Voyage from the Bottom of the Sea

IM15113-0078

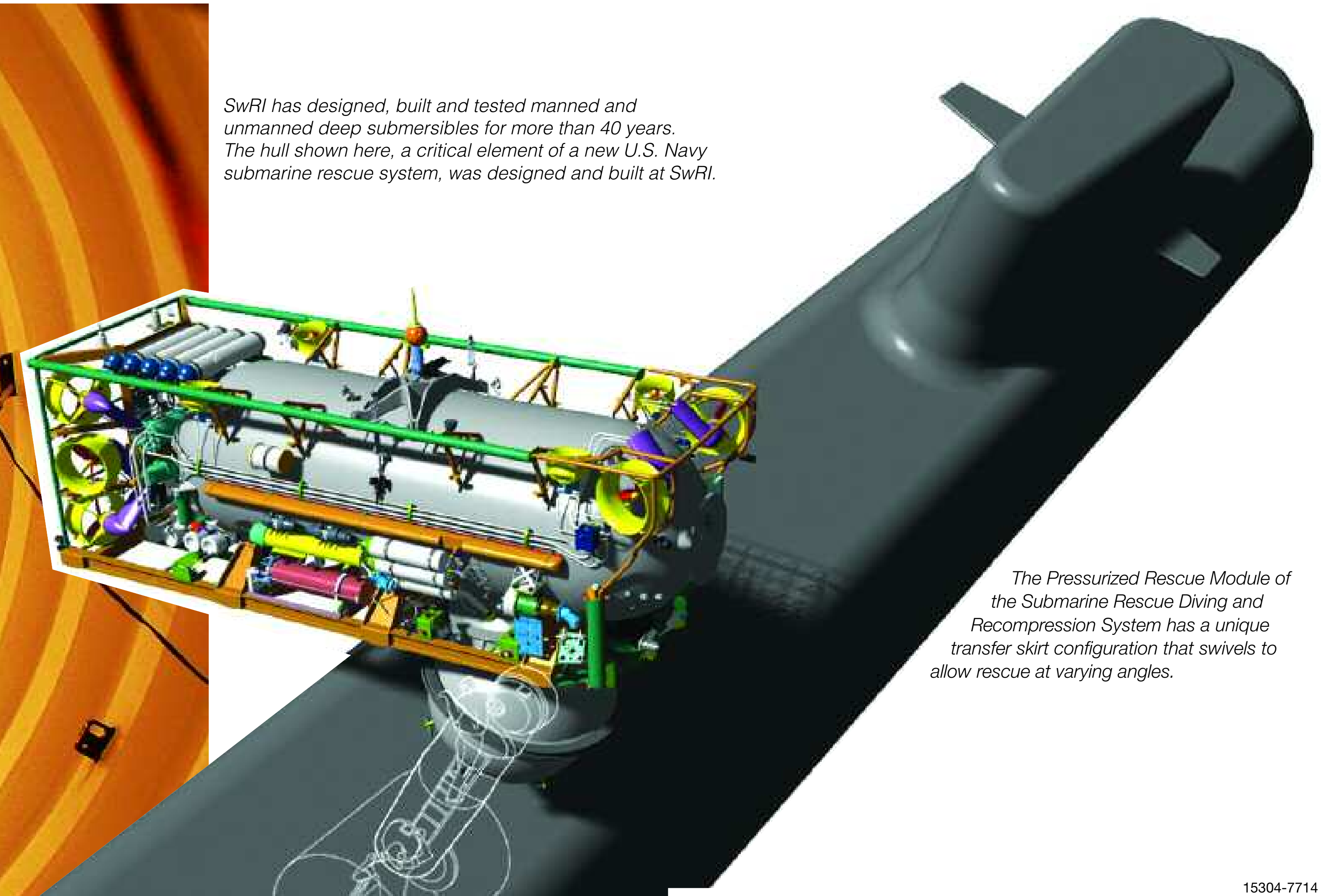
SwRI researchers help design a next-generation submarine rescue vehicle

By George K. Wolfe and B.K. Miller Jr.

