Admiral Rickover's Gamble
The Landlocked Submarine
COMMANDER E. E. KINTNER, U.S.N., JAN 1 1959, 12:00 PM ET

An Annapolis graduate, Commander E. E. Kintner was project officer for the STR Project, responsible directly to Admiral Rickover for the two crucial years which he has described in his article. Since 1955 Commander Kintner has been nuclear power superintendent at Mare Island Naval Shipyard in California, which recently delivered the first nuclear submarine to be built on the West Coast.

The highly dramatic and historic news that the submarine Nautilus had completed a passage under the roof of the world from the Pacific to the Atlantic excited the imagination of men everywhere. An equally dramatic and historic event, which proved that the Nautilus voyage could eventually be made, occurred five years earlier.

The Submarine Thermal Reactor plant (STR Mark I), the test version of the Nautilus machinery, commenced operating on May 31, 1953, in the desert of the Snake River plain, fifty-five miles west of Idaho Falls, Idaho. Its successful operation on that date, the first generation of any significant quantity of controlled atomic power, was the culmination of one of the largest, most daring, and most aggressive scientific ventures in history. No less than the polar voyage of the Nautilus, the design and operation of its prototype machinery required facing the hitherto unknown with physical courage, technical skill, and forceful and energetic leadership.

In 1946, one year after the unleashing of nuclear forces for destruction at Hiroshima, a Navy group, headed by then Captain, now Vice Admiral H.G. Rickover, was sent to Oak Ridge for a year's study of all available information concerning production of useful power from the atom. The Navy students decided that the first practical application of nuclear power should be made in a United States submarine. They realized that the installation of an atomic power plant would be much more difficult in a submarine than in a surface ship, but they made the decision—the first example of the daring aggressiveness of Rickover's methods—because the rewards of success would be greater in a submarine than in a surface ship. A nuclear submarine, not requiring air for combustion of fuel in its engines, would be able to divorce itself from the earth’s atmosphere and thus would be a true submarine rather than a surface ship which could submerge only for short periods. It would be an “underwater satellite.” To many in high places, however, the proposal sounded like a trip to the moon.

Upon his return to Washington in 1947, Rickover organized a unique joint agency with authority in both the Atomic Energy Commission and the Navy. Drawing on both AEC and Navy engineering experience and funds, this Naval Reactors Branch during the next three years organized and directed a huge research and development effort. Westinghouse Electric Corporation was given a contract to design and build the nuclear
reactor and power plant. The Electric Boat Company of Groton, Connecticut, which had long experience in the design and construction of submarines, was chosen as a subcontractor to Westinghouse, responsible for ensuring that the reactor plant was adapted to the rigid requirements of service in a submarine.

Because so many unknowns could be solved only in theory prior to the operation of a complete atomic power system, it was decided early that a full-scale land-based model should be built at the National Reactor Testing station in Idaho. This prototype was named STR Mark I. The propulsion plant which followed in the Nautilus would be STR Mark II.

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In the early stages of design, the problems of obtaining some small amount of power from uranium fission seemed so overwhelming that it was planned to build Mark I as a “breadboard” arrangement, with machinery and piping systems spread out over a large floor area to allow easy access for installation, test, modification, or replacement. Rickover opposed this plan. He felt that years would be lost by breadboarding, since it required an additional stage in the development—the redesign of an operating breadboard model into a submarine hull. After several bitterly argued discussions within the project, Rickover made the decision to build Mark I as a land-based submarine to all the Naval specifications later to be required of Mark II. Here was the second example of courageous leadership, which contributed directly to the Nautilus success.

And so Mark I, although located almost as far from sea water as possible in the North American continent, was a true seagoing power plant—no shore-based engineering short cuts were allowed in its construction. As the Naval Reactors Branch engineers put it, “Mark I equals Mark II.” This meant that while they were designing the world’s first nuclear power plant, they also would have to meet the special problems of seagoing submarines. Some of these were:

1. At operating depths, a submarine experiences hundreds of pounds of sea pressure on each square inch of its surface—hundreds of thousands of tons on the entire vessel. This pressure must be resisted by the hull which is in contact with sea water. Mark I and all its components could withstand very high sea pressures.

2. A submarine and its machinery must be able to continue operation after enemy depth charges have exploded just outside the hull. Mark I was built to the high mechanical shock standards which resulted from the Navy’s World War II experiences. Some of its important units were shock tested to destruction in an actual submarine submerged in Chesapeake Bay, and then redesigned to strengthen the failures.

