The USS Seawolf Sodium-Cooled Reactor Submarine

Address to
Washington DC ANS Local Section
on
May 17, 2012

Remarks by Eric P. Loewen, Ph.D.
President
American Nuclear Society

Thank you for the opportunity to speak tonight at the ANS local section here in our nation's capital. The origins of this fine Society can be traced to policy decisions developed here. I want to thank Donald Hall who is the current Chair. Thank you for your leadership.

It is good to be back with you tonight. I have previously addressed this local section three times – once on lead fast reactors, then on what I learned during my ANS Glenn T. Seaborg Fellowship, and most recently about my employer's activities during the Global Nuclear Energy Partnership. Those presentations were technical in nature.

Tonight I will tell a sea story. Old salts know what a sea story is. For the landlubbers in the audience, I share the difference between a fairy tale and a sea story. The fairy tale begins, "Once upon a time...." The sea story begins, "Now this is no bull...."

This address represents the confluence of two periods in my career: my service in the nuclear navy and now my current role with GE Hitachi Nuclear Energy supporting PRISM developments. I served in the Navy when John Lehman was Secretary of the Navy and President Reagan was in the White House. Our fleet had 594 ships! Today that number is 286. Eleven of these modern combat ships will be retired early. Please enjoy this sea story tonight, about how our nuclear technology has improved our national security.

Everyone here today most likely knows about the USS NAUTILUS (SSN-571), the world's first nuclear powered ship – a submarine – with her pressurized water reactor. This sea story is about the world's second nuclear powered submarine, the USS SEAWOLF (SSN-575), with the world's first operational sodium-cooled reactor.

When creating the new nuclear Navy in the 1950s, then-Captain Hyman Rickover determined that two types of reactor power plants would be evaluated to power submarines, a water cooled reactor and a molten sodium cooled reactor. Let me explain how this came about.

Late in the 1940s, Captain Rickover arrived at Oak Ridge National Laboratory (ORNL) to explore how nuclear power could be harnessed to power a submarine. The tactical benefit of not needing to surface to charge batteries, as the diesel boats were required to do, was obvious. At that time, the most-advanced reactor technology for power generation was a sodium cooled reactor. Why? Post WWII, many of the Manhattan scientists wanted to prove the peaceful uses of the atom. They assumed that uranium would be used in the core -- but uranium seemed scarce. With water-cooled reactors, using as they do less than 1% of the energy in the uranium, the known reserves were not enough to make a significant energy contribution. Therefore, a way to access the unused energy had to be found, and plutonium was the key. Thus, the breeder reactor was born. Westinghouse and General Electric competed on a contract to build a sodium cooled reactor. GE won the bid.

At ORNL, the laboratory director Alvin Weinberg had just patented the concept of the Pressurized Water Reactor ("Reactor," filed August 29, 1945, patent #2,736,696). Weinberg persuaded Captain Rickover to also develop this technology for submarine use. Westinghouse was awarded this contract.

What Rickover set up was competition between two great companies to build a paradigm-shifted power source for the benefit of national security. The Navy must remain superior, to protect our vital ocean commerce by controlling the sea lanes. About ten years later Rickover testified to congress that his intention had been to select a standard Navy nuclear plant for ship propulsion and electricity generation.

He ordered three reactors each of both types; a land-based prototype for training and testing, an operational reactor for ship installation, and a spare. Weinberg's pressurized water reactor concept was designed and developed by Westinghouse, and the prototype was built at the National Reactor Test Station (now the Idaho National Laboratory). The sodium cooled reactor was designed and developed by General Electric, and the prototype built at the Knolls Atomic Power Laboratory Kesselring Site near West Milton, NY. Development work began on both reactors while the design was still evolving.