On January 8, 2005, the nuclear submarine *USS San Francisco*, some 350 miles south of Guam, collided with an underwater mountain. The sub was 500 feet under water, traveling at more than 30 miles per hour. Despite heavy damage and 30 seriously injured personnel, the *San Francisco* somehow survived. However, there was a more tragic ending to another submarine story more than four years earlier, when the Russian submarine *Kursk* went to the bottom of the Barents Sea. Although 23 crewmen survived an initial explosion, they were lost when rescue attempts were too late.

Successful rescue of crew members aboard a disabled submarine presents significant technical and operational challenges. For surviving crew members, time is the worst enemy. A disabled sub will have very limited breathing air reserves and might lie on the sea floor, hundreds of feet under water and hundreds of miles from the nearest port. Cold water and fast currents can surround the vessel, so a functional submarine rescue system must mobilize and deploy quickly. Once on-site, it must be immediately capable of safely and reliably performing its mission.

In the 1930s, U.S. Navy researchers developed the "science" of submarine rescue. Their efforts were put into practice in 1939 when 33 men were rescued from the *USS Squalus*, which sank off the coast of Portsmouth, N.H. Many foreign navies subsequently developed similar submarine rescue capabilities. A major advancement in U.S. Navy submarine rescue occurred in the 1960s with the development of two then state-of-the-art, autonomous, deep-submergence rescue vehicles, the *Avalon* and the *Mystic*. Today, only the *Mystic* remains operational and will soon be beyond its allowable service life. Russia's failure to rescue the *Kursk* crew in August 2000 and the near-loss of the *USS San Francisco* emphasize the need for more advanced submarine rescue capabilities.



SwRI has designed, built and tested manned and unmanned deep submersibles for more than 40 years. The hull shown here, a critical element of a new U.S. Navy submarine rescue system, was designed and built at SwRI.

