The long shadow of Admiral Hyman Rickover (Part 3)

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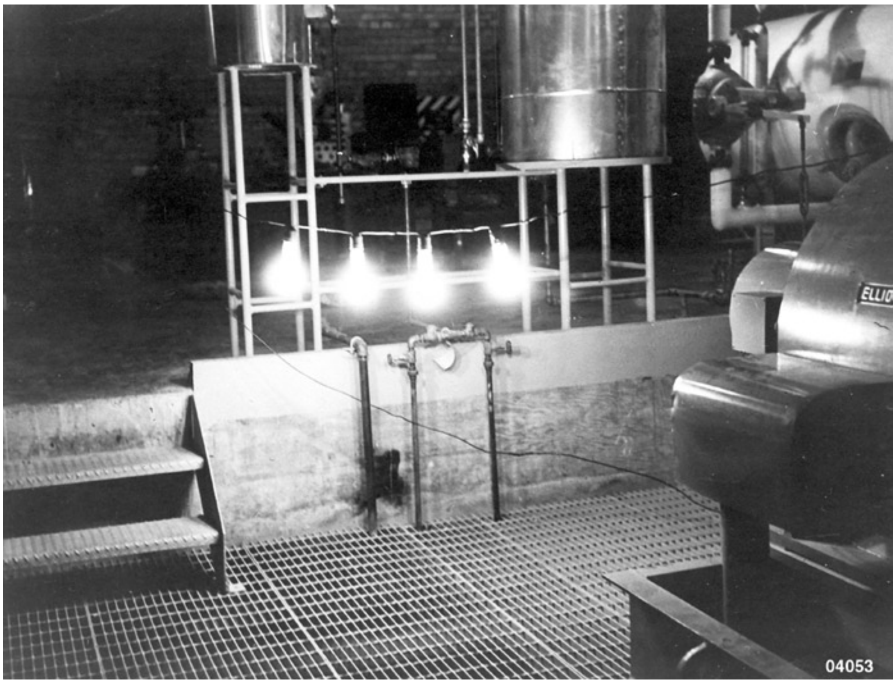
This is the eighth in a series of articles being published in Energize tracing the history of nuclear energy throughout the world, and Part 3 of the series on Admiral Rickover.

Outpacing other entries in the power-reactor sweepstakes

"Central to this account of the coming of age of nuclear power has been the pressurised-water and boiling-water reactors, which outpaced other entrants in the power-reactor sweepstakes and today [1968] dominate the commercial market" (Hogerton, 1968:30).

Although John Hogerton's review article "The arrival of nuclear power" was published in 'Scientific American in 1968, nearly four decades ago, his observations are still true today. Pressurised water reactors and boiling water reactors still dominate the commercial market.

The reasons for this are not hard to find. Again, the answers lie with Rickover. Having perfected a safe and workable PWR reactor prototype for the "Nautilus", Rickover was then asked to take charge of designing and developing the first civilian nuclear power plant in the USA at Shippingport. This was in addition to him continuing with his duties in the navy of developing and building the "Nautilus" and the "Seawolf".



The first known electricity generated by nuclear power on 20 December, 1951: enough to light four electric light bulbs.This was produced by in the USA by the experimental breeder reactor EBR-1. Photo: courtesy Idaho National Laboratory (INL) Photo).

One source notes that Rickover's involvement with civilian nuclear power was almost accidental. After the Department of Defense cancelled Rickover's project (begun in 1953, to develop "a large nuclear power system capable of servicing a vessel the size of an aircraft carrier" because of the cost), Rickover looked around to see other means of achieving his goal of building a nuclear navy (Ref. 20:5).

Aware that President Eisenhower was soon to suggest the use of atomic power for peaceful purposes (through his historic "Atoms for Peace" speech later delivered on 8 December 1953), Rickover, a shrewd politician, "approached the AEC and the Joint Committee on Atomic Energy (JCAE) (in the American Congress, where he had many friends) to sell them on the idea of a pressurized water central power station" (Ref.20; 5). Once such a large plant had been built and was working, Rickover realised, it would then be easier to propose a similarly large plant to power an aircraft carrier.