Not only were the reactors "first-of-kind," the ships – the submarines – were also a major change in concept and design. It would be the first time a steam plant would operate under water. The nuclear powered submarine would be half-again as large as the WWII diesel powered sub, with quite a different internal layout. The builders were excited about the nuclear power plant layout and its shielding and controls. The tacticians were excited about the increased underwater speed, and especially the ability to remain submerged for long periods without having to follow the diesel-powered-submarine requirement to snorkel (raise an air tube to draw fresh air into the boat to run the diesels) or to surface and shift from electric to diesel drive to charge batteries for underwater operations. The sailors were excited about the living space. Each man had his own bunk - no more "hot bunking." The galley had a built-in ice cream machine, soda-pop dispenser, and a nickel-a-play juke box connected to the ship's hi-fi system. The mess decks could seat 50 (full complement 101) to watch a movie. And the nuclear plant provided constant power for air conditioning and the potable water distillers.

As the prototype reactors were being built at the development sites – they were basically land-locked versions of the submarines' engineering spaces – system testing and crew training was carried out and ship construction started. Electric Boat, now General Dynamics Electric Boat, in Groton, CT, was selected by Captain Rickover to build the first nuclear powered submarines. The keel for USS NAUTILUS (SSN-571) was laid in June 1952, designed to carry the PWR for her power plant. The keel for USS SEAWOLF (SSN-575) was laid in September 1953. Her power plant would be the sodium cooled reactor. Rickover was initially leaning toward the sodium cooled reactor because, from liquid metal reactor experience with the EBR-I, the sodium cooled knowledge base was further advanced than the PWR, and the sodium cooled reactor did have higher steam cycle efficiency. To be fair, in an early issue of the *Naval Reactors Liquid Metal Handbook* Rickover stated:

"… in the liquid metals field there is still no substitute for testing. In equipment built and tested since the previous edition of this Handbook, many applications of 'good design practice' and 'reasonable heat transfer assumptions' have proved dead wrong and many important problems have been overlooked. With the present state of the art, thorough testing is still required to bring out the inadequacies of the present design guidelines."

As we all know, the PWR-powered NAUTILUS (SSN-571) was the first to get 'under way on nuclear power,' and her history has been told far and wide.

I digress for an historical aside. In response to President Eisenhower's 1953 "Atoms for Peace" initiative, then-Captain Rickover was directed to establish a commercial nuclear power plant. With the NAUTILUS PWR entering operational testing ahead of the SEAWOLF's sodium cooled reactor, he selected the PWR. The Shippingport (PA) Atomic Power Station's PWR (236 MWt) went on line in 1957, and Duquesne Light Co. fed the grid with nuclear generated, clean, environmentally friendly, stable base-load electricity for 25 years.

SEAWOLF also has a history, and a unique part of that history is the sodium cooled reactor that originally powered her. The Liquid Metal Reactor (LMR) uses a molten metal for the reactor coolant and, because of very little moderation, the neutrons maintain their energy. We call those neutrons "fast." The molten metal coolant circulates through heat exchangers to generate steam to drive a power turbine. The most common LMR coolants are sodium, sodium-potassium, and lead-bismuth. Most LMRs are "fast reactors" – "fast" because most fission occurs at energies above 100keV. The SEAWOLF core, however, used carbon to thermalize the neutrons to improve the cross sections, so it cannot be called a "fast reactor." The use of carbon reduces the amount of uranium needed to operate.

The world's first nuclear power generator was the EBR-I, a sodium-potassium cooled LMR, built at what is now the Idaho National Laboratory. LMRs go by many names – a real alphabet soup – depending on either their application or their coolant. EBR – experimental breeder reactor; FTR – fast test reactor; ALMR – advanced liquid metal reactor; CRBR – the Clinch River Breeder Reactor; SFR – sodium fast reactor; LFR – lead fast reactor, or LBFR, lead-bismuth fast reactor. The LMR has been operated around the world in test reactors, submarines, and semi-commercial plutonium-fissioning reactors in Russia. The LMR reactor type has accumulated more than 400 reactor years of operation. The LMR reactor type is no spring chicken.

Now back to my sea story. Back to SEAWOLF with her reactor core cooled by sodium.

