By Kevin Hardy and Ian Koblick

Following the theme of manned undersea habitats, outposts to explore, work and live in the sea, we continue the series with an excerpt from Dr. Joseph MacInnis's informative March 1966 Scientific American *article "Living under the Sea".*

Ed Link's Submerged Portable Inflatable Dwelling (SPID)

By Dr. Joseph B. MacInnis

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In 1956 Edwin A. Link, the inventor of the Link Trainer for simulated flight training, was engaged in undersea archaeological investigations. He recognized that a diver could work more effectively at substantial depths if he could live there for prolonged periods instead of having to be decompressed to the surface after each day's work. Link set out to build a vehicle that could operate as an underwater elevator, a diving bell and a decompression chamber. The "submersible decompression chamber" (SDC) he designed is an aluminum cylinder 11 feet long and 3 feet in diameter [see Figure 2]. With its outer hatches closed it is a sealed capsule in which a diver can be lowered to the bottom. On the bottom, with the internal gas pressure equal to ambient water pressure and the hatches open, the SDC serves as a dry refuge from which the occupant can operate as a free diver. Then, with the hatches again closed, it becomes a sealed chamber in which the diver can be decompressed safely and efficiently on shipboard or during his ascent to the surface. An inner hatch provides an air lock through which someone else can enter the chamber (or pass food and other supplies into it) during the decompression phase.

Early in September 1962, the SDC underwent its critical test in the Mediterranean Sea off Villefranche on the French Riviera. A young Belgian diver, Robert Stenuit, descended in it to 200 feet and lived there for 24 hours, swimming out into the water to work and returning to rest in the warm safety of the pressurized chamber. When the time came to return to the surface, Stenuit did not have to face hours of dangling on a lifeline or perching on a platform, decompressing slowly in the cold water. Instead he sealed himself into the chamber, was hoisted to the deck of Link's research vessel, the Sea Diver, and there was

Figure 1: An underwater dwelling called the SPID (for "submerged, portable, inflatable dwelling") was designed by Edwin A. Link as a base of operations for long dives to the continental shelf, here undergoing a pressure test at 70 feet. In the summer of 1964 two divers occupied the SPID for two days at 432 feet below the surface.

