mussen report results "into a form appropriate for policy-making purposes."

A third critic of the report—Henry Kendall, a Massachusetts Institute of Technology physicist and head of the Union of Concerned Scientists—was the only witness to reach a conclusion that was clearly adverse to nuclear power. Whereas Panofsky had simply argued that the Rasmussen estimates are subject to great uncertainty which could encompass either under- or overestimation, Kendall concluded that "the risks in a large reactor program are almost certainly substantially understated" by the Rasmussen study. He also expressed greater concern over the uncertainties, calling them "very large—large enough to accommodate risks that are entirely unacceptable."

The most substantial review of the final Rasmussen report so far seems to have been conducted by the Environmental Protection Agency (EPA) and one of its contractors, Intermountain Technologies, Inc., of Idaho Falls, Idaho. William D. Rowe, EPA's deputy assistant administrator for radiation programs, told the hearing his agency has identified "several significant areas" in which the report is either "deficient" or contains "unjustified assumptions."

The most significant was that it failed "to address fully the health effects expected after an accident." The EPA contends that the Rasmussen group should have calculated the delayed somatic health effects from reactor accidents in accord with an approach used by the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation in 1972. The Rasmussen group used a different approach that had the effect of reducing the estimated cancer fatalities by a factor of from 2 to 10, according to EPA. (The Rasmussen group says the factor is only 4, and it claims to have good support for the approach it uses.) The EPA also took issue with the Rasmussen report's assumptions concerning the protection that could be provided by evacuating people from the vicinity of an accident, and it disputed the estimates of the probabilities of radiation releases. But what it all added up to was unclear. Rowe told the congressmen that EPA believes Rasmussen has understated the overall risk by a factor ranging from 1 to "several hundred." If the figure lies at the upper end of that range, some nuclear critics believe the underestimate is significant. But Rowe seemed to back down a bit by adding that EPA, on the basis of information that was not in the Rasmussen report but has since been provided by the Nuclear Regulatory Commission, now believes "the most likely value lies in the lower part of this range."

Various critics also contended that the report ignored or downplayed such problems as sabotage, human error, aging of reactor components, hazards in densely populated areas, floating nuclear plants, and the possibility of a "real lemon" among reactors.

Supporters of the Rasmussen report tended to regard the criticisms as nitpicking and trivial. And even EPA's Rowe, after calling for corrections in the Rasmussen risk estimates, concluded that "it is not possible at this time" to assess what difference such corrections might make in judging the acceptability of nuclear power. At many points in the hearing, participants seemed to be haggling over numbers whose significance was not fully understood. Yet the haggling is important because, in the absence of substantial operating experience with reactors, risk assessment must be based on theory and judgment.

—PHILIP M. BOFFEY

Glomar Explorer: CIA's Salvage Ship a Giant Leap in Ocean Engineering

New information about the CIA's deep sea recovery vessel, the *Glomar Explorer*, makes it possible for the first time to envisage roughly how the ship and its associated systems were designed to operate in their technologically unprecedented mission. According to accounts that appeared in March and April last year, the recovery system was designed to salvage a Russian submarine that sank in 17,000 feet of water some 750 miles northwest of Oahu, Hawaii.

The new facts, made available as part of the government's effort to lease the ship, are at variance with many details of the descriptions reported in the national press last year. They also are hard to reconcile with the leading version of what the mission accomplished, according to which the submarine was raised in one piece, but during the ascent two thirds of it broke away and plunged back to the ocean floor, never to be recovered. Yet neither the *Glomar Explorer*'s interior well, nor its associated barge, the HMB-1, were designed to accommodate a full length submarine.