In 1954 on the building-way at Electric Boat, SEAWOLF was taking shape as NAUTILUS was being commissioned nearby. SEAWOLF was bigger than NAUTILUS. SEAWOLF's construction, like NAUTILIS's, was an adventure for the builders, the naval engineers and the commissioning crews. New challenges were frequent. And new sea tales were born.

The sodium cooled reactor, which used electromagnetic pumps (EMPs) to circulate the molten coolant mixture, heated an isolating and independent metal loop that heated the steam loop for the electro- and propulsion turbines. An interesting engineering challenge.

The steam superheaters' drum size was another challenge. Originally designed on paper to be sized with a 36-inch head, engineering evaluation during construction determined the size had to be increased to 48-inches. The re-fitting and installation was messy, to say the least, and took some ingenious re-routing and adjusting. But the builders and the crew did not miss the schedule.

While completing prototype construction, the SEAWOLF workers faced the challenge of applying a special thermal insulation to various surfaces, most of them hard to get to. Unlike asbestos, which could be wetted and molded to curves and corners, the special insulation was physically somewhat like Styrofoam, and expensive. In addition to the delicate and precise carving required, a 'no wastage' requirement made the work detailed and labor-intensive. The new nuclear Navy probably would have appreciated reincarnation of a few old seafarers with schrimshaw expertise (an historical aside many of you may know: scrimshaw is the art of carving walrus teeth and whales teeth practiced by the sailors of wind-power days). Once the prototype plant was fully insulated, a Navy engineer commented, "If gold had sufficient heat insulating properties, it would have been cheaper to use it."

During development of the NAUTILUS prototype, Admiral Rickover arranged to have the S2W (the Navy designation for the PWR - S for ship, 2 for the second unit, W for Westinghouse) provide electricity to power the lights in nearby Arco, ID. Not to be outdone by

Westinghouse, General Electric wanted to do the same – or better. They mounted a 10,000-KW steam turbo-generator on an external slab, tied it into the prototype's starboard screw steam supply line, hooked into the local Niagara Mohawk utility supply, and started generating commercial electricity. The sailors christened it the 'Publicity Turbine.' It worked. What Captain Rickover did was prove that a sodium cooled reactor could also deliver clean, environmentally friendly, stable base-load electricity.

Somehow, reports from the Naval Research Laboratory detailing adverse affects of sodium on 347 Stainless Steel were missed during initial planning. It was 347SS that was used for the steam superheaters. That was SEAWOLF's ultimate weakness. During initial trials leaks developed in the superheaters that used 347SS, and they were bypassed. Running without superheaters with the resulting lower-pressure, lower-temperature, saturated-steam supply to the turbines, she subsequently deployed, able to use only 80 percent of designed power. But SEAWOLF still served quite well.

Commissioned in March 1957 – a ship's commissioning is the formal ceremony in which the Navy takes custody of the ship from the building yard – she started sea trials, and the sodium cooled reactor went to sea. Upon completion of sea trials, SEAWOLF steamed 6,331 nautical miles non-stop in NATO exercises before surfacing off Newport, Rhode Island, on 25 September to embark President Dwight D. Eisenhower, the first President to go to sea on a nuclear submarine, for a short cruise.

Every ship – like most people – gains a nickname. SEAWOLF's was "The Blue Cloud." A blue glow was frequently observed in the water at times when the sub was under way, or during in-port periods when the reactor was operational and providing the sub with electrical power and utility services. It was attributed to "Chernenkov radiation," the effect created when gamma rays initially going faster than the speed of light in water are slowed, losing energy and giving off blue light.

Another story not often told was the first use of electromagnetic pumps in a submarine, even though Tom Clancy in *The Hunt for Red October* may have a different story. Moving liquid metal is a challenge for mechanical pumps. You can do it, but recognize that challenge. SEAWOLF exploited EMP technology, which, by the way, has no moving parts, to circulate the molten sodium reactor coolant. This technology is still not widely understood today.

