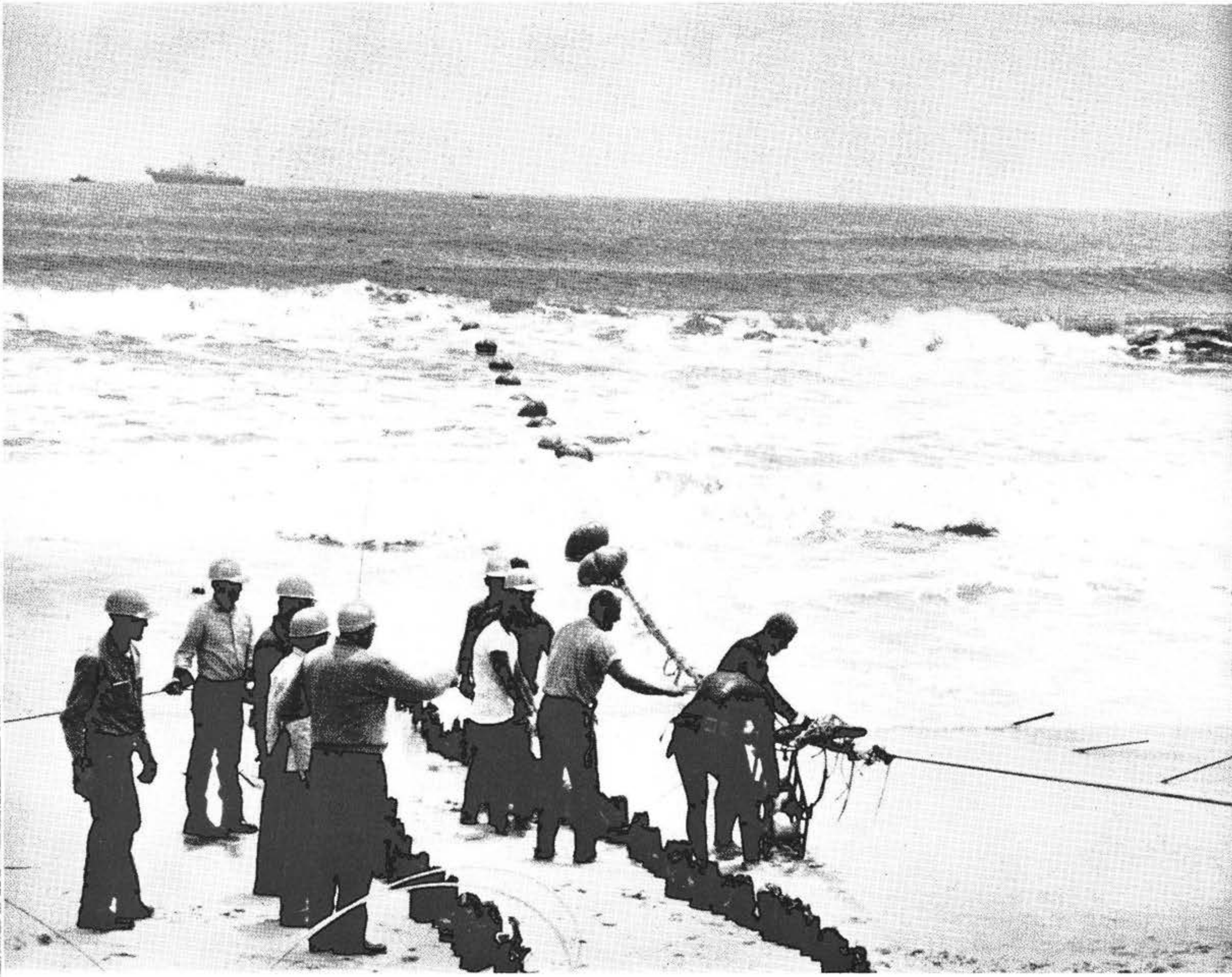


Long Lines craftsmen handle the shore end of an ocean cable being laid by the S.S. Long Lines, visible in the background.