3. The Nautilus would need to take air into hr hull while submerged to refresh the atmosphere after long cruises under water and to provide oxygen to her stand-by diesel engines if her reactor failed in enemy waters. Pressure variations due to this “snorkeling” might disturb sensitive instrumentation systems. Mark I could snorkel.
4. When a submarine is submerged, the sea surrounding it tends to reflect dangerous atomic radiation back into spaces occupied by the crew. Mark I was placed in a large tank of water to test the atomic radiation problems of a submerged sub.

In short, Mark I was built to reproduce the conditions of an actual submarine power plant in every respect save one: it could not be tested in the motion of the open sea. The ability to withstand such motion was designed into the Mark I systems and components, however, and these items were individually tested for thousands of hours ashore under the conditions of ship motion experienced at sea.

As time went on and as the problems of reactor plant design became more forbidding, it became increasingly difficult for Rickover to hold the designers rigidly to the concept that the submarine problems must be faced simultaneously with the reactor problems. There were bitter technical debates between Rickover and his engineers, already hard-pressed by a tight schedule and almost insurmountable difficulties of simply obtaining atomic power for the first time and hoping to postpone the submarine problems until the Mark II design stage. An example was the discussion as to whether air conditioning should be provided in Mark I.

Surface ships ventilate heat out of boiler and engine rooms by blowing large quantities of air through them. The Nautilus, as the first vessel to be driven submerged by steam propulsion, could not be ventilated—at least not while she was submerged. All the heat escaping from her machinery would have to be pumped overboard by large air conditioning sets. This problem did not have to be settled for Mark I, which could have been adequately ventilated with cool Idaho air. But the Captain insisted that Mark I be air conditioned, and in a typical example of his uncanny engineering insight, he ordered three times as much air conditioning capacity as was required. “In 1917 the British built two submarines which used steam for surface operations,” he said, “and they were failures because they became too hot when they submerged. The Nautilus will not be a failure for such a reason.” Operating experience has proved that the Nautilus would have been unsuccessful without the extra air conditioning.

Despite resistance, the concept that “Mark I equals Mark II” was maintained, and the problems of nuclear power and submarines were solved together for Mark I. When Mark II was designed for the Nautilus as an outgrowth of Mark I, none of the fundamental submarine problems remained; the entire effort could be applied to translating Mark I experience into an improved, simplified, more reliable propulsion plant for the Nautilus. Now Captain Rickover said, “But Mark II does not equal Mark I. It must be better in every practicable way.”

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As Operation of Mark I was about to begin in late 1952, there remained many unanswered questions, and there was not always assurance that satisfactory solutions would ever be found. Even Rickover, returning for a visit to Mark I at this time, said, “If the Nautilus makes two knots on nuclear propulsion she will be a success.”
The most serious question lay in the area of safety. A power reactor is a tremendously concentrated source of energy. No reactor had generated enough power to propel a ship. Although scientists believed that the power of the STR could be safely controlled, this belief had to be demonstrated beyond doubt before there could be a practical application in a submarine. The controllability of STR could not be known with certainty until it had safely generated power, and that might be too late.

It was concluded that for reasons of personal safety the start-up should be made by television from a point a mile away, but there proved to be so many difficulties in doing this that the scheme was dropped. Instead, a highly sensitive system of eighty different control circuits was designed to anticipate any dangerous instability of the reactor and within a fraction of a second initiate an emergency shutdown, or in the jargon of nuclear engineer, “scram” the reactor.

Because of high radiation levels associated with their operation, previous reactors had been encased in thick, heavy concrete blockhouses to protect operating personnel from dangers of irradiation by gamma rays and neutrons generated in the reactor core. Such cumbersome shielding could not be floated in a submarine of practical size. Mark I was provided with the first mobile radiation shield, lighter and smaller than any previously employed. Because compact and light, its ability to reduce radiation to safe levels was in serious doubt.

A submarine must be in exactly neutral weight equilibrium while submerged. The Nautilus, to save valuable time, was already well along in her construction period. If the STR radiation shielding calculations were too low, additional weight would have been necessary and the Nautilus would not have been capable of diving safely.

Another fundamental question of feasibility involved safe transfer of heat from the reactor core. The reactor plant must remove heat from the fuel elements where it is generated and carry it outside where it can be converted into useful power. Until this heat transfer had actually been demonstrated in the prototype, there was considerable doubt as to whether, on the contrary, its fuel elements would overheat and destroy themselves, spewing enormous quantities of radioactivity throughout the plant. The higher the power level the more dangerous the heat transfer situation would become.