Another historical aside – with a lesson. The SEAWOLF EMP technology, and maintenance and operating instructions, were captured in a Navy Technical Manual 347-2686, only 28 pages long. It provided the sailor all the general information, equipment description, mounting, maintenance and operation in one book. The pictures on the accompanying slide come from this manual. It's a lesson in the professionalism of the electrical and mechanical engineers of those days and their ability to assemble technical information in a clear, useable fashion. By the way, the EMPs work without cause for failure. Here are a few quotes from the manual you might find informative:

> "There are no moving parts within the pump; therefore, no lubrication or similar type maintenance is required."
>
> "The a-c electromagnetic pumps covered by this manual are composed of three major subassemblies and the pieces required to hold them together and [sic] provide the necessary leaktight seals."
>
> "After initial installation, no adjustments or tests are required except the precautions discussed in the 'Operating' and 'MAINTENANCE' section of this Manual."

SEAWOLF continued normal submarine operations, and on 7 August 1958 she submerged for a two-month 13,700 nautical mile operation – that's 15,570 miles in a car. For perspective, that's three airline round trips between New York and San Francisco, or one round trip from New York to Cape Town, South Africa. The SEAWOLF crew was awarded the Navy Unit Commendation for demonstrating the ability of the nuclear-powered submarine to remain independent of the earth's atmosphere for the period of a normal war patrol.

Because of her reduced operating efficiency and accelerated depletion of reactor fuel due to the bypassed steam superheaters, SEAWOLF returned to Electric Boat in December 1958 for conversion of her power plant from her S2G (G for General Electric) sodium reactor plant to the S3W (the third PWR unit built by Westinghouse as a spare for the NAUTILUS).

Because of the superheater problems in SEAWOLF, Captain Rickover selected the NAUTILUS PWR plant as the standardized Navy nuclear plant. Thus, to this day all U.S. Navy ships employ PWR power plants. And our nation's commercial reactor fleet operates water cooled reactors. The Navy influence continues, as most of our commercial nuclear reactor operators (NROs) and maintenance personnel are former Navy nukes - sailors qualified on submarine and surface ship reactors.

The LMR didn't lose favor with all sailors. The Soviet Union/Russian Navy Alfa (NATO class designator) hunter/killer nuclear powered submarines took advantage of the smaller size and greater energy efficiency of lead-bismuth (Pb-Bi) cooled reactors, about which I spoke in another presentation to this local section many years ago. The seven Alfa class subs were the fastest operational military submarines built, with only the prototype K-222 (NATO Papa class) exceeding them in submerged speed.

The Russian Alfas performed impressively, seriously challenging the NATO navies from 1977–1990 before they were done in by the shore establishment, or more accurately, by lack of shore support. To keep the Pb-Bi coolant from freezing when in port and the plant was shut down, the shore establishment was charged with providing external heating to keep the Pb-

Bi hot and circulating. The decline of the Cold War Soviet Union's military budgets hindered maintenance of the Russian Navy's shore establishment, eventually shutting down the external heating systems and allowing the subs' reactors to 'freeze up.' The Alfas have all been decommissioned and are waiting in the breaking yards to be scrapped. The solidified lead encasement prevents removal of the reactor fuel, and - oh, by the way - provides very long term "repository management" as the heat loads decay.

Despite the lessons learned from the proving trials of rigorous sea duty in the U.S. and Russian navies, the nuclear community has stuck the LMR in a fast test reactor (FTR) 'rut,' somehow failing to accept the more than 400 reactor fission years in a total of 22 fast test reactors (FTR) around the world and two navies' operational experience. The SFR is about to break out of the test reactor rut and jump into the commercial world. India and China are soon to join Russia in using LMRs as electricity generators. And the United Kingdom is evaluating the SFR as a means of fissioning away their commercial stockpile of plutonium while generating commercial electricity for the grid.