Although the SF *cable has not yet been laid on the ocean floor, Bell Laboratories engineers know how its attenuation of signals will be affected by pressure at ocean depths and by the passage of time. The cable has been tested in a simulated environment.*

Sixteen Oceans at Chester, New Jersey

B. J. Kinsburg

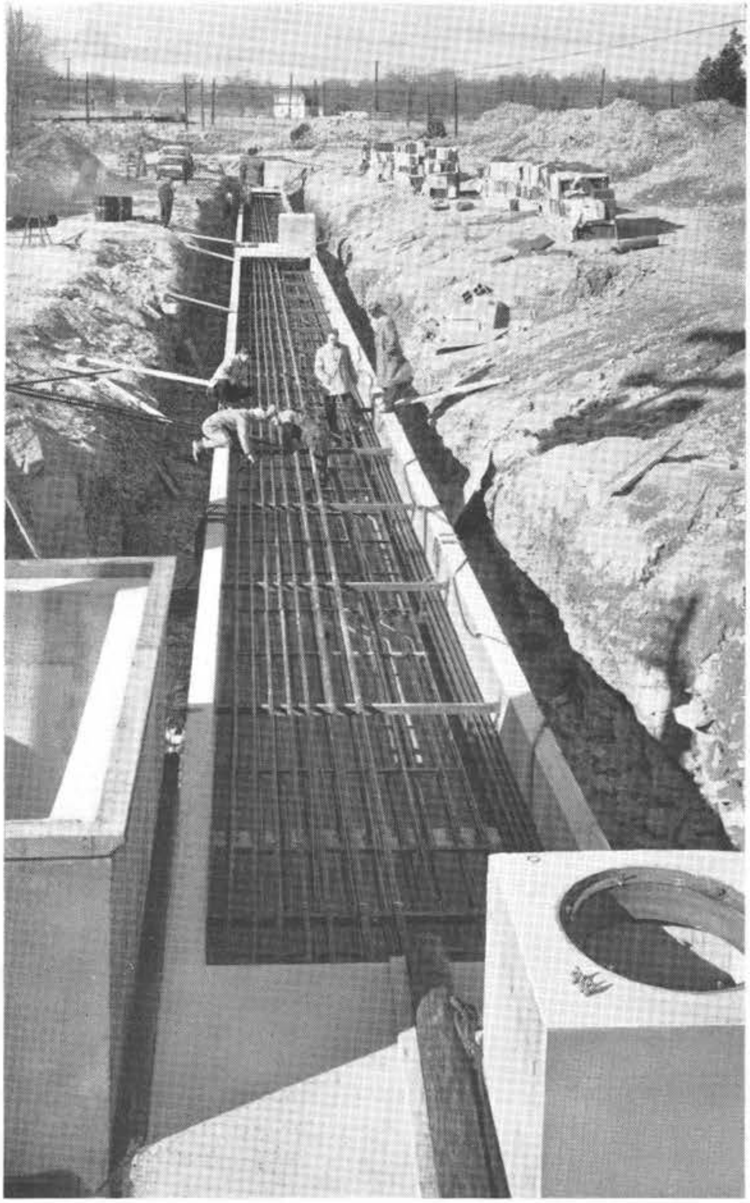
BEFORE NEW ELECTRONIC DEVICES and systems are introduced commercially by the Bell System, they are tested extensively both in simulated and in actual environments. In some cases, field trials are either impossible or impractical, and laboratory trials must suffice. Such was the case when an entirely new "armorless" cable design was proposed for submarine cable systems.

It was not practical to use the sea to test the new cable. Experimental cable sections laid near the shore would have been subjected to higher and more variable temperatures and much lower pressure than on the ocean bottom. On the other hand, sections laid on the ocean bottom would have had to have their ends raised periodically for measurements, risking changes or damage to the cable during raising.