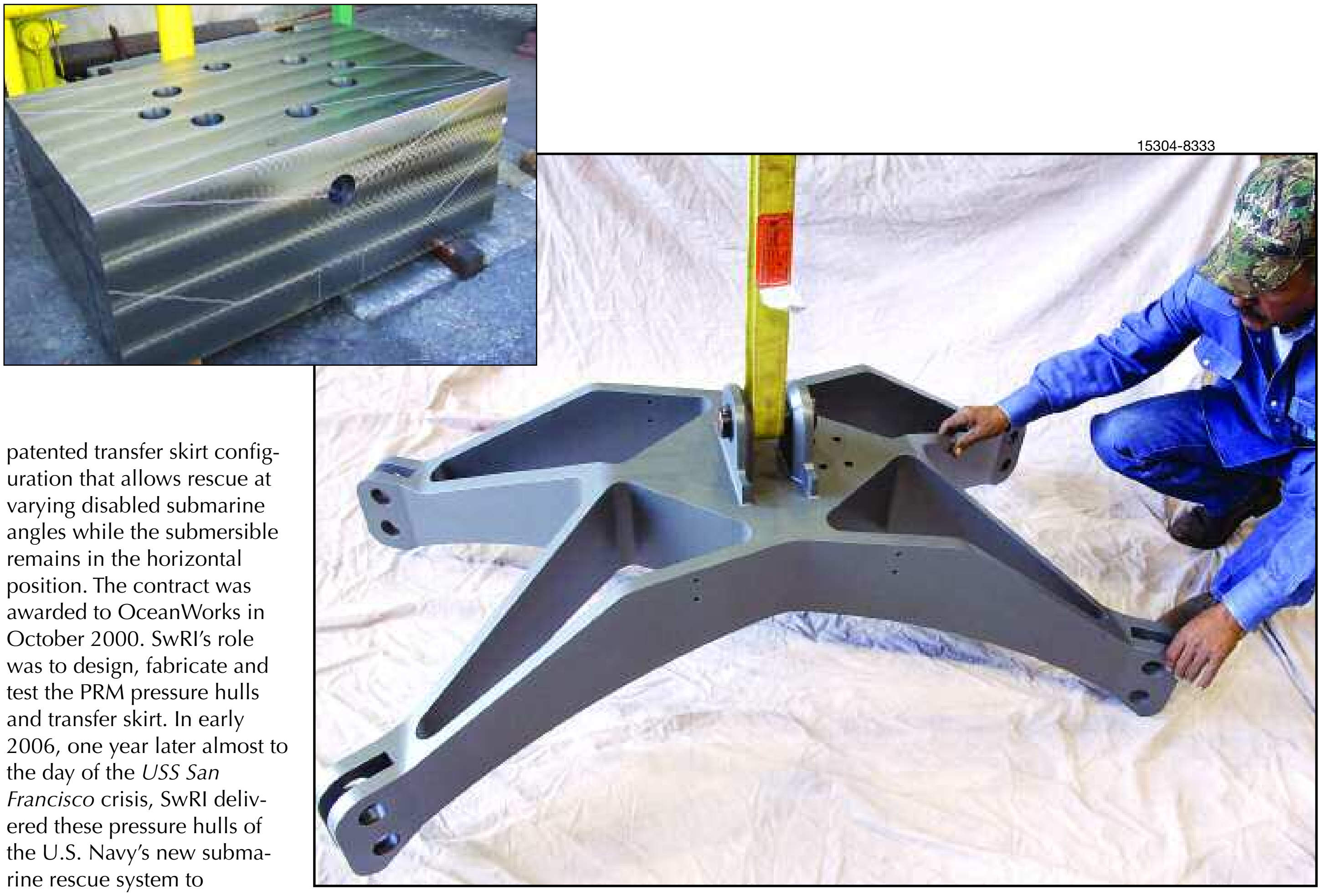
The Pressurized Rescue Module of the Submarine Rescue Diving and Recompression System has a unique transfer skirt configuration that swivels to allow rescue at varying angles.

To address this need, the U.S. Navy Naval Sea Systems Command (NAVSEA) requested proposals for a next-generation submarine rescue system, the Submarine Rescue Diving and Recompression System. The Navy had a general idea of the system configuration and had previously contracted for design and fabrication of the "on deck" portion, which comprises the decompression chambers and transfer system. A critical element of the overall system is the pressurized rescue module system (PRMS), which is the remotely operated vehicle launched into the ocean to retrieve crew members from the disabled sub. Once the rescue module is launched from the ship, a pilot topside steers it and positions it on the disabled sub. Two crew members on the rescue module operate systems to support rescue operations. The rescue module is designed to operate down to 2,000 feet, rescuing 16 persons per trip.

OceanWorks International, Inc., based in Houston, teamed with Southwest Research Institute (SwRI) on the winning proposal to build the PRMS. "Team OceanWorks," as the collaborative effort was called, based the proposal on OceanWorks'

15304-7714

George K. Wolfe (left) is assistant director of the Structural Engineering Department in SwRI's Mechanical and Materials Engineering Division. Wolfe has 36 years of experience in marine technology including structural systems development, fabrication and testing. B.K. Miller Jr. (right) is a program manager in the Structural Engineering Department. Miller, who served for 20 years in the U.S. Navy, also specializes in marine technology.



The lifting bridle was machined from a single large titanium 6Al-4V ELI alloy forging (top left). The bridle, which attaches to the rescue module hull, anchors the umbilical cable and also lifts the rescue module assembly.

patented transfer skirt configuration that allows rescue at varying disabled submarine angles while the submersible remains in the horizontal position. The contract was awarded to OceanWorks in October 2000. SwRI's role was to design, fabricate and test the PRM pressure hulls and transfer skirt. In early 2006, one year later almost to the day of the *USS San Francisco* crisis, SwRI delivered these pressure hulls of the U.S. Navy's new submarine rescue system to OceanWorks.