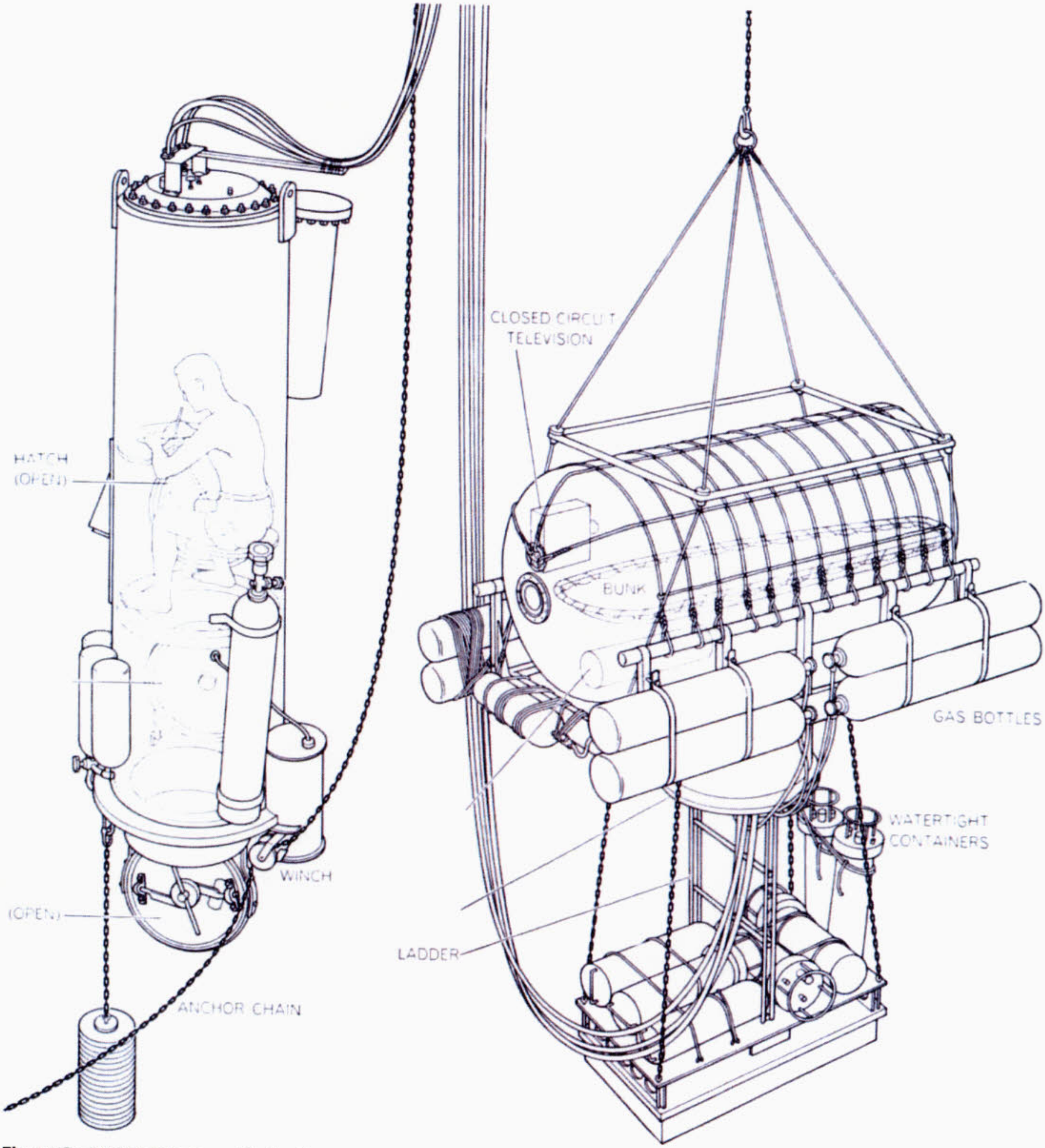

Figure 2: Two chambers used in the Man in Sea 432-foot, two-day dive are diagrammed. The "submersible decompression chamber," or SDC (left), is an aluminum cylinder II-feet long and 3-feet in Diameter. With the hatches open and the inside gas pressure equal to the external water pressure, the SDC serves as a diving bell. The SPID (right) is an eight-by-four-foot inflatable rubber dwelling with a steel frame and ballast tray. Access to it is through an open entry port at the bottom.

decompressed in safety and relative (although somewhat cramped) comfort.

Link had decided that the second phase of his "Man in Sea" project would attempt to demonstrate that men could work effectively at 400 feet for several days. He established a "life-support" team under the direction of Christian J. Lambertsen of the University of Pennsylvania School of Medicine to undertake preliminary research and supervise the medical aspects of the dive. Under Lambertsen's direction James G. Dickson and I first evaluated the accuracy and reliability of gas analyzers that would monitor the divers' breathing atmosphere. In addition to proving out the system, our experiments showed that mice could tolerate saturation at (and decompression from) pressures equivalent to 4,000 feet of seawater.

The 400-foot dive required the design of a larger and more comfortable "dwelling" on the ocean floor. Such a dwelling presents unusual engineering problems. It must provide shelter and warmth and be easy to enter and leave underwater, simple to operate and resistant to the corrosive effects of seawater. The dwelling must be heavy enough to settle on the bottom but not so heavy that it is hard to handle from the deck of a support ship.

Link's unique solution was in effect an underwater tent: a fat rubber sausage eight feet long and four feet in diameter, mounted on a rigid steel frame. Deflated at the surface, the "submerged, portable, inflatable dwelling" (SPID) is remarkably easy to handle: an important advantage when undersea habitations are established in remote locations. As it is submerged, the tent is inflated so that its internal gas pressure is equal to the ambient water pressure. There are no hatches; an open, cuff like entry port in the floor of the SPID allows easy access and provides the necessary vertical latitude for variations in the pressure differential. Inside the SPID