Some sort of simulated ocean was obviously needed. Therefore, Bell Laboratories' Chester, New Jersey, facility constructed "artificial oceans" that simulate ocean bottom conditions at a depth of about two miles, where the temperature is close to three degrees Centigrade and the pressure is approximately 5000 psi (340 atmospheres).

Submarine cables such as SD and SF are "aged" in these artificial oceans to determine whether their electrical properties will change with time under actual operating conditions. In the first transatlantic submarine cable system (SB), for example, the cable attenuated transmitted signals less as it aged. When the system went into service in 1956, total attenuation at 164 kHz (the highest frequency) in the 2000 nautical miles of armored cable between Scotland and Nova Scotia was 3200 dB. After a year of normal operation, total attenuation had decreased 4 dB, one-eighth per cent of the total. If this decrease in attenuation had continued at the initial rate, even the generous signal-to-noise margin of the SB system would have been used up in five or six years. Fortunately, the attenuation did not continue to change at the initial rate. Instead, the attenuation in armored cable decreased exponentially toward an asymptotic value that differed from initial attenuation by about five times the change occurring in the first year.

In the original, armored submarine cable, signals travel between inner and outer coaxial conductors, both of which are formed from a number of spiraled copper tapes with butting edges. One theory of cable aging is that the high pressure at great depths gradually forces these edges



Consisting of two troughs, one 15 feet long, the other 315 feet long, the artificial oceans at Chester, N. J., contain pairs of pipes filled with salt water. Shown under construction are the trough and pipes of the longer ocean-simulating facility.

closer together and improves conduction. To avoid this aging mechanism, the armorless SD cable was designed with a closed copper tube for the inner conductor and a copper tube with a single longitudinal seam for the outer conductor. These design changes were expected to eliminate the dominant cause of cable aging. Nevertheless, even relatively small changes in cable attenuation with time threatened to be a serious problem because of 1) the higher operating frequency of 1052 kHz, 2) greater system length, and 3) lower allowance for aging in the design of the system.

The SD system was to be 3500 nautical miles long with a designed initial attenuation of 8500 dB and an allowance of 17 dB for aging. This meant that if attenuation changed by an equal amount each year for the 20-year estimated life of the system, the maximum allowable annual change was 0.85 dB or 100 parts per million. On the other hand, if the aging pattern followed that of the armored cable, attenuation could change as much as 3.4 dB or 400 parts per million for the first year.

Because the mechanism of aging in the new armorless cable was unknown, however, it could not even be determined whether attenuation would decrease or increase with time. Thus, it became necessary to design artificial oceans in which to age the cable.

The ocean-simulating facility at Chester consists of pairs of pipes immersed in water-filled troughs. Inside the pipes, salt water simulates the environment on the ocean bottom. A cooling liquid, which is pumped through tubes in the sides and bottoms of the troughs, permits the ambient temperature of the salt water to be controlled precisely.

