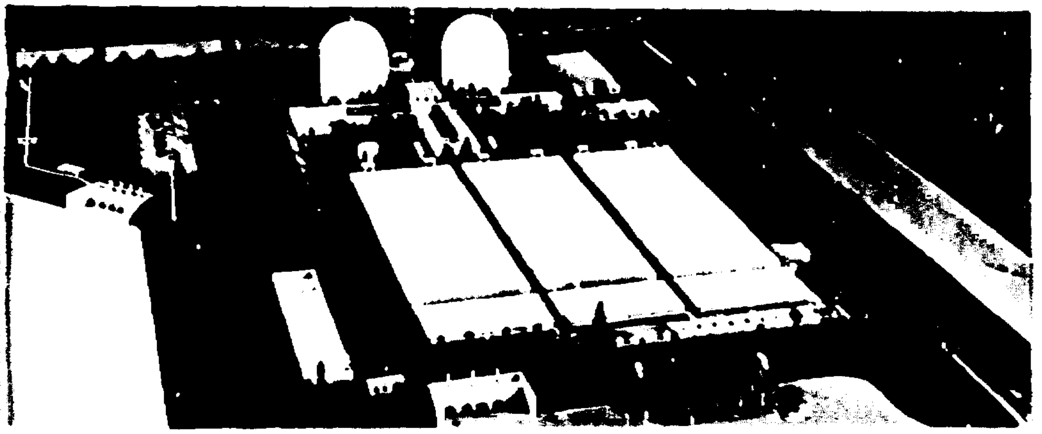
to begin construction of a very large nuclear-power desalting plant on a man-made island off the California coast. The plant, when completed in the 1970s, will have an initial water capacity of 50 million gallons per day and also will generate about 1,800,000 kilowatts of electricity. Additional desalting capacity is planned for addition later to achieve a total water capacity of 150 million gallons per day.

Plans for other nuclear-powered desalting projects around the world are being discussed by the United States government, the International Atomic Energy Agency and the governments of many other nations. Some of these also may be in operation during the early 1970s.*

These projects followed extended detailed studies, including one "milestone" investigation at the AEC's Oak Ridge National Laboratory in Tennessee, in which the economic feasibility of using very large nuclear reactors

*For an explanation of how these will function, see *Nuclear Energy for Desalting*, another booklet in this series.

Model of the nuclear power desalting plant to be built on the coast of Southern California.



coupled to very large desalting equipment to produce power and water was determined.

The significance of these studies was recognized by President Johnson in 1964, when he told the Third International Conference on Peaceful Uses of Atomic Energy: "The time is coming when a single desalting plant powered by nuclear energy will produce hundreds of millions of gallons of fresh water— and large amounts of electricity— every day."

It is obvious that today realization of that goal is much nearer.

The installation of new and larger desalting plants will in itself require extensive additional oceanographic research. By the nature of their operation these plants will be discharging considerable volumes of heated water with a salt content higher than that of the sea. Throughout the ocean, but particularly in the estuaries, sea life is sensitive to the concentration of ocean salts and temperature. Studies of the effect of such discharges will be an essential part of any large-scale desalination program.

Radiation Preservation of Seafood

The use of nuclear radiation for the preservation of food is a new process of particular importance for seafood. The ocean constitutes the world's largest source of animal protein food. Yet the harvests of the sea can be stored safely, even with refrigeration, for far shorter periods than can most other foods. In many parts of the world, this tendency to spoil makes fish products available only to people who live near seacoasts.

Many types of seafood, however, when exposed to radiation from radioisotopes or small accelerators, can be stored under normal refrigeration for up to four weeks without deterioration. The process does not alter the appearance or taste of the seafood; it merely destroys bacteria that cause spoilage. This fact holds promise not only for the world's protein-starved populations, but also for the economic well-being of commercial fishermen, whose markets would be much expanded.