Design and manufacture

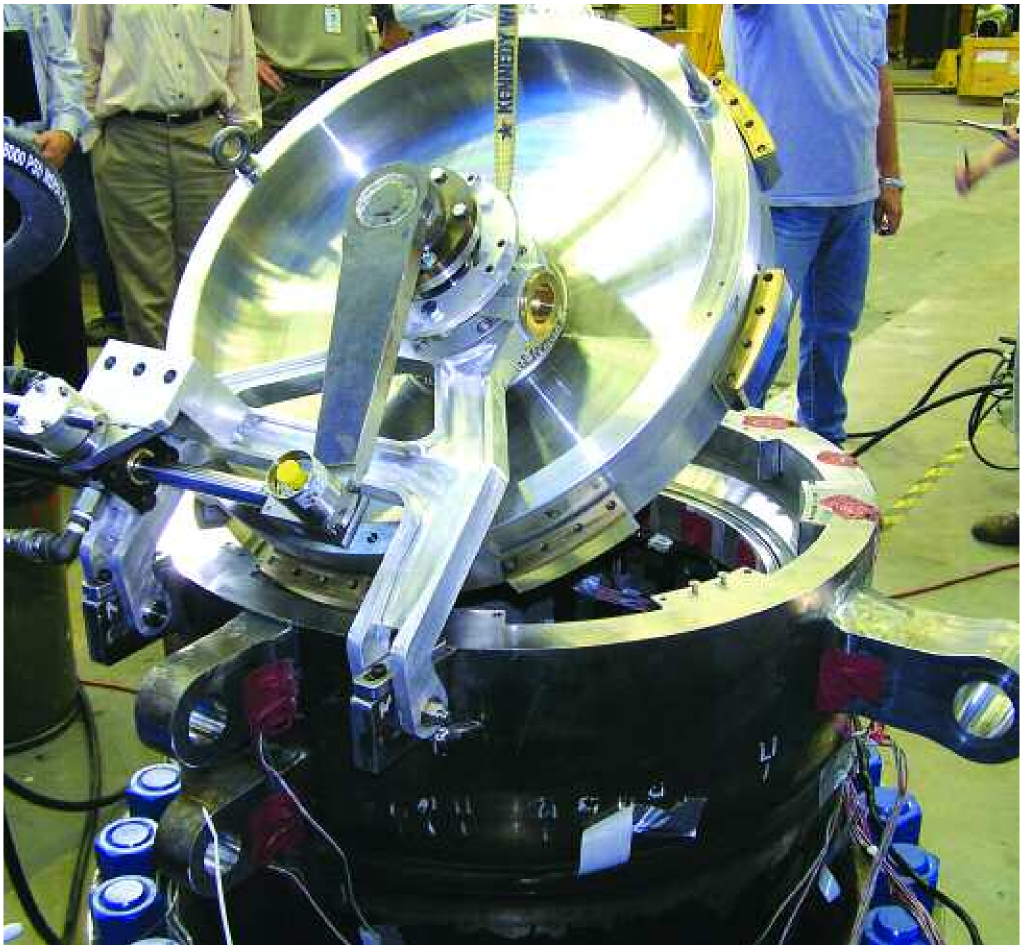
SwRI has a 40-year history of successfully designing, building and testing manned and unmanned deep submersibles. For the PRMS project, SwRI engineers had to design and build a lightweight, manned submersible hull system that could operate safely while deep under water. To achieve these goals, engineers chose a submarine steel (HY-100 alloy steel) for the rescue module hull, hatches and transfer skirt hull. SwRI has one of the few fabrication shops in North America qualified by the U.S. Navy and American Bureau of Shipping to build manned pressure vessels made of HY-100.

