Research in Progress

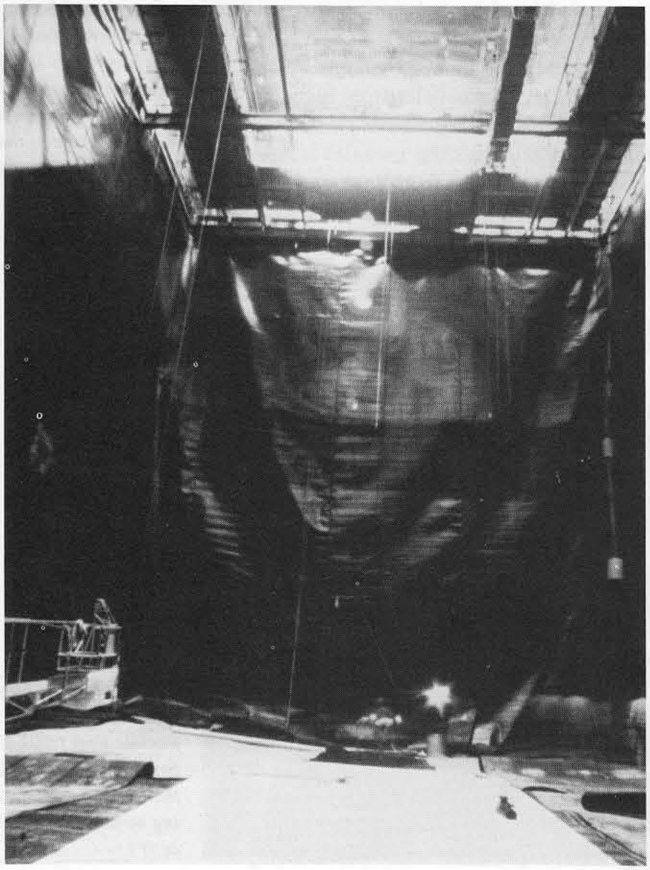
Proton Pool

A TANK of water the size of Millikan Library can't help but inspire visions of the ultimate water prank. And it also inspires a few jokes among the physicists who dreamed up the giant pool holding thousands of tons of water (which is not drowning the stacks in Millikan but is located 2000 feet underground in an Ohio salt mine). John LoSecco, assistant professor of physics at Caltech, refers to the plastic-lined pit as "the world's largest underground water bed" and proposes to throw in a lot of Jello if it should start to leak. Even Woody Allen commented on the project in his film *Stardust Memories*, expressing great dismay on reading of the attempt to prove that all matter will eventually disintegrate.

The giant pool is a proton-decay detector (and if protons decay, so does everything else). The $4-million project in the Fairport mine of Morton Norwich Products Inc. was initiated in 1979 by UC Irvine, the University of Michigan, and Brookhaven National Laboratories (hence IMB) and funded largely by the Department of Energy. Caltech's link to the undertaking is LoSecco, who came here this year but is also still working in the salt mine on the world's largest such detector.

Why does it have to be so large? The water serves two functions — it's the detector, and it also contains the protons themselves — the more water, the more protons. Protons are very stable particles and were thought to exist forever; if they decay at all, it is very, very slowly. Their lifetime has been derived theoretically to be at least 10^{30} years, or 10^{20} times the age of the universe, so Woody Allen need not be too alarmed. Since you can't sit around watching one for that long, the only other way to catch one in the act of decaying is to observe an enormous number of protons. Since the 8000 tons of water in the detector contain about 4½ times 10^{33} protons, the IMB group hopes to see four or five hundred decay events in a year.

If researchers do observe a proton decaying, many pieces of the puzzle of mod-



At left, the proton detector pit, 60' x 80' x 70' and 2000' underground, is lined with thick black plastic before being filled with water. Below, John LoSecco displays one of the 2048 photomultiplier tubes (others are lined up behind him) that will pick up the signals of decaying protons.

ern physics will fall into place. Since the understanding in recent decades of the weak and strong forces holding the nucleus of an atom together, the holy grail of physicists has been to link these two to electromagnetism and gravity and show that all four of the fundamental forces of nature were once part of the same process. Mathematical tools such as gauge theories permitted the integration of the weak force and electromagnetism in 1967 (the 1979 Nobel Prize in physics was awarded for this work); this theory predicted the existence of a new interaction — the weak neutral current — which was duly observed experimentally a few years later. Although gravity is still a holdout, a grand unification theory combining under one gauge group both the weak and strong forces and electromagnetism was proposed in 1975. This theory, however, also predicts another leftover piece of the puzzle — an as yet unobserved interaction, the decay of the proton. The proton-decay experiment is therefore a test of grand unification models, and physicists around the world are now watching protons in detectors that range in size from 100 tons to 8000 tons.

