Oak Ridge: The birth of the nuclear navy, part 1

(As published in The Oak Ridger's Historically Speaking column the week of August 11, 2025)

Oak Ridge has been the location for many firsts. When you mention being from Oak Ridge, you do not even need to add Tennessee. Most people will immediately identify Oak Ridge with the atomic bomb. Many will even know that the uranium-235 for Little Boy came from Oak Ridge. However, not many will identify Oak Ridge with the birth of the nuclear navy, the first shipment of isotopes for nuclear medicine, the creation of the first industrial-size nuclear reactor, much less the first use of nuclear energy to produce electricity (a small but early demonstration at the Graphite Reactor).

This Historically Speaking series will feature the birth of the nuclear navy. It will bring out the details that resulted in what became one of the most effective nuclear deterrence elements of the nation. The first part of the series will focus on the support given to the U.S. Navy by Oak Ridge National Laboratory.

The K-25 Gaseous Diffusion Plant, Oak Ridge National Laboratory, and the Y-12 National Security Complex have all played distinct but interconnected roles in supporting the U.S. Navy's nuclear program since the Manhattan Project. Their involvement has primarily revolved around the production of enriched uranium and the development of nuclear technologies, with one significant exception: the USS Seawolf propulsor.

The United States' nuclear-powered submarines and aircraft carriers have long been a cornerstone of America's strategic deterrence. This most powerful military force's inception can be traced to the unique scientific expertise and visionary leadership that existed in the early years of nuclear development in Oak Ridge. While the thought existed, the practical application was what was needed. Oak Ridge was where practicality prevailed, and that is where the U.S. Navy went to learn how to build a nuclear navy.

The idea of a nuclear navy began with Philip Abelson's "Atomic Energy Submarine." This groundbreaking physics report detailed how a nuclear reactor could be installed in a submarine to provide both propulsion and electrical power. It was written in March 1946 while Abelson was at the Naval Research Laboratory and was later published by the Carnegie Institution.

It concluded that, "with a proper program, an atomic-powered submarine capable of operating at 26 to 30 knots submerged for many years without surfacing or refueling could be operational in about two years." It also projected that a submarine with twice that submerged speed could be developed in five to ten years.

This report was highly influential and was later supported by Admiral Hyman G. Rickover, who, through his relentless leadership, turned the concept into a reality with the USS Nautilus, the world's first nuclear submarine.

Then the first steps were taken when Captain (later Admiral) Hyman G. Rickover attended a pioneering reactor training program at Clinton Laboratories in Oak Ridge led by Nobel laureate Eugene Wigner. As a result, he profoundly shaped the course of naval history.

Rickover and seven others from the U.S. Navy were selected to attend this newly formed program in Oak Ridge. They were here for approximately one full year. Housing would have been provided to them in the city of Oak Ridge.

That is when Rickover met Alvin Weinberg, and a close relationship soon developed as Rickover continued to pursue the practical steps required to create a nuclear navy. This relationship would continue through the years, keeping Oak Ridge close to and involved in Rickover's progress.

One of the first things needed was the design of the nuclear reactor, which Rickover managed through his powerful position on the Atomic Energy Commission's Division of Reactor Development, and as Director of the U.S. Navy's Naval Reactors Branch. The USS Nautilus was the first nuclear submarine, and the USS Seawolf the second.

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Each of Oak Ridge's facilities contributed to the creation and development of the U.S. Navy's nuclear navy in different but related ways. This relationship with the U.S. Navy and Oak Ridge started in 1946, continues to today and is anticipated for the foreseeable future.

The Clinton Laboratories (which became the Clinton National Laboratory and then the Oak Ridge National Laboratory in March 1948), in addition to providing the initial training, was also instrumental in the very early stages of reactor technology. In 1947, Rickover asked for assistance in the development of the USS Nautilus, the Navy's first nuclear-powered submarine. The concept of the pressurized-water reactor recommended by Alvin Weinberg was critical to the Nautilus's design.

In the early 1950's Rickover arranged to have 100 naval officers spend a year in Oak Ridge for intensive study and collaboration with scientists at Oak Ridge National Laboratory. The design of the pressurized water reactor, which became the standard for naval propulsion, and shielding for the protection of personnel on a submarine, was all done by scientists at Oak Ridge National Laboratory, as Ted Rockwell, who worked directly for Rickover, told me in an oral history interview.

The fuel rod cladding using "half-free" zirconium (zirconium with hafnium reduced, which was done in Building 9211 at Y-12) was chosen because of its low neutron absorption and corrosion resistance. This remains the primary method for fuel rod cladding in nuclear reactors today. On a tour of Y-12, Finis Patton, who managed Engineering for the Union Carbide Nuclear Division, told me of his personal experience doing the research that resulted in the purification of zirconium.