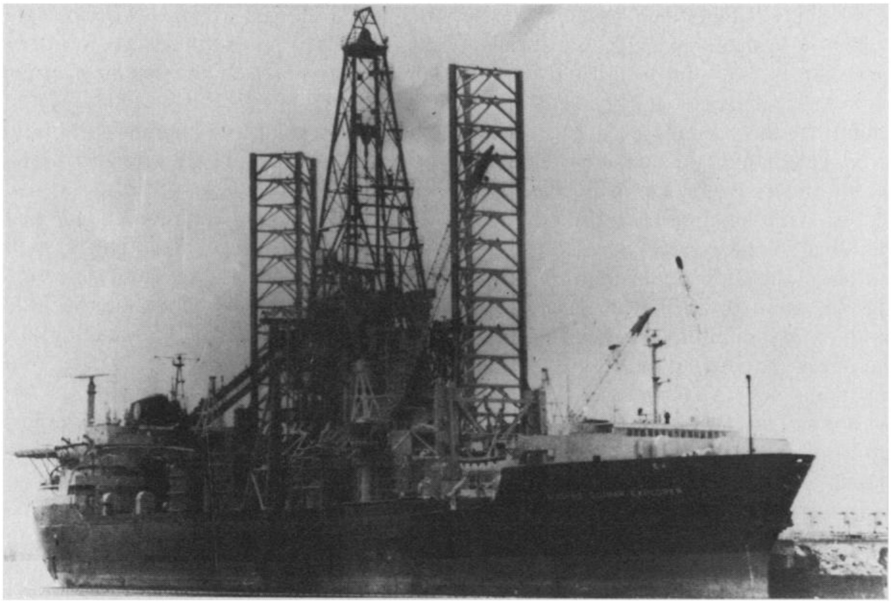
The CIA's deep sea recovery system, despite its unique capabilities, has now been broken up. The submersible barge has been given to the Energy Research and Development Administration for an ocean heat experiment. ERDA also has custody of the "strongback," which was the main frame of a crucial and still secret component of the system, the grappling machine that enveloped the submarine wreckage. The strongback, reputedly the largest single piece of steel ever made, was recently saved from the cutter's torch at 24 hours' notice.

The *Glomar Explorer* itself is moored at Long Beach, California. No government agency has an immediate use for it. Unless a civilian user can be found in the next few months the ship, which cost about $250 million to build, will probably go to the scrapyard.

Yet the National Advisory Committee on Oceans and Atmosphere described the vessel in a recent letter to the White House as a "great national asset." William A. Nierenberg, director of the Scripps Institution of Oceanography and a consultant to the National Security Agency, has compared the achievement of constructing the *Glomar Explorer* with that of the Manhattan project. And Admiral J. Edward Snyder, until recently the Oceanographer of the Navy, told *Science* that the system "is probably the greatest technical achievement in ocean engineering in my lifetime."

The chief reason for these plaudits is the considerable leap by which the *Glomar Explorer* exceeds the best existing technology. Hitherto the deep sea weight-lifting record has been held by the *Alcoa Seaprobe*, which can raise 50 tons from 18,000 feet. According to a Global Marine Corporation brochure, the *Glomar Explorer* can handle "payloads in excess of 1500 tons" to about 17,000 feet, an increase of more than 30-fold.

The advantage seems to have been gained by skillful use of existing techniques rather than any dramatic break-



World Wide Photos

through. The ship was built with impressive speed. The design contract was let in May 1971, the hull delivered in July 1973, and the system completed by May 1974. Designed specifically for salvaging the Russian submarine, the *Glomar Explorer* could also raise manganese nodules in accordance with the CIA's cover story that the ship was a mining vessel in the employ of Howard Hughes.

Three sources of information about the system are now available. The General Services Administration, the government's housekeeping agency, has put the *Glomar Explorer*'s operating manual on public view as part of its effort to lease the ship. The GSA has also released a Global Marine brochure which gives a brief description of the strongback, and ERDA has released details of the barge. None of these sources describes how the three components operated together as a system, which remains a matter of conjecture.

The key operation of the system was to raise and lower the grappling machine. With a weight in air of 2130 tons, the device was almost as massive as the entire submarine it was to salvage. The machine was equipped with a seawater hydraulic system, presumably to power the attachments that secured the wreckage, and with thrusters for fine positioning.

A principal purpose of the submersible barge was to transfer the grappling machine into the central well, or "moon pool," of the *Glomar Explorer*. The machine was too big and heavy to come on board from above, so it had to be introduced from below water. The barge, which could dive to and return from a depth of 165 feet with a load of 2500 tons, was the solution to this problem. Presumably the barge carrying the grappling machine was towed out to the rendezvous point, whereupon it sank to the bottom and rolled back its roof.

The *Glomar Explorer* would then have maneuvered overhead, flooded its moon pool, and slid back the gates on its bottom to open the moon pool to the sea. Visible on either side of the main derrick (see figure) are two tall towers, whose purpose, according to one account last year, was "to deceive observers (including Soviet fishing ships) into believing that the Explorer was deep sea mining." In fact the towers are steerable docking legs. Placed at either end of the moon pool, their purpose is to slide down until they penetrate the barge below and mate with docking pins on the grappling machine. The machine is then drawn up, probably by the docking legs alone, the gates are closed, and the moon pool dewatered. By the reverse of the same operation, the barge could have been used to transfer the grappling machine or large pieces of submarine from ship to shore.