If you're going to use 8000 tons of something, it had better be cheap, says LoSecco, explaining why water was chosen as the detector medium. Purified water from Lake Erie was funneled into the hollowed-out pit 2000 feet below the lake; the depth is necessary to block out background noise from cosmic rays, which occur three orders of magnitude less often at that depth than at the earth's surface.

A decaying proton would produce very energetic charged particles that would travel through the water faster than the speed of light. (The speed of light in water is 30 percent lower than in a vacuum.) This action creates Cerenkov radiation, a shock wave similar to the sonic boom from an aircraft flying faster than the speed of sound. The rigid structure of Cerenkov light enables the experimenters, when they pick it up, to trace exactly what produced it.

In the IMB project, 2048 photomultiplier tubes positioned around all six sides of the tank are poised to pick up Cerenkov light. These photomultipliers in turn are linked up to three serially operating computers, arranged in a decisionmaking hierarchy, which quickly record information of all events in the detector, then process and discriminate among the data to decide what is worth keeping for further analysis by the human scientists. Caltech's LoSecco, whose background is actually in theoretical physics, was involved in the sophisticated electronics that make up this system, specifically in the design of the digital data readout system. Even at California's considerable distance from the salt mine he will be analyzing printouts of the proton watch.

For conclusive results the IMB group will probably continue to watch protons for a few years. In the meantime (or subsequently) the biggest detector in the world can also, with a few modifications, be used to study other phenomena, for example, neutrinos and their possible mass and the origin of cosmic rays (the cosmic rays that do reach the detector are high-energy ones that aren't bent much and so remember where they came from). LoSecco is also interested in some of the "crazier" proposals for the huge pool — looking for signals of the sun's missing neutrinos and of collapsing stars at the center of our galaxy. □ – *J.D.*

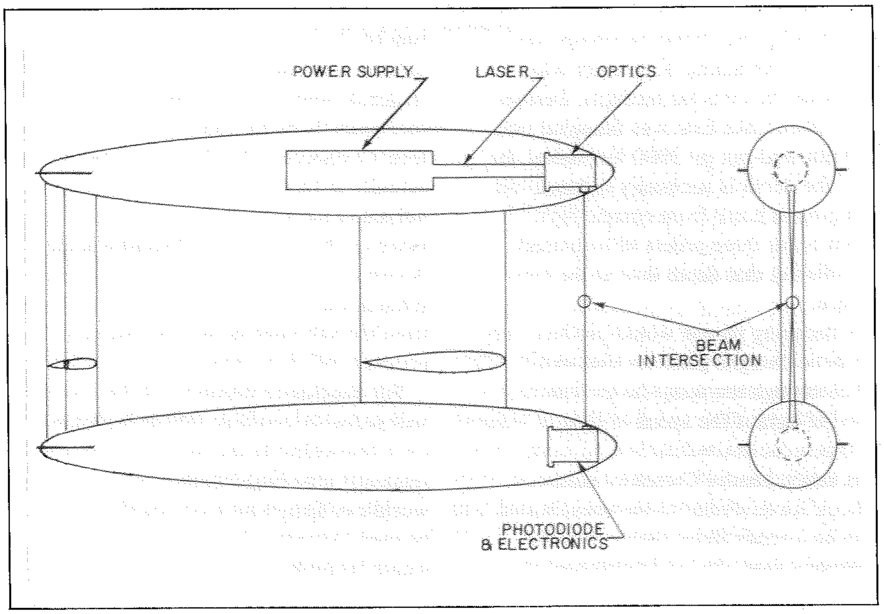
Ocean Motion

DUMPED into southern California's coastal waters every year are 288,000 metric tons of particulate matter carried by rain runoff and treated waste water. Among these tiny particles, which account for 75-90 percent of coastal pollutants, are hundreds of tons of chlorinated hydrocarbons and such toxic metals as chromium, lead, cadmium, and arsenic.