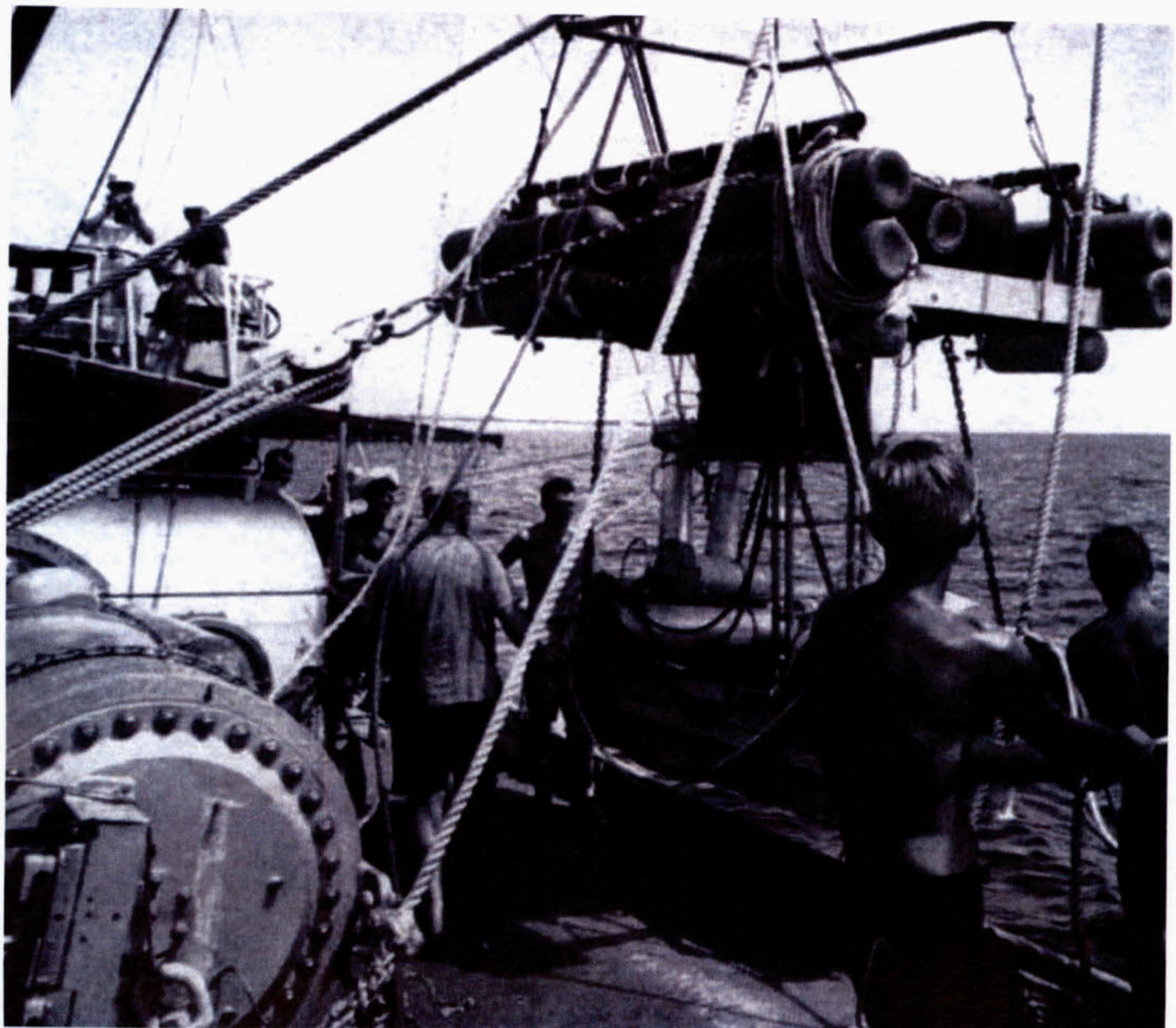

Figure 3: The deflated SPID is hoisted over the side of Link's vessel Sea Diver. One end of the SDC is visible in the left foreground, with part of the deck decompression chamber beyond it.

and in watertight containers on the frame and on the ballast tray below it are stored supplies and equipment: gas cylinders and the gas-circulating system, a closed-circuit television camera, communications equipment, food, water, tools and underwater breathing gear.