Rolled HY-100 plates were welded to form the rescue module's cylindrical hull and strengthened with internal "T-ring" stiffeners. On the bottom of the rescue module is the transfer skirt hatch. Rescued submariners enter the rescue module through this hatch. The hemispherical heads on each end of the rescue module hull were "hot formed" from 2.5-inch HY-100 plate, machined to the appropriate dimensions, then welded to the cylindrical portion of the hull. A hatch is built into one head to allow personnel to exit the module on the surface vessel after rescue. This is called the deck transfer lock hatch. The rescue module is supported by a lower frame that attaches to the hull at six points. The lightweight, high-strength welded frame also was designed and fabricated at SwRI.

The transfer skirt hull allows the rescue module to mate to a disabled submarine, then transfer personnel from the sub into the rescue module. This pressure hull comprises three HY-100 segments: transfer skirt adapter, transfer skirt mid-section and transfer skirt mating section. The mid- and mating sections are hemispherical and were machined from HY-100 forgings. The adapter, also machined from an HY-100 forging, is a "transition spool piece" that will bolt to the rescue module hull. The mid-section is joined to the adapter and can rotate 180 degrees on a diagonal joint. The mating section is joined to the mid-section and can also rotate 180 degrees. It is the mating section that attaches to the "rescue trunk" of the disabled sub during rescue operations.

At the rescue site, the assembled transfer skirt hull is attached to the rescue module hull. This is done by bolting the transfer skirt adapter to the transfer skirt hatch reinforcement. Once joined, the rescue module/transfer skirt hull assembly is raised and lowered by a launch-and-recovery system A-frame using the lifting bridle. The lifting bridle is attached to the top of the rescue module hull at four points and allows for anchoring of the power/strength umbilical cable as well as lifting the rescue module assembly. Designed by SwRI engineers, the lifting bridle was machined in one piece from a very large titanium 6Al-4V ELI alloy forging.

D015324



A test transfer skirt hatch assembly was built to evaluate performance. Rescued submariners enter the subsea vehicle through this hatch.

Material challenges

SwRI engineers incorporated several novel technical approaches to minimize system weight without compromising safety requirements or operational capabilities. Use of a bayonet locking lug hatch design and the use of high-strength, low-weight titanium alloys are two notable examples.

The rescue module, deck transfer lock and transfer skirt hatches open into the rescue module hull. This configuration reduced the exterior “hatch operation envelope,” thereby reducing weight. Inward-opening hatches tend to unseat as external pressure increases. This means that the gap between the hatch’s sealing surfaces increases as the rescue module’s depth increases. If the gap becomes too large, o-ring seal leakage or failure can occur.