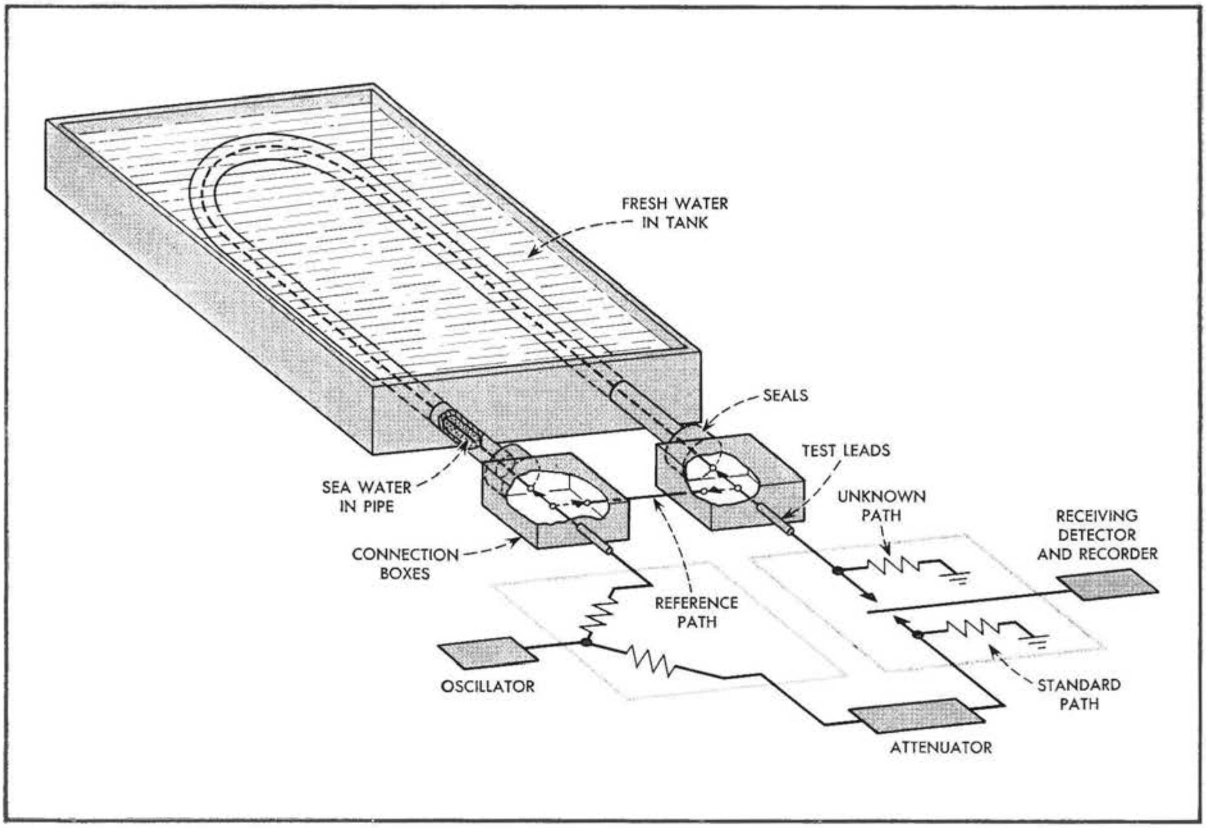
There are two troughs, one 15 feet long, the other 315 feet long. Each contains eight pairs of pipes, five pairs being equipped for the application of high pressure. One end of each trough terminates in a manhole; the other end terminates in a pit in the test building. A common high-pressure enclosure for each pair of pipes can be opened or closed at the manhole end.

Each cable sample is bent into a U-shape (like a hairpin), and both ends are simultaneously pulled into a pair of pipes from the manhole side of the trough. Coaxial connections to the cable are made by seals, which are attached at the test-building end of the trough. These seals also anchor the cable so that tension can be applied to it. Cable is tested in 30-foot-long and in 630-foot-long sections.

Once the pipes are sealed, salt water is pumped in. Ordinary salt, dissolved in water to produce a salinity of 34 parts per thousand, adequately simulates the electrical conductivity of the ocean.

During the tests, tension and pressure on the cable are varied in six steps to simulate forces on the cable during the actual laying process. Starting tension applied in the tests is 7900 pounds, while terminal pressure is 5000 psi. When a cable is laid, it is under maximum tension and minimum pressure as it leaves the ship and under minimum tension and maximum pressure when it reaches the ocean bottom.

A 630-foot-long armorless SD cable section tested in the Chester ocean attenuates a 1-MHz



To determine effects of aging submarine cable in the artificial ocean, the difference in attenuation between a signal transmitted on cable and one passed through a standard attenuator is detected.