In the 400-foot dive the SPID was to be one of three major pressure chambers. The second was the proved SDC and the third was a new deck decompression chamber (DDC). This time the SDC was to serve as an elevator and also as a backup refuge on the bottom but not as the main decompression chamber. After a long, deep dive, decompression takes several days, and it is important that the divers be as comfortable as possible. An eight-by-five-foot decompression chamber with a four-foot air lock was therefore secured to the deck of the Sea Diver. The SDC could be mated to it so that the divers could be transferred to it under deep-sea pressure. Decompression could then proceed under the direct supervision of life support personnel.

Early in June 1964, Link and his research group sailed to the Bahamas to test the three-chamber diving concept. We checked the chambers with dives to 40 and 70 feet, spending several weeks refining techniques for handling the SDC and the SPID and coping with potential emergencies. The exact site for the dive, chosen with the cooperation of Navy personnel using sonar and underwater television, was a gentle coral sand slope 432 feet deep, about three miles northwest of Great Stirrup Cay.

On June 28 the underwater dwelling, with its vital gear carefully stowed aboard, was lowered slowly to the ocean floor. When it had settled on the shelf, the oxygen level inside was adjusted to 3.8 percent, the equivalent of a sea-level partial pressure of 400 millimeters of mercury. The inert gas was helium with a trace of nitrogen because there had been air in the tent to start with. Then the SPID was left, a habitable outpost autonomous except for communications, power and gas lines, ready for its occupants.

The next step was to transport Stenuit and Jon Lindbergh, another experienced diver, to the shelf. As usual, the SDC was placed in the water at the surface so that the divers could enter it from below. At 10:15 A.M. on June 30 Stenuit and Lindbergh went over the side and swam up into the chamber, closed the outer hatches and checked their instruments. At 10:45, still at the surface, the SDC was pressurized to the equivalent of 150 feet with oxygen and helium to check for leaks; one minor leak was discovered and repaired. At noon the chamber started down, slipping through the clear purple water toward the deep shelf. When it reached 300 feet, Lindbergh reported the bottom in sight. At 1:00 P.M. the anchor weights touched bottom and the chamber came to a stop five feet above the sand. It was just 15 feet from the waiting SPID. During the descent the SDC's internal pressure had been brought to 200 feet; now pressurization was completed. At 1:15 the bottom hatches were opened and Stenuit swam over and entered the dwelling. Lindbergh joined him and they began to arrange the SPID for their stay.

At that point Lindbergh reported that the carbon dioxide scrubber had been flooded and was not functioning. The divers found the backup scrubber in its watertight container and prepared to set it up as the carbon dioxide level rose to almost 20 millimeters of mercury. Then they found they could not get at the reserve scrubber: the pressure-equalizing valve that would make it possible to open the container was missing. With the carbon dioxide level rising rapidly as a result of their muscular exertion, they had to leave the dwelling and return to the SDC. We had hoped to maintain the diving team on the shelf with a minimum of support from the surface, but it now became necessary to send a spare scrubber down on a line from the Sea Diver. The divers installed it in the SPID and the dwelling was soon habitable.

Later that evening the divers took over control of the dwelling's atmosphere, monitoring it with their own high-pressure gas analyzer and adding makeup oxygen as required. We kept watch from the surface by closed-circuit television as Stenuit and Lindbergh settled down for the night. While one slept the other kept watch, checking instruments and communications (a procedure that, as confidence in the system increases, should not be necessary in the future). The water temperature that night was 72 degrees and the dwelling was at 76 degrees, yet both divers later reported that the helium atmosphere was too cold for comfortable sleeping.

In the morning the divers swam over to check the SDC, making sure that it was available as a refuge in case of trouble in the SPID. For the rest of the day both men worked out of the dwelling, observing, photographing and collecting samples of the local marine life. While they were in the water the divers breathed from a "closed" rebreathing system connected to the SPID rather than from an "open" SCUBA system. An open apparatus spills exhaled gas into the sea. At 432 feet, under 14 atmospheres of pressure, each exhalation expends gas equal to a sea-level volume of some seven liters, which would be prohibitively wasteful. Link had designed a system that pumped the dwelling atmosphere through a long hose to a breathing bag worn by the diver. Exhaled gases were drawn back to the dwelling through a second hose to be purified and re-circulated. The apparatus worked well except that the breathing mixture was so dense under 14 atmospheres that the pumps could not move quite enough of it to meet the divers' maximum respiratory demand.