According to bargemaster Harvey Smith, the only voyage the barge has ever made is to Santa Catalina Island, a few miles off Long Beach. It was presumably here that the transfer to and from the ship took place.

With the grappling machine on board, its weight still supported by the docking legs, the *Glomar Explorer* would have journeyed alone to the mid-Pacific site of the sunken submarine. Equipping the ship for its task were a number of unusual features. A dynamic positioning system kept the ship hovering to within an average of 10 feet from its target site. To insulate the pipestring from strains caused by the buffeting of winds and waves, the derrick was mounted on gimbals which allowed the ship to pitch around while the derrick and its pipestring kept steady.

Transfer of the grappling machine from docking legs to pipestring would have been a maneuver of some delicacy, since the two would be responding differently to the movements of the sea.

The pipestring was formed of segments 60 feet long and weighing about 18 tons apiece. An automatic system of cranes and elevators selected the pipes from their storage racks and delivered them to the derrick at the rate of one every 10 minutes. Each segment was screwed into the growing string. The string was lowered or raised by a heavy lift system consisting of two yokes, each powered by a pair of hydraulic cylinders, which grasped the pipe alternately in a hand over hand motion.

The 17,000 foot string, which had extraordinary stresses placed upon it, was no everyday piece of pipe. It was made of enriched gun tube steel, and tapered in six stages from pipe segments a massive 15½ inches in diameter through to segments 12¾ inches across. The inner diameter of all segments was 6 inches.

Bridle and dutchman

To the bottom of the pipestring was attached a strengthening device known as a dutchman, and an apex block with a three-legged bridle which attached to the grappling machine.

Divers fastened an electromechanical cable to the outside of the pipe as the string was let down. According to the Global Marine brochure, the seawater hydraulic devices on the strongback can be operated by pumping water down the bore of the string. The ship's operating manual also states that the pipe has the capacity for air injection when raising materials. If both statements are true, possibly seawater was first pumped down to power the grapples, followed by air injected into chambers in the grappling machine, perhaps, so as to offset some of its weight.

The possibility of air injection into the grappling machine makes it hard to assess the *Glomar Explorer*'s lifting capacity. According to the operating manual, the heavy lift system "is not intended to operate above 14.8 million pounds [6607 long tons] static load," although higher loads can be tolerated for short periods. Much of this capacity would have gone into lifting the pipestring and grappling machine. Figures given in the operating manual for the weight of the various pipe segments indicate that the full string would have weighed about 9 million pounds in air, giving a wet weight of 3525 tons. The operating manual also gives the wet weight of the "mining machine" (presumably the grappling machine—the manual is written to accord with the mining vessel cover story) as 1830 tons.

Subtraction of these two figures from that for the capacity of the lift system gives 1252 tons, which, with the 1½ safety factor that salvors like to allow for, would suggest a payload of 835 tons. (Curiously enough, the figure of 800 tons turned up in last year's accounts, being quoted by the Washington *Post* as the lifting capacity of the barge and by the *New York Times* as that of the derrick. These quantities are as far out as *Time*'s figure for the weight of the pipestring, 400,000 pounds, and *Newsweek*'s estimate of the lift system's capacity as 12,000 pounds.)

The Global Marine brochure, however, states that payloads in excess of 1500 tons can be deployed, the difference perhaps being due to the capacity for offsetting the weight of the strongback by air injection. And a figure quoted by R. Curtis Crooke, president of the Global Marine Development Corporation, to a recent meeting of the National Advisory Committee on Oceans and Atmosphere, implies a payload of just under 2000 tons.

The *Glomar Explorer*'s exact payload is a figure of some interest because of its bearing on whether the Russian submarine could have been salvaged in one piece. The first press accounts, including that of the Los Angeles *Times*, which broke the story, had the submarine being picked up in pieces. But the Los Angeles *Times* in a later story specifically denied earlier information that "the submarine was found in three separate sections" in favor of a version that the vessel, "intact but badly damaged, was raised about 5,000 feet . . . before two thirds of it broke away."