The “crud problem” aggravated the doubts of STR heat transfer capabilities. Only a few months before operation was to begin, a sample fuel element was removed from an experimental exposure of several months under irradiation in the Canadian reactor at Chalk River, Ontario. When it was examined, it was found to be covered with “crud” (Chalk River Unidentified Deposit), an impolite word applied to rust deposited on the fuel elements in the high radiation zones which exist in the heart of a reactor. The Chalk River results seemed to indicate that the STR reactor core, already a questionable heat transfer quantity, might clog up entirely and overheat like the radiator of the family automobile.

All the moving parts in the STR reactor plant were lubricated by hot, radioactive water instead of by oil. This, too, was something new. Much testing had been devoted to
choosing moving parts which could operate dependably in hot water, but it was uncertain whether the many valves, pumps, and control rod mechanisms would continue to operate for long periods in their unusual lubricating medium.

Finally, there was the important question of core life. One argument for the Nautilus STR plant was that it would have a very long submerged range. If its power life was days or weeks, it would be acceptable for combat use. If it would provide continuous power for only a matter of hours, it would be no better than the electric storage battery used by conventional submarines. When Mark I began operating, it was feared that its core life was only a few hours and that much additional development would be necessary before the Nautilus could operate long enough to be useful in combat.

These and many other serious problems remained unanswered when in late May, 1953, construction of Mark I was completed.

The pumps and valves and heat exchangers, turbines, electrical generators, thermometers, control panels — all the many hundreds of items which made up the complex and interrelated systems of the plant — had been mechanically and electrically tested until they were as nearly perfect as they could be made. The crews had practiced for a week at carefully opening the main turbine throttle from an oil-fired boiler so as to disturb the reactor as little as possible. They were rehearsed in casualty drills, and STR Mark I was ready for an attempt at power operation.

Captain Rickover, who had followed preparations on an hourly basis, flew to Idaho in company with Atomic Energy Commissioner Thomas E. Murray, a man who had contributed much support to the Navy’s nuclear propulsion program and who was to have the honor of opening the turbine throttle valve, admitting steam generated by a power reactor into a turbine for the first time. Murray knew that eight years had passed since Hiroshima and that, except for the Navy’s program, no U.S. atomic power project was anywhere near fruition. He knew also that the Navy and the AEC were committing almost one quarter of a billion dollars to the project was success was now to be determined.

That first operation was amazingly successful. After a two-hour run, during which power levels of several thousand horsepower were achieved, the reactor was shut down. Six years of study, organization, planning, conniving, fighting for funds, building laboratories, manipulating people, developing new materials and devices had paid off. The first day of Mark I had surprised its most optimistic proponents.

There were many happy people in the Idaho desert the night of May 31, 1953. The happiest was Captain Rickover, who had had the vision, constantly forced the program against opposition, and provided the technical judgment to steer it through areas far beyond those previously known.

Then followed a month of careful, precise building up in power level. Test operations went on night and day, seven days a week. Power was increased in small steps. What
could happen on these increasing steps could only be conjecture until the trial run had been completed. Every man at the desert site knew the danger associated with each increase in power.

The first feasibility question to be answered affirmatively was that of safety. Mark I turned out to be a calm and stable machine and even when treated roughly, as its inexperienced operators often treated it, showed no tendency to become an atomic bomb. There was no indication of any dangerous overheating in the reactor fuel elements. The shield designers were surprised to find that radiation levels were less than half of those which they had calculated, indicating that the Nautilus could easily carry her radiation shield. As additional physics data became available, the estimate of reactor life was greatly increased.

The major difficulty was with the numerous safety circuits, any one of which could cause the reactor to shut down suddenly. These circuits were meant to be extremely tender in their operation; they were, in fact, so sensitive as to provide a serious difficulty to the operators. A submarine propulsion plant not capable of operating without emergency shutdowns under sea motion and depth-charge attack would not be satisfactory, yet the Mark I had a constant plague of “scrams” from such slight causes as vibration from a crew member’s walking through the reactor compartment or a bolt of lightning striking a Montana power line three hundred miles away.

As the crew gained operating experience, and as additional information was obtained concerning safety, the number of signals causing “scram” was selectively reduced to less than twenty. By this means, and by intensive crew training, the problem was licked. As a result, the Nautilus experienced very little difficulty of this sort.

On June 25, 1953, full design power was reached. Not one part of the plant indicated failure to meet the rigid specifications. In less than a month after power generation by the world’s first nuclear power plant, Mark I was running smoothly at its maximum rating. The one remaining question was whether the machinery could withstand long high-power running.

