What is the total cost of building a new *Alvin* rated for 6,500 meters?

Preliminary estimates are that it will cost less than $20 million. The design team is in the process of verifying and refining that estimate.

What is the difference in building and operating costs between a new *Alvin* rated for 6,500 meters and one for 4,500 meters?

The main building cost differences are related to additional material for the hull and additional syntactic foam required for the 6,500-meter submersible. The cost increase is estimated to be less than $1 million.

In terms of operating costs, the current plan calls for them to be similar to present *Alvin* operating costs.

Does extending the depth rating to 6,500 meters reduce vehicle capability?

Engineers and scientists are developing the specifications for a new 6,500-meter *Alvin* so that no current *Alvin* capabilities will be degraded, and, in most cases, they will be improved. The vehicle is likely to have an increase in air weight of 3,000 to 5,000 pounds due to the increased size and pressure rating of the personnel sphere. The increased mass will not affect maneuverability because the plan also includes improvements in the vehicle's hydrodynamics and its propulsion system, including more powerful thrusters and a dynamic positioning control system.

How does the new vehicle design improve deep-diving capabilities?

The design offers:

- faster ascent and descent rates to increase bottom time,
- enhanced energy capacity,
- expanded view port fields of view,
- greater access to the seafloor (99 percent of the global ocean),
- improved interior ergonomics (due to increased sphere size and better layout),
- advanced interior electronics and larger science payload,
- reduced physical and chemical disturbances to science study areas (using a water-based ascent/descent system), and
- the opportunity to install upgraded sensors, enhance safety characteristics, and undertake other improvements.

How is the deep submergence science community being involved in the design effort?

Science input to the design and specification process for a new 6,500-meter *Alvin* is provided through a special advisory body, the New *Alvin* Design Advisory Committee, which was formed in collaboration with the UNOLS Deep Submergence Science Committee.

New *Alvin* design Website: http://www.whoi.edu/marops/vehicles/newalvin/index.html

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The World's Deep-Sea Research Submersibles

	Proposed *Alvin*	*Alvin* (US)	*Mir I & II* (Russia)	*Nautile* (France)	*Shinkai 6500* (Japan)
Depth (meters)	*6,500*	4,500	6,000	6,000	6,500
% Ocean coverage	*99%*	62%	98%	98%	99%
Dives/Year	-	180	Variable (low)	100–115	60
Scientists/Dive	*2*	2	1 or 2	1	1
Battery Operating Costs per Dive	-	$40	Unknown	$210	$35,000
Bottom (hrs)	*8 Hours@2,500 meters*	4–5	10–15	4–5	4
Payload (kg)	*Greater than present* Alvin	680	290	200	150
Interior Sphere Volume (m^3)	*4.84*	4.07	4.84	4.84	4.19
Observer Visibility	*Forward/Central plus Side*	Side/Down	Forward/Central	Forward/Central	Side/Down

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Design Study for an *Alvin* Replacement

Alvin was conceived as a way for the US Navy to reach the seafloor quickly with a small, easily maneuverable vehicle. While providing this capability, the submarine also became a much sought-after scientific research tool.

Since its launch in 1964, *Alvin* has made close to 4,000 dives, in recent years averaging 180 dives per year. A dive usually lasts about 8 to 9 hours, with 3 to 4 hours (depending on the operating depth) devoted to ascent and descent.

E. Paul Oberlander

Artist's conception of 6,500 meter Alvin.

Alvin is the only deep-diving, human-operated, research vehicle (HOV) in the US (though there are several with shallower capabilities), and it is one of only five in the world (see chart on back). *Alvin* has taken more scientific "eyes and brains" to the deep seafloor than any other HOV. Since the 1970s, the unique and groundbreaking accomplishments of scientists working in *Alvin* have often been cited, and *Alvin*'s capabilities and reliability continue to be the standard by which other HOVs are measured.

Though *Alvin* has continuously been upgraded over its 40-year history (only the name is now original), and has an excellent operational record, replacement and improvement of major system components are needed to provide significant enhancements to operational and science systems and to maintain the nation's deep-diving HOV capability. These needs, and the decommissioning of *Sea Cliff* by the US Navy, have spawned discussions of replacing the current *Alvin* with one designed to reach 6,500 meters or 99 percent of the seafloor, compared with the current 4,500-meter rating, which covers 62 percent of the seafloor.