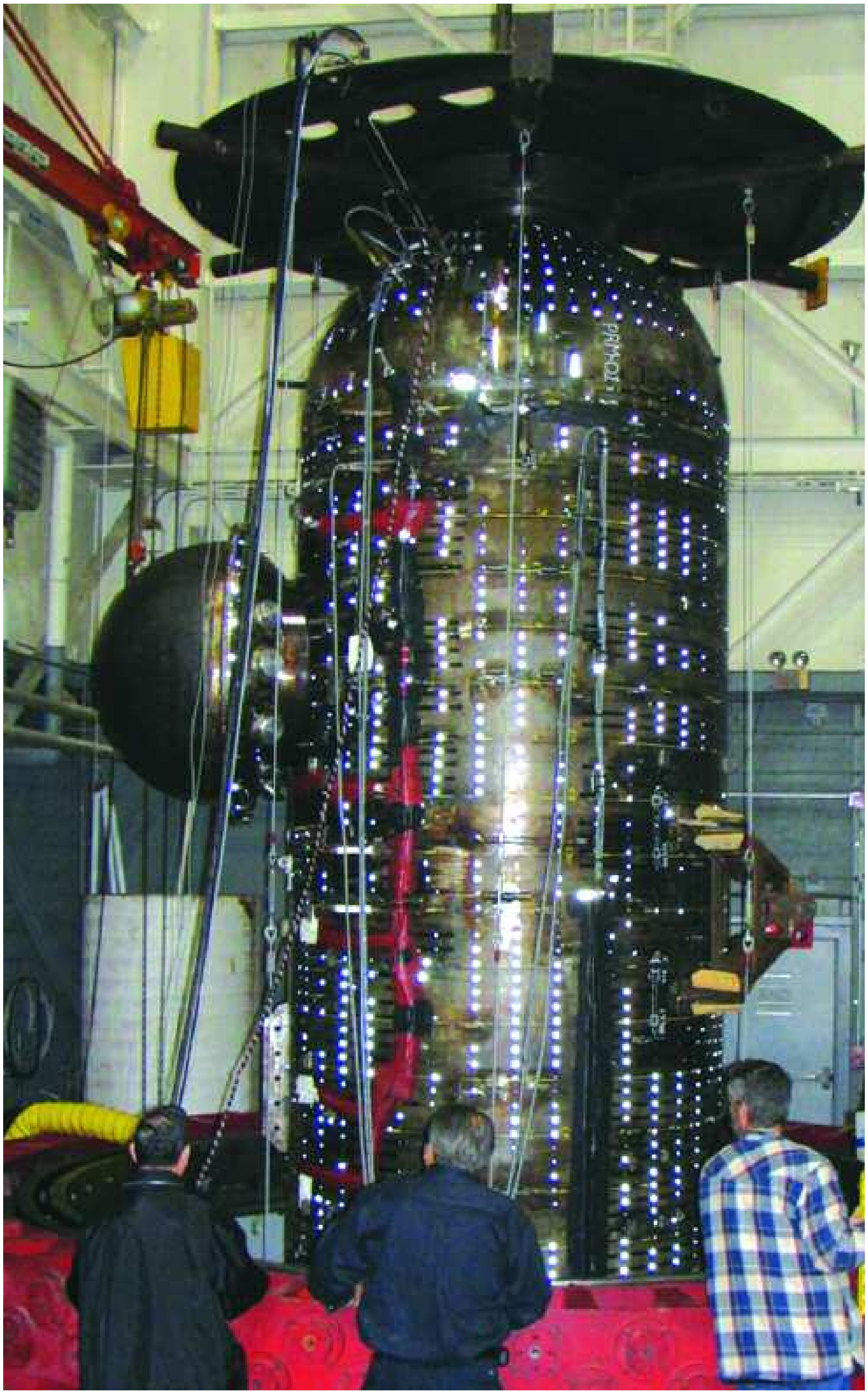
Internally opening hatches for commercial manned diving systems have been used successfully for several decades, but required extensive testing to meet U.S. Navy certification requirements. Significant proof-of-concept research and development, as well as extensively instrumented full-scale and first-article testing, were required.

Proof-of-concept testing

Two years of extensive hatch-related research, development and evaluation culminated with successful tests of the rescue module hull (with hatches installed) at the U.S. Navy Deep Submergence Laboratory in Carderock, Md., during November 2005. During the hatch proof-of-concept test period, SwRI researchers determined the maximum allowable seal gap prior to leakage; seal and wedge friction (rotation of the hatch during lock and unlock operation); seal compression forces; temperature effects

D015325

The transfer skirt hatch reinforcement is installed on the rescue module.



D015321

Technicians lower the rescue module hull into a deep ocean simulator at the U.S. Navy Deep Submergence Laboratory in Caderock, Md.

on seal-related factors; and effects of seal surface defects on seal effectiveness. Also, engineers completed the design, prototype testing and first-article manufacture of a lightweight hatch operating gearbox; design and fabrication of a full-scale hatch operational test fixture; and successful full-scale hatch operational testing. During final testing at Carderock, the transfer skirt hatch performance met or exceeded all design requirements.