The operating crews began a forty-eight-hour test at full power to obtain important physics information. At the twenty-four-hour point the data obtained seemed sufficient, and the engineers intended to shut down the plant. Rickover, who was at the site, inadvertently learned of this plan and immediately overruled it. He had visualized that if the forty-eight-hour run turned out well, they should continue on a simulated cruise across the Atlantic. He reasoned that such a dramatic feat, if successful, would end the doubts in the Navy that nuclear power was a feasible means for propelling ships. It would give the project the momentum and breathing space needed to carry on the development without constant harassment until the Nautilus could get to sea.

I was the senior Naval officer at the site. I felt that extension of the run was unwise considering the many uncertainties, and told Rickover that beyond forty-eight hours I could not accept responsibility for the safety of the $30 million prototype. Rickover directed me to proceed with the simulated voyage.
Charts of the North Atlantic were posted in the control room and a great-circle course to Ireland plotted. The position of the ship after each four-hour watch was computed and marked on the chart. For watch after watch, the course plotted in the control room crawled toward Ireland. No submarine had covered more than twenty miles submerge at full speed. A propulsion unit, even for a surface ship, needed steam only four hours at a full power to obtain acceptance for Naval use.

At the mid-point of the Atlantic crossing, the operation seemed to be going well. As one of the Nautilus crew members standing watch in the hull state, “She just sits there and cooks.” A veteran marine engineer, familiar with the large quantities of fuel oil which would have been required to drive a ship so far with a conventional propulsion plant, pointed to the propeller shaft and then to the reactor and said, “So much comes out back here, and nothing goes in up there!”

At the sixtieth hour, however, difficulties began. Carbon dust from the brushes depositing in the windings caused difficulty in the vital electrical generating sets. Nuclear instrumentation, operating perfectly at the beginning of the run, became erratic, and the crews could not be sure what was happening within the reactor core. One of the large pumps which kept the reactor cool by circulating water through it began making a worrisome, intermittent whining sound. We had not had any check on “crud” build-up; we feared that heat transfer would be so reduced by this point that the core would burn up. The most pressing problem, however, was caused by the failure at the sixty-fifth hour of a tube in the main condenser into which exhausted turbine steam was being discharged. Steam pressure fell off rapidly.

The Westinghouse manager responsible for the operation of the plant strongly recommended discontinuing the run. In Washington, the technical directors of the Naval Reactors Branch was so concerned that he called a meeting of all its senior personnel, who urged Rickover to terminate the test at once. But the Captain was adamant that it should continue until an unsafe situation developed. “If the plant has a limitation so serious,” he said, “now is the time to find out. I accept full responsibility for any casualty.” Rickover had twice been passed over by Naval selection boards for promotion to Rear Admiral. As a result of congressional action, he was to appear within two weeks for an unprecedented third time. If the Mark I had been seriously damaged, Rickover’s prospects for promotion and his Naval career were ended.

The tensions surrounding the test increased the challenge to the crews, and as each watch came on duty it resolved it would not be responsible for ending the run prematurely. Crew members worked hard to repair those items which could be repaired while the plant was in operation.

Finally, the position indicator on the chart reached Fastnet. A nuclear-powered submarine had, in effect, steamed at full power non-stop across the Atlantic without surfacing. When an inspection was made of the core and the main coolant pump, no “crud” or other defects which could not be corrected by minor improvements were found. It was assured that the Nautilus could cross an ocean at full speed submerged.
A month after nuclear power was first produced, the most doubting among those who had participated in the STR project knew that atomic propulsion of ships was feasible, that it was only a matter of time before the technology developed for Mark I would bring about a revolution in Naval engineering, strategy, and tactics. We knew, too, that industrial nuclear power could be built on the same technological foundations. The Pressurized Water Reactor at Shippingport, Pennsylvania — the world’s first solely industrial power reactor — was in fact developed from STR experience under Admiral Rickover’s direction.

To those of us who had participated in the STR project, who knew how many chances were taken, how far previous engineering knowledge had been extrapolated, the fact that all the unknowns had turned out in our favor was a humbling experience. Rickover, paraphrasing Pasteur, put it this way: “We must have had a horseshoe around our necks. But then Nature seems to want to work for those who work hardest for themselves.”

STR Mark I is now a flexible facility providing much of the experimental information for the Navy’s nuclear propulsion program, which today includes thirty-three submarines, a guided missile cruiser, and the first nuclear-powered aircraft carrier. It provides the practical training for all the hundreds of officers and enlisted men who will man our nuclear fleet. The courage, the will, the judgment and resourceful which went into STR Mark I have made the United States Submarine Nautilus an outstandingly successful venture in man’s long struggle with nature.