I will close with some words that Admiral Rickover delivered to the graduating class of Stevens Institute of Technology in 1958, around the same time the Seawolf fate was in balance. His words emphasize the behind-the-scenes effort that it took to develop nuclear-power technology from the gleam-in-the-eye stage, through a practical propulsion system for submarines, to a competitive provider of electricity to the general public. He said,

> "Unfortunately, the average person is touched only obliquely by most of the new knowledge, as when he benefits from some new commodity or service which has grown out of an addition to scientific knowledge. These new things he usually accepts as just another gift from his fairy godmother Science, and he gives little thought to the manner in which they have been brought about: the chain of human effort, which began in a remote laboratory where the germinal idea originated; the long process of applied research to verify its practicability; the detailed engineering to transform it into something useful; and the final step taken by industry and commerce to make it available to the consumer."

As ANS members, please learn and understand the relatively short history of our nuclear sciences and technologies, and continually challenge the present paradigms to make the future better.

Continue to strive to leave this earth a better place than when you found it by continuing to use and expand our nuclear sciences and technologies. This is the most significant mission that our Society and you, its members, can pursue. And may you master the nuclear sciences technologies and grow in our nuclear professions with either land- or sea-legs.

ANS local section address

CREDITS:

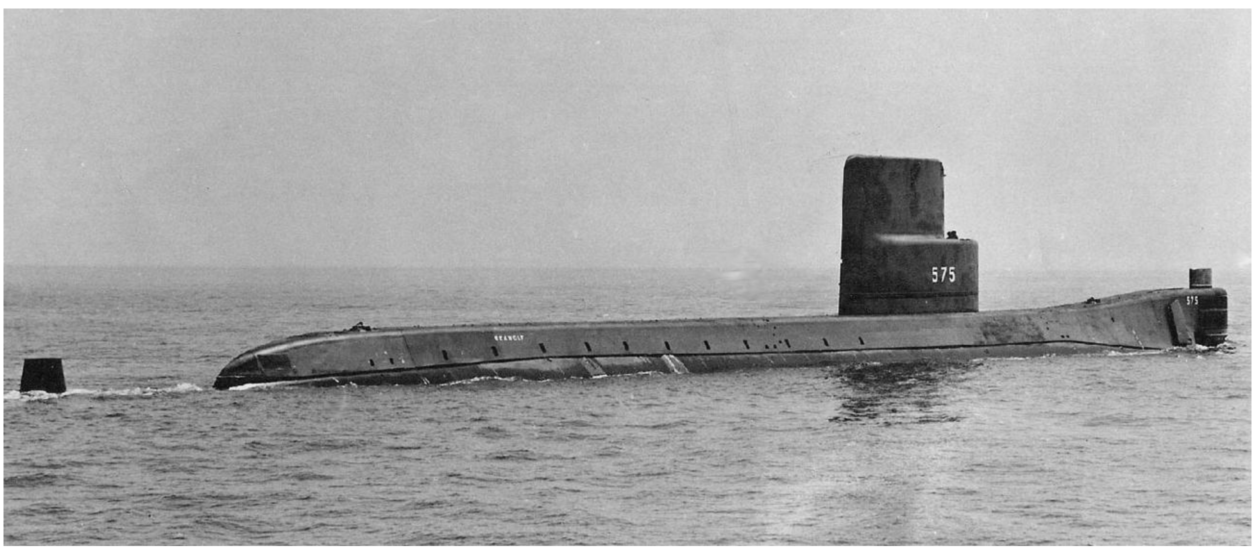
Mr. ‘Terry’ Terras, Commissioning Crew, USS SEAWOLF (SSN-575)

“COLD WAR SUBMARINES The Design and Construction of U.S. and Soviet Submarines,” Norman Polmar and Kenneth J. Moore, Potomac Books, Inc. Washington, DC 2001 ISBN975-1-57488-594-1 (2004)

DOE/NE-0088 “The History of Nuclear Energy” (2002)

IAEA-TECDOC-1569, “Liquid Metal Cooled Reactors: Experience in Design and Operation” (2007)