Other examples of support provided to the U.S. Navy over the years by Oak Ridge National Laboratory are:

1. Neutron embrittlement of metals
2. Long-term behavior of structural alloys
3. Degradation of reactor materials over time
4. Vibration-damping materials
5. Reactor pump noise analysis
6. Computational modeling of fluid-structure interaction
7. Alternate fuel forms, including high-density uranium fuels and advanced ceramics
8. Contributed to safety modeling and reactor transient analysis, including loss-of-coolant scenarios relevant to compact naval reactor designs
9. Radiation shielding for confined spaces — optimizing protection with minimal weight and volume
10. Studied how radiation exposure affects electronics and human performance in submarine environments
11. Assisted in reactor life-extension studies, refurbishment planning, and decommissioning procedures for aging submarine power plants
12. Provided technical guidance on long-term storage of naval spent nuclear fuel and disposal of activated components
13. Contributed to nuclear propulsion training through simulation tools and data for naval nuclear schools; and,
14. Maintained critical databases of nuclear cross sections and thermal performance
15. The Acoustic Measurement Facilities Improvement Program combined instrumentation and signal processing engineering to assure the nuclear "quiet underwater platform," i.e., submarine, fleet was operating as discreetly as designed. This was done by the Instrumentation & Controls Division for the Navy in the late 1980s and early '90s. At the time, this project had the largest computer in the Laboratory.

Additionally, developing and testing materials that can withstand the extreme conditions within nuclear reactors, which is vital for the longevity and safety of naval reactor cores, was done at Oak Ridge National Laboratory. The education of nuclear engineers needed by the Naval Reactors Program was

also done there until universities began nuclear engineering programs. Cybersecurity has also been provided to protect the Navy's digital infrastructure and systems. And finally, specific isotopes needed by the U.S. Navy have been provided.

In the book *Critical Connections*, written by Lee Riedinger, Al Ekkebus, William Bugg, and Ray Smith, Appendix 2, is found: "1957 UT Department of Nuclear Engineering formed as a result of collaborations in reactor R&D." This was in collaboration with Oak Ridge National Laboratory

So, the Oak Ridge National Laboratory played an extensive role in the creation of the U.S. Navy's nuclear navy. Much of what was developed for the Nautilus also applied to other nuclear reactors. The collaboration quickly advanced many aspects of the Nuclear Age. Rickover and Weinberg played significant roles in the establishment of the understanding and implementation of the practical use of nuclear energy.

Next, we will look at the roles played by the K-25 Gaseous Diffusion Plant and the Y-12 Plant (Y-12 National Security Complex) in the birth of the U.S. Navy's nuclear navy.

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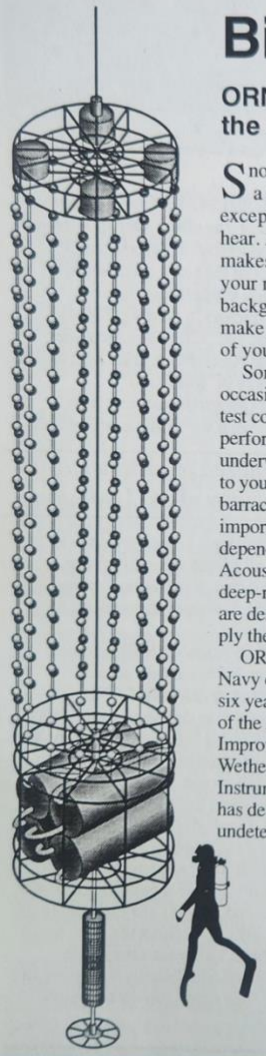
Lab notes

Oak Ridge National Laboratory

Big fish make little noise

ORNL helps the Navy "measure the undetectable"—the sound of its silent subs.



AMFIP II's instrument arrays feature numerous hydrophones and sophisticated underwater electronics. That's what's required to measure the sound, or lack of it, from the nuclear submarine fleet.

Snorkeling in the Bahamas is as interesting a sport in terms of sound as it is sight, except that it's more about what you *don't* hear. A barracuda as long as a good-size leg makes no sound as it swims gracefully by your nose. All you hear is gurgling background noise and, if large fish with teeth make you uncomfortable, the peculiar sound of yourself screaming underwater.

Some of the U.S. Navy's "fish" take an occasional swim in Bahamian waters along a test course designed to see if they are performing to specifications. These "quiet underwater weapons platforms"—submarines to you and me—are huge, but like that barracuda, make no sound. That is an important attribute when mission success depends largely on being able to stay hidden. Acoustic signatures are the primary way these deep-running craft are detected, and so they are designed to emit almost no sound as they ply the seas.

ORNL has been working with the U.S. Navy on a very special program for the past six years called AMFIP II—the second phase of the Acoustic Measurement Facilities Improvement Program. According to Randall Wetherington, who heads the program in the Instrumentation and Controls Division, ORNL has devised ways to "measure the undetectable" for the Naval Surface Warfare Center's Carderock Division.