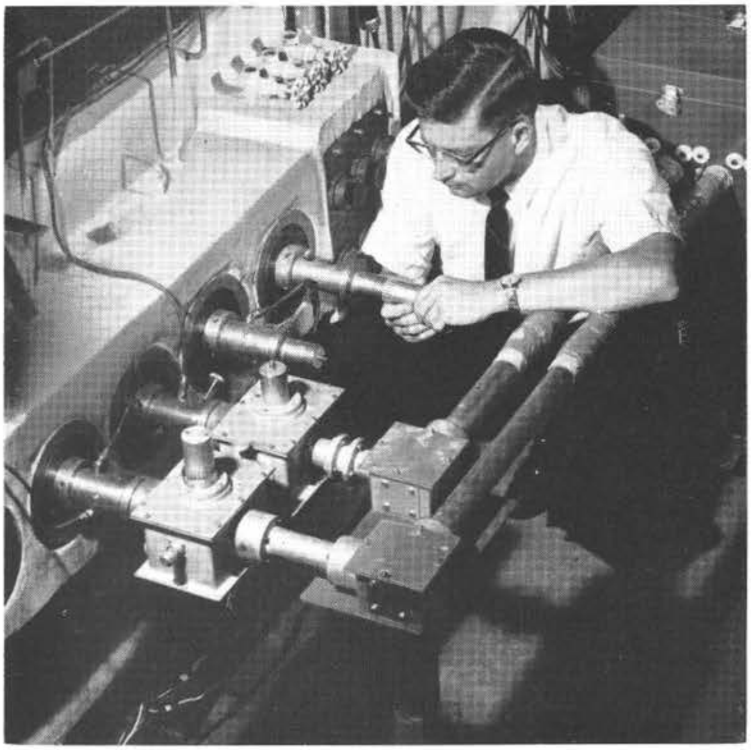
signal about 0.25 dB (250,000 micro dB). To determine whether changes in attenuation were within the system aging allowance, attenuation had to be determined to an accuracy of ±25 micro dB. This is an accuracy of ±100 parts per million due to all sources of error. Included is a ±25 parts per million allowance for temperature error and a ±16 parts per million allowance for pressure error. This means that changes in temperature over the duration of the test must be measured to ±0.015 degree Centigrade, and changes in pressure must be measured to ±10 psi.

The unprecedentedly stiff requirements were set because it was necessary to know how much 3000 miles of cable would age in 20 years. But only one-tenth of a mile of cable was being measured, and an answer was desired in one year. Combining distance and time ratios resulted in a combined extrapolation ratio of 600,000 to 1.

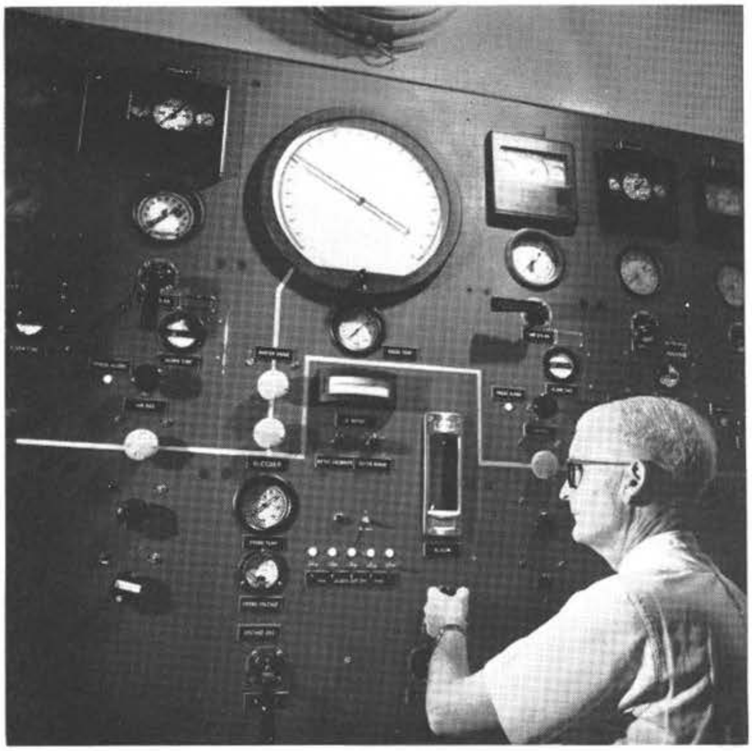
It proved relatively easy to locate a pressure gauge that could measure 5000 psi to within ±6 psi of accuracy. Finding a way of measuring the change in average temperature of the long sample was not easy, however. (The dc resistance of the cable could not be used for measurements because of the possible effect on it of the cable's aging.) So Bell Laboratories asked the National Bureau of Standards to recommend a temperature-measuring material that would not age appreciably. The suggestion was to use platinum—properly supported to avoid strain, annealed in place, and set in an inert environment, such as special, dehydrated oil.