The significance, perhaps, of the latter version is that it provides a neat explanation for the one piece of information on which all press accounts were agreed—that the CIA recovered only one third of the submarine. Yet this version of the *Glomar Explorer*'s mission, though possible, seems unlikely for several reasons. First, submarines implode on sinking below their design depth, and the crumpled wreck may then smash into the bottom at high speed, an experience which the submarine is unlikely to survive in one piece. Of the two American nuclear submarines that have sunk, the *Scorpion* lies with its bow and stern broken off from the midship section, and the *Thresher* disintegrated into a larger number of pieces surrounded by a debris field half a mile in radius.

Second, even if the *Glomar Explorer* had lifted the Russian submarine off the bottom in one piece, it is hard to see what would have happened next. The obvious way for the ship to recover objects is to bring them into its flooded moon pool, then close the gates and dewater the pool. According to *Jane's Fighting Ships*, however, the length of a Golf class submarine is 320 feet, too long by far to fit into the 199 foot moon pool. Alternatively, the *Glomar Explorer* might have kept the submarine suspended just beneath her, sailed for the nearest shallow water, and dumped the submarine there within easy reach of divers. But if this were the approach, it would make more sense to dump the submarine into the barge. Yet though the barge is 324 feet long, its interior envelope is only 256 feet in length. Since the whole system was designed, with no expense spared, for the specific purpose of salvaging the submarine, it would seem reasonable to infer that the largest piece the CIA expected to retrieve was no longer than the moon pool.

Grappling Machine Sloppily Designed?

As for the submarine breaking free from the grappling machine, it seems surprising that the designers of the recovery system should have been caught out by so obvious a contingency. Since the wreck would clearly have been in fragile condition, it would make sense to design the grappling machine so that it could wrap securely around the entire object being recovered.

Another reason for doubting that the submarine was raised in one piece is that such a task may have been a little bit beyond even the *Glomar Explorer*'s capacity. The displacement weight of a Golf class submarine is given by *Jane's* as 2350 tons. Soviet publications on submarine design suggest that about 80 percent of such a vessel would consist of metallic objects. With a factor of 0.87 to offset the weight of steel in water, the wet weight of the flooded out submarine might be estimated as 1640 tons. Payload capacity to lift such an object, with a prudent 50 percent safety factor, would be some 2500 tons, which seems more than the *Glomar Explorer* probably had.

Assuming for the moment that the submarine was not in fact raised in one piece, why should such a cock-and-bull story have worked its way into several circumstantial accounts of the *Glomar Explorer*'s mission? Speculation can go only so far, but it seems reasonable to expect that the CIA, which had kept the project secret for so long, was in control of most of the information that appeared last year. Intelligence agencies are not on oath in their communications with the press. Remembering the affair of the U-2 spy plane, which the Soviet Union tolerated until the first official confirmation by the U.S. government, the CIA would presumably have sought to avoid humiliating the Russians by admitting that anything of much interest had been recovered from the submarine. Yet the agency might not have wished to pretend that the *Glomar Explorer*'s mission was a complete failure at a time when it was under heavy public criticism for activities nearer home.

As it happens, the story that emerged last year seems almost tailor-made, as it were, to justify the *Glomar Explorer*'s operation without embarrassing the Soviet Union. A third of the submarine was recovered, according to most of the newspapers briefed by the CIA, but it contained no missiles, no code room, and only the indication of two nuclear tippable torpedoes. The CIA specifically denied reports that the whole submarine, or two of its nuclear torpedo warheads, had been recovered.

Yet most accounts, while agreeing on that, differed with each other and the probable truth in many technical details of the *Glomar Explorer*'s operation and in most estimates of the system's characteristics. That might reflect simply the difficulty of acquiring hard to come by information against tight deadlines. It might also reflect a pattern of manipulation by the chief source of information.

If the latter is the case, the actual results of the *Glomar Explorer*'s mission can only be guessed at. The expedition may have been a total failure. On the other hand, the ship bears the stamp of such powerful design and superior capabilities that a technical failure through lack of foresight would be more surprising than not. It seems quite possible that the Russian submarine was broken into several pieces. For what it is worth, the *Glomar Explorer* is reported to have spent a month at the recovery site in 1974. From the information now available this would seem to be time enough for the grappling machine to have made perhaps as many as five journeys to the ocean floor and back, retrieving a piece of submarine on each occasion. Just conceivably, the *Glomar Explorer* has been declared surplus because she scooped up almost everything her designers intended her to garner.—NICHOLAS WADE