In support of this program, the AEC has built and is operating at Gloucester, Massachusetts, a prototype com-

1/

The first shipboard irradiator (inset) was on The Delaware, *a research fishing vessel. Fish, preserved through irradiation soon after they are caught, have a refrigerated storage life two or three times longer than nonirradiated fish.*

mercial seafood irradiator plant capable of processing 2000 pounds of seafood an hour. The radiation is supplied by a cobalt-60 source. Private industry is cooperating with the AEC in the evaluation of this facility.*

Project Plowshare

Nuclear explosives are, among other things, large-scale, low-cost excavation devices. In this respect, with the proper pre-detonation study and engineering, they are ideally suited for massive earth-moving and "geological engineering" projects, including the construction of harbors and canals. The western coasts of three continents, Australia, Africa, and South America, are sparsely supplied with good harbors. A number of studies have been undertaken

*See *Food Preservation by Irradiation*, another booklet in this series, for a full account of this installation.

as to the feasibility of using nuclear explosives for digging deepwater harbors. Undoubtedly at some time in the future, these projects will be carried out.

In addition, there are many places in the world where the construction of a sea-level canal would provide shorter and safer routes for ocean shipping, expedite trade and commerce, or open up barren and unpopulated, but mineral-rich lands to settlers and profitable development. The AEC Division of Peaceful Nuclear Explosives operates a continuing program to develop engineering skills for such projects.* Construction of a sea-level canal across the Central American isthmus is one well-known proposal for this "Plowshare" program.

The use of nuclear explosives in this manner may one day change the very shape of the world ocean.

A New *Fram*

Just about 70 years ago, the oceanographer and explorer, Dr. Fridtjof Nansen completed his famous voyage aboard the research vessel *Fram*, which remained locked in the Arctic ice pack for 3 years, drifting around the top of the world while the men aboard her studied the oceanography of the polar sea. Now the National Science Foundation has taken the first steps toward building a modern version of *Fram* for Arctic studies. This time the vessel will be an Arctic Drift Barge containing the best equipment modern technology can offer—including, it is proposed, a central nuclear power plant to guarantee heat and power. Scheduled for completion sometime in the 1970s, this project represents yet another use of the atom in the study of the ocean.

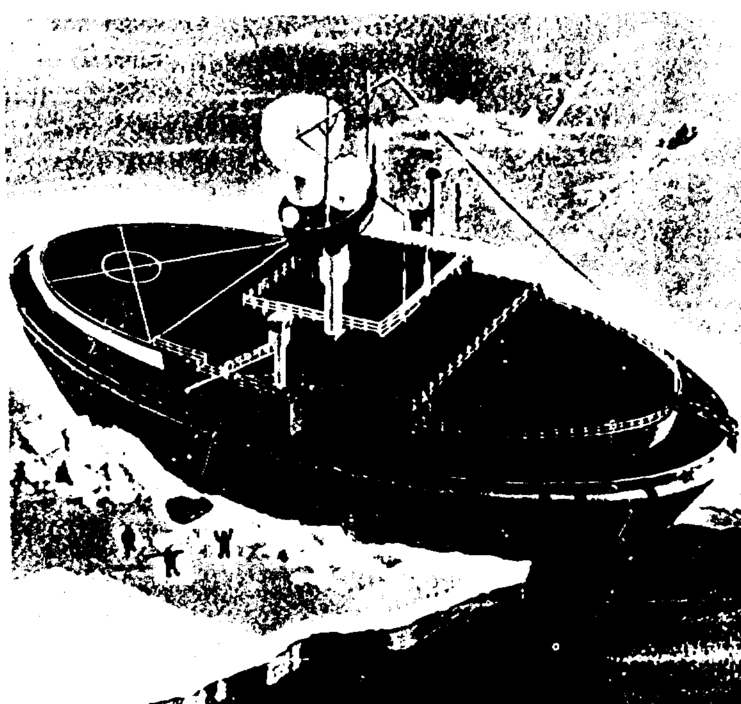
Fridtjof Nansen

*Details are described in *Plowshare*, another booklet in this series.

THE THREE-DIMENSIONAL OCEAN

The ocean is no longer an area of isolated scientific interest, nor merely a turbulent two-dimensional surface over which man conducts his commerce and occasionally fights his wars.

In today's world, the ocean has assumed its full third dimension. Men and women are going down into it to study, to play, to work, and, alas, sometimes to fight. As they go, they are taking atomic energy with them. In many instances, only the harnessed power in the nuclei of atoms permits them to penetrate the depths of the mighty sea and there attain their objectives.



Artist's conception of one of three proposed designs for the National Science Foundation's Arctic Drift Barge. All three designs incorporate a nuclear power source.