Accordingly, a platinum wire was installed in a U-shaped copper pipe which followed the course of the pressure pipes simulating the ocean. The platinum was threaded through ceramic tubes for support and electrically annealed. Heat dissipated in the copper pipe during annealing was sufficient to elongate it about a foot.

Two copper "thermometers" were also installed in the test setup. Provided its resistance remains constant, copper wire obviously offers a much cheaper means of measuring temperature changes than does platinum. In addition, knowledge of the effect of time on the resistance of copper wire is of general interest. On the basis of comparative



J. L. Robson adjusts connector on coaxial cable that extends from sealed end of artificial ocean facility. Connections are brought from interconnecting cables overhead to detection equipment, which measures attenuation to an accuracy of ±10 micro dB.



During cable tests, tension and pressure are varied to simulate actual laying process. Starting tension applied in tests is 7900 pounds, while terminal pressure is 5000 psi. P. W. Rounds operates control panel for the sixteen artificial oceans.

tests, it now appears that copper would have been satisfactory in measuring temperature changes in the artificial oceans.

The elaborate thermal insulation at both ends of the troughs, the high thermal mass of the system, and the method of cooling and cooling control, have collectively enabled temperature changes to be held to within 0.05 degree Centigrade. Measurements of these changes are thought to be accurate to ±0.01 degree Centigrade.

Since the desired accuracy for the attenuation measurements themselves was ±10 micro dB—roughly two orders of magnitude better than the capability of any test equipment then available—a new test circuit was developed. A series of relays, operated by a timing function generator, feeds signals to a detector and recorder, which detect the difference between a signal transmitted on the cable and one passed through a standard attenuator. (See the drawing on page 293.) All circuit components were selected or designed for stable, low-noise operation. Crosstalk requirements between signals on the cable and through the attenuator are stringent.

Maintaining absolute accuracy in attenuation measurements requires an absolutely invariant standard. Therefore, a bridged-T network with equal resistors in all arms was chosen. The loss of the network is equal to 20 $\log_{10}2$ (slightly over 6 dB). Thus, the table of logarithms becomes the fundamental standard of accuracy. A 1000-Hz calibration circuit uses the logarithmic function as a reference standard to calibrate the losses of the attenuators in the set. At 1000 Hz the test circuit is accurate to ±1 micro dB.

While the basic purpose of the Chester oceans is to measure the attenuation changes as the cable ages, the artificial oceans also are equipped to measure changes in delay, capacitance, and resistance. Inclusion of these capabilities involved comparatively little added expense and effort.

Results of the attenuation measurements were so good they were suspected. The armorless cable samples appeared not to have aged at all. Such an ideal result roused understandable skepticism, doubt, and some fear that the artificial oceans did not adequately simulate ocean conditions.

To evaluate the accuracy of the artificial ocean, a section of the older armored cable was tested. Results showed a decrease in attenuation that closely matched that under actual operating conditions, thus lending support to the measurements of the armorless cable.

Though originally designed and constructed to test the SD cable, the Chester artificial oceans have been modified and used to measure the pressure coefficients of the new SF armorless cable. In the future, other uses will probably be found for these simulated oceans to further extend knowledge of how materials behave under the sea.