With the hull manufactured to the minimum safe thicknesses for all major components, further weight reduction was achieved by use of Titanium 6-4 and 6-4 ELI alloys. Material properties and material characteristic testing, coupled with detailed analysis, were required before the Navy would approve Ti-6-4 and Ti-6-4 ELI for use. Because the rescue module lifting bridle and transfer skirt crown rings (the components that allow the transfer skirt pieces to rotate) will be immersed in seawater, they were machined from 6-4 ELI ring-forgings. The transfer skirt and deck transfer lock hatch mounting yokes are inside the rescue module hull. They were manufactured from Ti-6-4 alloy forgings to reduce weight while providing acceptable structural strength.

Component and assembly testing were major program milestones. Static load testing up to twice the rated load, followed by nondestructive inspections, verified the performance of key load path attachment points. These tests were performed on the lifting bridle, lower frame, rescue module hull and transfer skirt hull. Both the rescue module and transfer skirt assemblies were subjected to two hydrostatic tests to 1.5 times their maximum operating pressure, equivalent to a depth of 3,000 feet of seawater. Strain gages were used on both structures at all high-stress areas and on selected points at which there were geometric discontinuities in the shape. Engineers monitored 178 gages on the PRM hull and 26 more on the transfer skirt during testing. Additionally, various operational aspects of the hatches and transfer skirt were evaluated at their maximum operating pressure, equivalent to 2,000 feet of seawater. Following hydrostatic testing, the rescue module and transfer skirt assemblies were subjected to additional nondestructive inspections as required by ABS and NAVSEA specifications.

Following successful testing and inspection, the rescue module, lower frame and transfer skirt were painted per U.S. Navy specifications. The exterior of the rescue module and transfer skirt hulls are bright yellow. A special white paint was used on the interior surfaces. Unlike the yellow epoxy paint used on the exterior, the white paint will not emit toxic fumes after

After successful testing and inspection, the rescue module (at left, top) and the transfer skirt assembly (below) were painted per U.S. Navy specifications.

curing. This is important, of course, because the interior spaces are to be manned. The lower frame is dark grey, almost black. A special coating process used for titanium alloys, comparable to anodizing aluminum, was used to enhance the non-corrosive properties of the lifting bridle and transfer skirt crown rings.

The rescue module hull assembly and lower frame were joined and delivered to OceanWorks in January 2006. The transfer skirt hull assembly and lifting bridle were delivered in May 2006.

2006 and beyond

Many important lessons were learned during this program. These include fabrication and design efficiencies, as well as methods to improve project and program management for future projects. It is anticipated that a second rescue module will be built, and SwRI believes it is well-positioned to build this follow-on vessel. Most importantly, these new submarine rescue systems will be available to assist disabled subs and hopefully circumvent tragedies such as the *Kursk*.❖

Comments about this article? Contact Wolfe at (210) 522-2428 or george.wolfe@swri.org or Miller at (210) 522-3442 or benjamin.miller@swri.org. To comment on this story online, click on www.swri.org/forums

SwRI researchers are currently designing a personnel sphere, or pressure hull, for Woods Hole Oceanographic Institution (WHOI). The sphere will be made from Titanium 6-4 ELI, designed to operate to a depth of 6,500 meters (21,325 feet) of seawater, and will be classed by the American Bureau of Shipping. WHOI will authorize fabrication after approval of the hull design. After the hull is built and tested, it will be delivered for use in a new deep submergence research vehicle. WHOI currently operates the deep submergence research vehicle *Alvin*. Owned by the U.S. Navy, it can operate to a depth of 4,500 meters. Once in service, the new vehicle could eventually replace the *Alvin*.

Acknowledgments

The PRMS project required the knowledge and skills of a number of SwRI staff members. The team gratefully acknowledges the contributions of the Structural Systems Section and the Test and Evaluation Section, both in SwRI's Structural Engineering Department, and the SwRI Machine Shop, among others.