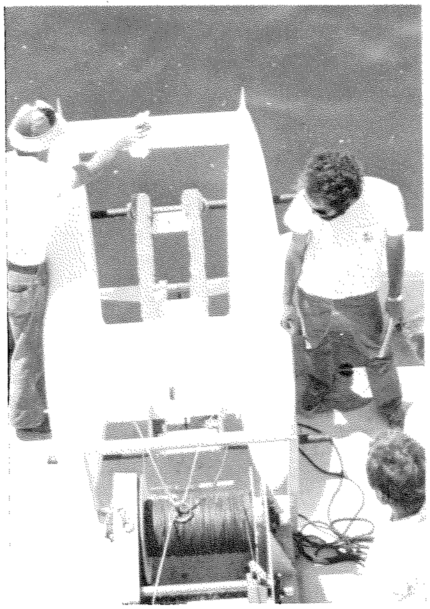
The fate of these particles has important implications for this area both in the reduced intensity of the sunlight reaching the giant kelp beds because of the particles and in the possible accumulation of toxic wastes near shore. It has been assumed that these particles were carried out to the ocean where their concentrations would be insignificant. But this is not known.

To try to find out what happens to them, a six-foot-long submarine equipped with lasers has been developed to observe these particles in the act of whatever they do down there. Conceived in the Keck Laboratories of Hydraulics and Water Resources by E. John List, professor of environmental engineering science, and built by research fellow Gregory Gartrell, Jr., the little submarine — a twin-hulled "fish" — is part of a larger project investigating the chemistry and physics of particulate matter in seawater. Much of the research, with postdoc Henry Pearson and graduate student Iraklis Valioulis, has involved computer simulation to construct mathematical models of the physical processes involved. The little catamaran, with its laser and sophisticated electronics, will be towed behind a larger boat to gather data in the field, that is, under the water, to complement some of these simulations.

The ultimate destination of the particles depends on whether they are deposited as sediment or remain in suspension, eventually to be transported far out in the ocean. Two basic physical mechanisms affect what happens: ocean turbulence and the particle coagulation rate. If the particles collide with each other and coagulate into bigger and bigger particles, they will fall to the bottom. How often they collide is a function of Brownian motion, of differential sedimentation (if some particles fall faster than others, they will catch up and collide), and of the relative velocities of the particles induced by turbulence.



To determine the speed of suspended particles in seawater, a laser is generated in one hull of the catamaran submarine and passed through a beam splitter. Where the two beams intersect between the hulls, particles will create an interference pattern, which is received by the photodiode and transmitted back to the towing vessel.



The "fish" is readied for a test run from the research boat Osprey.

Since turbulence is the major determinant of coagulation of particles between 1 and 100 micrometers (the size of treated wastewater particles), List and his colleagues believe this must be the controlling process in the size distribution of the particles. It is this process that the submarine will investigate.

A key element in the description of turbulence-induced particle coagulation is the rate of dissipation of turbulent kinetic energy, and this can be affected by density stratification. The coastal waters consist of layers of different temperatures. Between the top warm layer, stirred by wind and waves, and the colder, also turbulent, depths below, lies a sharply defined zone, the thermocline, which is somewhat static. The role of the thermocline in damping the dissipation of turbulent kinetic energy is of interest to List, who believes this role has been underestimated. Although the nonturbulent zone would retard mixing with the wider ocean waters, it would also slow down the coagulation rate, maintaining the smaller size particles that would remain in suspension and not settle out.

The submarine fish houses a laser-Doppler velocimeter, an instrument that has already revolutionized velocity data measurement in the laboratory. The laser beam is generated in one hull of the catamaran and passed through a beam splitter. The resulting two beams (eventually there will be three) intersect at a point midway between the hulls, and any particle in the intersection (200-300 per second) will create an interference pattern of flashes, which are picked up by a photodiode in the opposite hull. Measurement of the time between flashes gives the speed of the particle. From this speed the rate of dissipation of turbulent kinetic energy can be determined.

As the fish is towed behind a boat, "porpoising" up and down across the stratifications up to 100 meters below the surface, its signals are transmitted to an onboard data storage system through an electrical support cable. Caltech's 32-foot research vessel *Osprey* has been used in testing the submarine, which will soon be ready for its maiden research voyage. Fieldwork is being conducted out of the Kerckhoff Marine Biological Laboratory at Corona del Mar.

The research is funded by the Office of Marine Pollution Assessment and Sea Grant, both of the National Oceanic and Atmospheric Administration, by the National Science Foundation, and by part of a Mellon Foundation grant to Caltech to study the fate of hazardous substances. James J. Morgan, professor of environmental engineering, is co-investigator with List on the project, studying the chemical aspects of coagulation. The hull of the fish was designed by Carl Gibson, associate professor at UC San Diego, originally for temperature and salinity measurements; and James Hunt, now assistant professor at UC Berkeley, developed the coagulation hypothesis for his Caltech doctoral thesis. Graduate student Panayiotis Papanicolaou is also involved in laboratory work associated with the project. ☐ – *J.D.*

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