I&C Division's AMFIP II researchers occasionally travel to sunny Eleuthera Island, which some say resembles a subtropical Oliver Springs, and board the *USNS Hayes*, a ship that contains the instrumentation systems used in tests to determine whether the Navy's ships are running as quietly as they are designed to run. As the *Hayes* stands by, Navy subs run through a course set up in Exuma Sound. Hydrophone arrays that include more than 1000 sensors are placed to pick up sounds from the vessels.

The initial problem, Wetherington said, is how to measure something that virtually makes no sound. "Staying hidden is part of their job," he said. "Acoustics is one of the few ways these ships can be found. The craft in the Trident class can be the length of two football fields and not make any noise as they go by. Our systems help characterize the normal acoustic signature of the vessel as it runs through a course of instrumentation. Our system is not classified, although the data it generates is. If you know what a vessel's acoustic signature is, you could develop ways to detect it."

The system uses several arrays of hydrophonic sensors—laceworks of underwater microphones that dangle from buoys—to gather sound from the craft as it goes by and computers to process the sound signatures to increase the signal over the

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Inside Lab Notes

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AMFIP

(Continued from page 1)

background noise. "There is an ambient noise level in the ocean caused by waves and wind," Wetherington explained. "This new technology can detect noises below this ambient level.

"It's like a TV satellite dish in that the array focuses energy to amplify the sensor signals. As you add sensors, you get more signal gain over a large bandwidth. Placement of those sensors is based on sophisticated math and geometry."

The ORNL researchers have focused on two areas—creating the electronic instrumentation and developing a processing system that takes the data and generates information in a usable form. As might be imagined, handling data from thousands of instruments takes a huge amount of computing power. Devising ways to handle and analyze the amount of sensor data coming in—160 megabytes per second—takes very specialized programming, and that is a specialty of I&C's Real-Time Systems group. I&C Division is home to a 40-gigaflop computer—for a time the biggest at the Laboratory—to perform the signal processing algorithms.

"ORNL was a significant enabler for this program," Wetherington said. "We contributed expertise and identified technologies. For instance, we convert signals from the hydrophones to digital almost immediately, which gives us very high resolution signals, then transmit the data by fiber-optic cable to the test ship. We identified a $20 digitization chip that does what used to cost $3000. We also used a 'hot rod' multiplexer chip developed by DARPA that combines information on 40 lines into a single line. It has amounted to significant cost savings for the Navy."

Because the system operates in seawater at considerable depth, it has to be well built. The hydrophone arrays feature thick-hulled cylindrical instrument packages that are custom made by the Navy and pressurized with helium, which conducts heat away from the electronics. When something does malfunction, such as when a sensor goes out, it can be detected and compensated for aboard the *Hayes*. Calibration of the system can also be done remotely.

"Close to half of our effort is for testing: proving that the system is working and debugging it when it doesn't," Wetherington said. "In all, we've put about 20 man-years into software development and 10 into electronics design, integration, and tests. We've also done the fabrication and quality assurance on 1300 multilayer printed-circuit assemblies.

"Another important aspect of this project is the teamwork," he continued. "ORNL had 147 staff members who worked on the effort. Our sponsor was very supportive and worked as a member of the team; we also had top-notch support from several subcontractors, including Planning Systems, Inc.; Cray Research, Inc.; Colonial Assembly and Design; and the University of Tennessee.

"This program has gone well beyond what we've done before and is I&C Division's largest program to date—all of that effort to lift one analog signal, a submarine's acoustic signature, up out of the ambient noise of the ocean."

Specialized programming is a specialty of I&C Division.

I&C Division's AMFIP project began in 1986; the first acoustic processing system that ORNL developed was delivered in late 1989 and AMFIP II followed soon after. The meticulous and ongoing attention to detail and project planning came to fruition again last October when ORNL successfully delivered and installed the first portion of the new AMFIP II measurement technology. The Navy sponsors have indicated that they intend to apply the technology to other tasks throughout the fleet. In the meantime, Lab researchers have contributed significantly to making the adage "run silent, run deep" no idle boast. ❑

Working on the AMFIP II project entails traveling to the Bahamas' Eleuthera Island and Exuma Sound. Robert Collier of the I&C Division uses a "quiet underwater weapons platform" as a backdrop.

Lab notes

is published for the staff members of Oak Ridge National Laboratory, which is managed by Lockheed Martin Energy Systems for the U.S. Department of Energy. The editorial office is in Building 4500-S, Room F-60, MS 6146, telephone 574-4399, fax 574-1001. Editor and principal writer: Bill Cabage (w7c@ornl.gov). Readers' comments and participation are welcome and encouraged: Drop us a note.

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The first nuclear-powered submarine, the U.S.S. Nautilus, was launched in Groton, CT, on Jan. 21, 1954, and entered Navy service in September that year. (Courtesy of U.S. Navy/Naval History and Heritage Command)