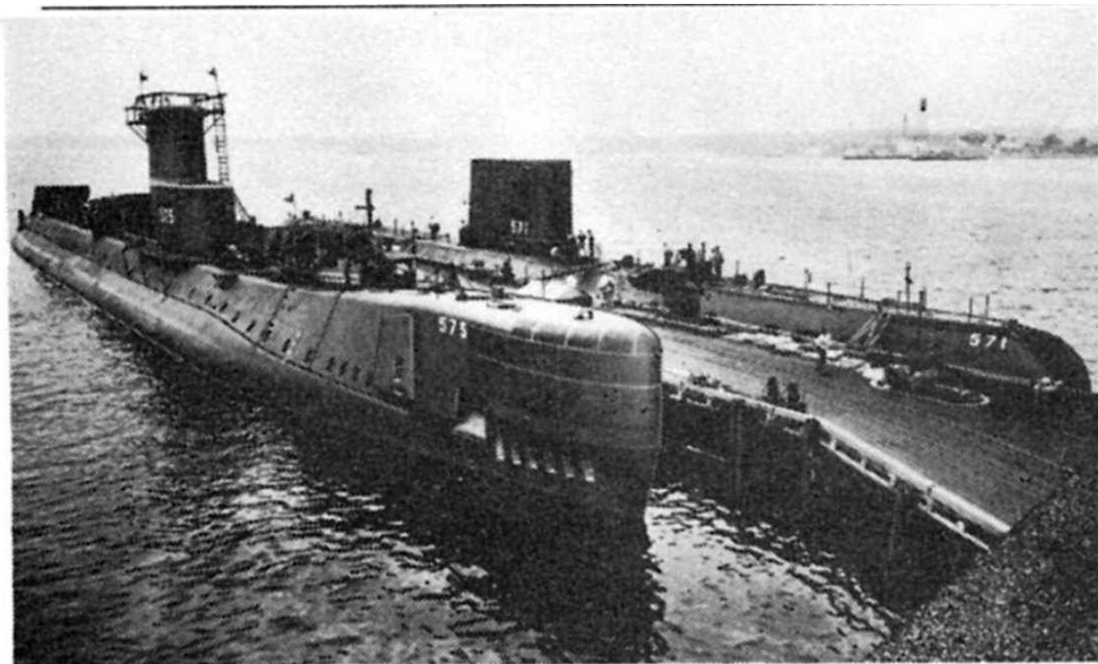
Various Navy and USS SEAWOLF (SSN-575) ship societies.



Crew member aboard submarine ***Seawolf* (SSN-575)** getting massage with relaxacizor set to keep up physical fitness during extended voyage. Photographer: Yale Joel, courtesy of time.com. via / images.google.com & Life.

Official U.S. Navy ship's patch

Provided by Walt Disney to Navy ships during and immediately after WW II, this patch was special to the commissioning crew.



NUCLEAR NAVY — Uncle Sam's first atomic submarines are shown at opposite moorings. The world's first sub operating on nuclear energy is the USS Nautilus at right and the second atomic craft is the USS Seawolf in the foreground, both using equipment built at Phillipsburg. More A-powered subs will join them soon as forerunners of what eventually will be a nuclear navy.

—Navy photo

IT'S A FACT . . . The world's first atomic submarine, the Nautilus, described for local readers in this newspage when the craft was under construction in 1953, has made a remarkable record in its first 18 months in operation. The Navy reports that it has made numerous dives and has logged 15,000 miles under water and more than that on the surface. The atom-powered sub, which employs I-R boiler-feed pumps and high-pressure compressors, has made a number of long underwater runs. On her shakedown cruise, from New London to Puerto Rico, a distance of 1300 miles submerged, her average speed was more than 16 knots During her whole career afloat she has not been refueled with uranium and is still operating on the original supply. In addition to her crew the Nautilus has carried many passengers including military and naval officials, Congressmen and other notables.

. . . The second atomic sub, the Sea Wolf, has I-R pumps, too. And the several other nuclear subs under construction will also have I-R pumps and compressors built at Phillipsburg plant.