Extensive consideration of the US HOV capability over the past five years at national meetings and workshops indicates the majority of the nation's oceanographic community believes that a new *Alvin* with deeper capability should replace the current vehicle.

As part of the feasibility study for a new research submersible, NSF and NOAA funded the University National Oceanographic Laboratories System (UNOLS) National Deep Submergence Facility (NDSF) at the Woods Hole Oceanographic Institution (WHOI) to undertake concept development. This first step in the process will convert rough scientific and engineering requirements and initial concepts into a detailed engineering specification for a new *Alvin* with a depth capability of 6,500 meters. The performance requirements and principal system characteristics will be based upon past and continuing input from the scientific community, the collective experience of WHOI NDSF personnel, and information compiled from foreign operators of research submersibles rated to 6,000 meters or more.

The concept development and community review will be completed by December 2003. The request-for-proposal process followed by preliminary and detailed designs will take approximately one year, while the fabrication, assembly, and testing of a new *Alvin* will require approximately two years.

Frequently Asked Questions

What are the first-order assumptions for the design of a new 6,500-meter *Alvin*?

- A crew of 3 (1 pilot and 2 scientists). To date, a total of 7,287 individuals (including just 34 pilots) have made *Alvin* dives with this configuration.
- A daily single dive routine, but with the capability for two sequential dives within a 24-hour period.
- Use of R/V *Atlantis* (delivered in 1997) as the support ship without major modifications to the hull or launch/recovery A-frame system.
- Scientific sampling and observational capabilities at least as good as the current *Alvin* with significant improvements in most areas.

What will be the depth capability of the new submersible?

The actual depth capability will be based on engineering and cost trade-offs, with the underlying requirement of producing a vehicle with the general size, weight, and performance characteristics that have made *Alvin* the leading deep-diving research submersible in the world. Due to limitations of currently available high performance syntactic foam (see "Flotation" opposite), the maximum operating depth is likely to be 6,500 meters.

Are there science requirements at depths deeper than 4,500 meters?

Interest in earth and oceanographic processes at depths greater than 4,500 meters is manifest in the 12-year dive record of the Japanese *Shinkai 6500*, which shows 27 percent of its dives were deeper than 4,500 meters. There are substantive scientific problems to investigate at depths greater than 4,500 meters. Some of these deep areas are within the US Exclusive Economic Zone, primarily in the Pacific US Territories and Hawaii, Alaska, and around Puerto Rico. Specific science problems include:

- Geophysical, geological, hydrological, and macro/microbiological processes in sediments that accumulate on the upper inward slopes of oceanic trenches.
- Volcanic, tectonic, and hydrothermal processes in extensional tectonic settings, including ultra-slow spreading mid-ocean ridges, pull-apart basins, oceanic transforms, and propagating rifts. These areas provide windows into the deeper portions of the oceanic lithosphere.
- Questions of biodiversity, biomass, and processes at work on the world's abyssal plains.

Why not go to full ocean depth (11,000 meters)?

The personnel sphere for an 11,000-meter capable submersible would weigh approximately 8,500 pounds more in air and 6,500 pounds more in water than a 6,500-meter HOV sphere. Because the only available syntactic foam rated for an 11,000-meter depth capability is 50 percent as weight efficient as the foam used on a 6,500 meter HOV (see box opposite), this would result in additional air weight of nearly 28,000 pounds.

The significant increase in volume (366 cubic feet just for the syntactic foam) and total air weight would make the vehicle too large for the present support ship to handle, and would negatively impact *Alvin*'s current excellent maneuverability and capabilities in mid-ocean ridge and hydrothermal vent environments—characteristics that the science community insists be maintained.

In addition, it is likely that other vehicle systems (remotely operated and autonomous vehicles) currently being designed by several groups could more effectively and economically carry out science operations at full ocean depth in the coming decade.

Why replace *Alvin* rather than upgrade it?