During the second evening we carried out and recorded voice-communication tests with the divers breathing either pure air or a mixture of 75 percent air and 25 percent helium. Voice quality was considerably better than in a helium atmosphere, but even 30 seconds of breathing air caused a noticeable degree of nitrogen narcosis. At 11:00 P.M. the two men bedded down for the second night. They were disturbed from time to time by heavy thumps against the outside of the dwelling. It was found that large groupers, attracted by the small fishes that swarmed into the shaft of light spilling from the open port of the SPID, were charging the swarm and hitting the dark bulk of the dwelling.

The next day the divers measured the visibility in the remarkably clear water; they could see almost 150 feet in the horizontal plane and 200 feet vertically. Then they took more photographs and collected animal and plant specimens. At 1:30 P.M. on July 2 both men were back in the SDC with the hatches secured. At 2:20, after 49 hours on the deep shelf, the SDC began its ascent. The internal pressure was maintained at 432 feet; although the divers were being lifted toward the surface, they were not yet being decompressed. At 3:15 the dripping SDC was hoisted onto its cradle aboard the Sea Diver. Now the internal pressure was decreased to 400 feet to establish a one-atmosphere differential between the divers' tissues and the chamber environment and make it possible for helium to begin escaping effectively from their tissues. Then, at 4:00, the SDC was mated to the deck decompression chamber, which was also at a pressure of 400 feet. Stenuit and Lindbergh, transferred to the deck chamber and we began to advance them to surface pressure at the rate of five feet, or about 0.15 atmosphere, per hour. With the divers safe in their chamber another advantage of deck decompression became evident: mobility. While decompression proceeded the Sea Diver weighed anchor and steamed for Florida. By the time it moored in Miami on the afternoon of July 5 the pressure had been reduced to 35 feet.

During the shallow stages of decompression, breathing pure oxygen establishes a larger outward pressure gradient in the lung for the inert gas to be pulled out of the diver's tissues, thus helping prevent the bends. Since breathing pure oxygen under pressure for a sustained period can cause lung damage, Lambertsen had in the past suggested alternating between pure oxygen and compressed air. We instituted this interrupted oxygen-breathing schedule when the divers reached 30 feet. Still, we had one period of concern about decompression sickness. At about 20 feet Stenuit reported a vague "sawdust feeling" in his fingers that seemed to progress to the wrists. I examined him under pressure in the chamber. There were no abnormal neurological findings, but decompression sickness is so diverse in its manifestations that almost any symptom has to be taken seriously. Dickson and I therefore recompressed the chamber one atmosphere and then resumed decompression at the slower rate of four feet per hour. Finally, at noon on July 6, Stenuit and Lindbergh emerged from the chamber in excellent condition after 92 hours of decompression. The important point about saturation diving is that their decompression time would have been the same if they had stayed down 49 days instead of 49 hours.

Their dive had shown that men could live and work effectively more than 400 feet below the surface for a substantial period, protected by an almost autonomous undersea dwelling, and be successfully recovered from such depths and decompressed on the surface at sea. More specifically, it demonstrated the flexibility and mobility of the three-chamber concept. It also emphasized some problems, including the voice distortion caused by helium and the need for a larger breathing-gas supply to support muscular exertion. It showed that the control of humidity in an atmosphere in direct contact with the sea is extraordinarily difficult. The relative humidity in the chamber was close to 100 percent and both divers complained of softened skin and rashes. Temperature was a problem, too. Both men preferred having the chamber temperature between 82 and 85 degrees. In the water, we realized, heated suits are required to keep divers comfortable even in the Caribbean Sea.

Author: Dr. Joesph MacInnis currently studies leadership in lethal environments. He worked on James Cameron's last three deep-sea science expeditions, including the DEEPSEA CHALLENGE Expedition. His latest book, "Deep Leadership: Essential Insights From High-Risk Environments," was published by Random House.

The full text of MacInnis' original Scientific American *article is available for a small fee at: <http://www.scientificamerican.com/article/living-under-the-sea/>*