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Available for loan without charge from the AEC Headquarters Film Library, Division of Public Information, U. S. Atomic Energy Commission, Washington, D. C. 20545 and from other AEC film libraries.

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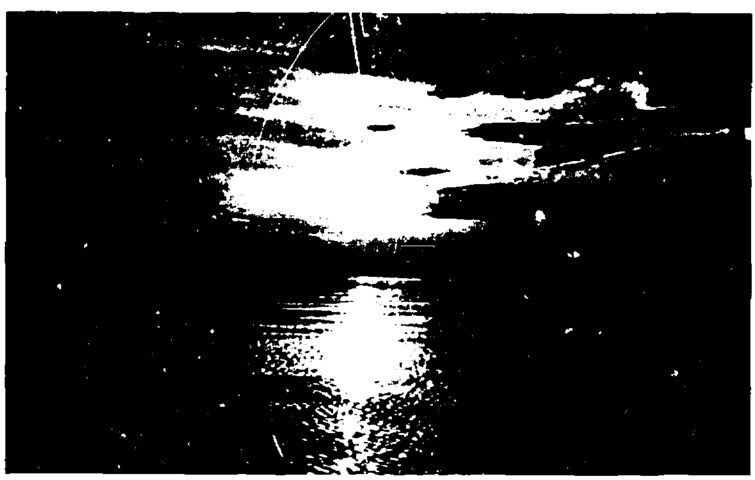
Desalting the Seas, 17 minutes, sound, color, 1967. Produced by AEC's Oak Ridge National Laboratory. Describes various methods of purifying saline water through the use of large dual-purpose nuclear-electric desalting plants.



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9	Top, Oregon State University (OSU); bottom, University of California, San Diego, Scripps Institution of Oceanography (SIO)
10	Lamont Geological Observatory of Columbia University
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19	R. H. Backus. *Physics Today* (November 1965), "Sound Reflections In and Under Oceans," J. B. Hersey
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57	National Science Foundation
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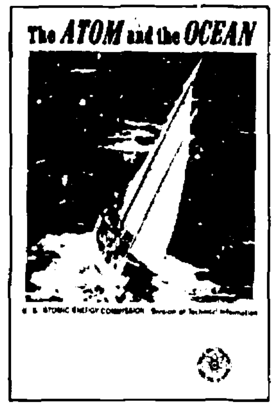
Frontispiece from Jan Hahn

THE COVER



The ship on the cover is the trim *Atlantis* riding the waves about 200 miles south of Bermuda. The first craft built by the United States as an oceanographic research vessel, she traveled more than 1,200,000 miles across the seven seas for a period of 30 years. She "ran" over 6000 hydrographic stations and was used for innumerable dredging, coring, biological, physical, and acoustical research operations. After she was retired from active service at the Woods Hole Oceanographic Institution in Massachusetts, she was sold to Argentina, where she has resumed her role as an oceanographic research vessel.

THE AUTHOR

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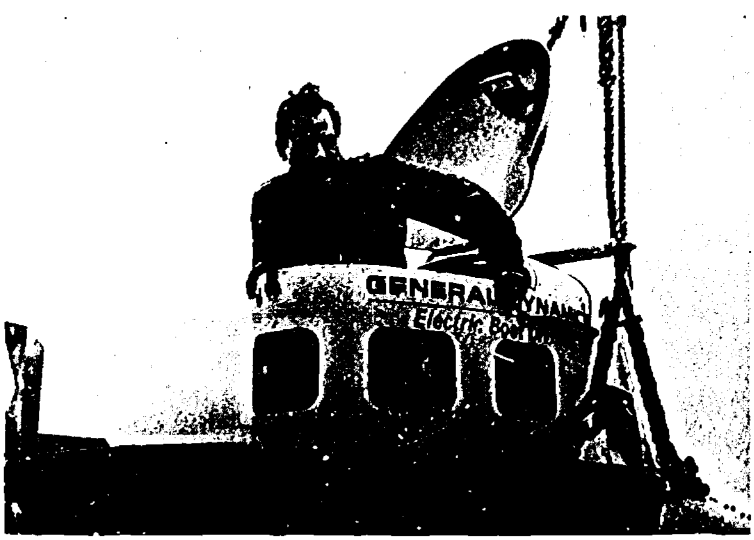

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