The consensus within the scientific community, documented in reports of various meetings and by users who responded to a request for input on the design of a new *Alvi*n, is that a new 6,500-meter *Alvin* is critically needed for the next several decades. Implementing the many improvements defined by the scientific community—in fields of view, energy capacity, depth capability, ascent and descent rates, science equipment, sample capacity, and ergonomics—requires an entirely new vehicle. Upgrading of the current *Alvin* would not be cost- or science-effective, and would not meet the desired performance requirements.

Key Technical Issues

Flotation

Syntactic foam provides flotation to compensate for the heavy components of the new submersible (primarily batteries, pressure sphere, and pressure housings). It is composed of tiny, hollow glass spheres embedded in epoxy resin. High-buoyancy, deep-rated foam is difficult to design and manufacture. It usually requires a mixture containing two sizes of hollow glass spheres. This binary mixture can typically be produced only in one-cubic-foot units that must be shaped and glued to obtain the required volumes. The lightest syntactic foam suitable for deep submersibles provides 1.13 pounds of buoyancy per pound of air weight and is rated for use to 6,500 meters. Syntactic foam is quite expensive at about $2,250 per cubic foot or about $1.1 million for the entire HOV after machining and assembly.

The only available syntactic foam rated for 11,000 meters (i.e., full ocean depth) provides only 0.48 pound of buoyancy per pound of air weight, therefore requiring over twice the volume and weight to obtain the same amount of buoyancy. A new syntactic foam development program would probably only be able to improve the ratio to 0.73 pound of buoyancy per pound of air weight. Hence, the syntactic foam characteristics provide a fundamental constraint on the depth range and size of a new research submersible to replace *Alvin*.

Energy Source

The design team is studying two groups of energy systems—fuel cells and batteries. Characteristics the team is evaluating include energy density (watt-hour per liter), specific energy (watt-hour per kilogram), initial costs, operating costs, life cycle costs, and maintenance and operational considerations. Fuel cells being considered include proton exchange membrane (PEM), aluminum, zinc, and borax types. Batteries include lithium ion, lithium polymer, and nickel cadmium. The goal is a substantial improvement over *Alvin*'s current energy capacity of 42 kilowatt-hours, and routine on-bottom operating capability of about 5.5 hours per dive to maximum depth of 6,500 meters.

Field of View

General view port arrangements that will increase the total field of view and allow observers' views to overlap with the pilot's are being evaluated for both observational and sampling suitability. The design team is consulting with optics specialists to determine whether there are practical methods for improving the basic field of view and minimizing the distortion encountered with standard deep-sea windows. The principal design currently under consideration includes five view ports—one on each side and three forward, with vastly improved overlap in field of view between the pilot and the two observers. In addition, improved ergonomics are being considered as part of the new view port placement design study.

Ballasting System

A ballasting system using only water is being evaluated to determine the feasibility of achieving ascent and descent rates of 6,500 meters in two and a half hours. This will also have the ecological and operational advantage of eliminating the need for disposable steel dive weights and the sealed mercury trim system, and should also improve the bottom time at more traditional operational depths of 2,000 to 3,000 meters.

HOV Science Highlights

The FAMOUS Project—This project, conducted using *Alvin* and two French submersibles in 1974, constituted the first detailed investigation and sampling of lava flows referenced to local geological context on the mid-ocean ridges. FAMOUS and subsequent observations have contributed significantly to understanding of volcanic processes that create the oceanic crust.

Hydrothermal Vents—Scientists diving in *Alvin* in 1977 were the first to view the vents in person. Since then, extensive sampling of vent fluids, chimneys, and biota at tens of vent sites has revolutionized several areas of ocean science.

Bacterial Blizzards Following Volcanic Activity—*Alvin* divers made the first direct observations of bacterial debris emanating from the seafloor, suggesting the existence of a biosphere within the oceanic crust.

Whale Falls—Observations from *Alvin* led to the discovery of a biological community sustained by a dead whale carcass that is similar to that at vents, suggesting that whale falls may act as "stepping stones" for the dispersal of vent animals.

Fluid Flow in Accretionary Prisms—Scientists interested in sedimentary processes have found *Alvin* invaluable for precise collection of samples and deployment of in situ instrumentation for studies of sediment accretion, dewatering, and lithification.