Not surprisingly, Rickover won, and got the job of overseeing the construction of the first civilian nuclear power plant (and later, the first nuclear-powered aircraft carrier).

The choice of Rickover for both these tasks was not surprising, when one considers that huge sums already invested by the United States in gas-cooled reactors to produce nuclear-powered aircraft had literally failed to fly. Or that these strange aircraft were later made redundant by ballistic missiles, many of which were incorporated into Rickover's nuclear-powered submarines.

Shippingport

"Shippingport demonstrated in a way a thousand paper studies never could have that nuclear power was an engineering reality rather than a scientific dream. The performance of Shippingport launched the development of civilian nuclear power in the United States and ultimately throughout the world" (Ref. 9; 382).

Today, while with more than 103 nuclear power plants operating in the USA and more than 440 operating in the world, Rickover's pioneering role in developing Shippingport is largely forgotten.Few people know that while he was supervising the development of the reactors for the "Nautilus" and "Seawolf" between 1953 and 1957, Rickover's Nuclear Reactor Branch "designed, engineered, and constructed" the first civilian nuclear power in the USA(Ref9; 14). This meant, in effect, that the plant was constructed under Rickover's personal direction (Ref 11; 4).

And, not surprisingly, the reactor at Shippingport was "modeled on the pressurized water type reactor used to power the first atomic submarine, the "Nautilus"(Ref.11;4). While the AEC historians were talking about civilian nuclear power in general in the above quote, they could just as well have been referring specifically to the launch of the Pressurised Water Reactor.As McNeill states in his article

(Ref.13;1), "most PWRs in the United States today are adaptations of the Shippingport reactor". Rickover's experience of problems with the reactors in the "Seawolf" had made him wary of using reactors cooled by liquid metals for a civilian power plant.

In 1960, the first boiling-water reactor (BWR) began operating at Dresden, Illinois.In contrast to the 60 000 kW produced by the Shippingport reactor, the first BWR (a logical development from the PWR) produced 180 000 kW.

The story of the BWR is a story in itself, and essentially reduces to a clash between two very tough individuals, Rickover and Dr Walter Zinn, Director of the Argonne National Laboratory. Zinn was initially in charge of virtually all reactor development projects in the USA, including the nuclear submarine reactor, since he had supervised the construction and operation of the very first reactor in the USA under Enrico Fermi in 1942. The world's first fast breeder reactor, the EBR-1, also the world's first reactor to generate electricity, was "developed directly under Zinn's supervision at Argonne", (Ref. 19;2), and first produced the first known electricity (enough to light four electric light bulbs on 20 December, 1951 (Ref.20:4).

Infuriated by Rickover's continual interference with the submarine reactor, Zinn handed over the main responsibility for the nuclear submarine reactor to Westinghouse's Bettis Laboratory (and Rickover). Zinn then started to experimentwith boiling-water reactors. Thus was born the Boiling Water Reactor (BWR), which "now accounts for about 20% of the world's fleet of approximately 440 reactors" (Ref 19:3). The first experimental BWR achieved criticality on 1 December, 1956 (Ref.20:4).

In essence, the BWR were developed by General Electric, largely without government finance, while PWR were developed by Westinghouse (and Rickover) with government finance.

These and other civilian power plant reactors that followed soon proved themselves as safe, remarkably trouble-free, and, in many cases, were able to produce more power than their nominal ratings. They also proved easy to operate under steady state and fluctuating-load conditions: perhaps because the submarine reactors they were derived from had to be able to run flawlessly at maximum power for long periods, or rapidly change power output to suit the changing needs of a submarine carrying out complicated maneuvers.

It was not surprising that, in the safety-critical industry of nuclear power, reactors that had established themselves as safe and dependable soon came to dominate the market in the United States.It was also not surprising that, with one man supervising reactor development for both the US navy and (at least initially) civilian power generation, the regulatory process to approve new reactors was strongly influenced by his experience of what should constitute a safe and practical reactor design.

Not for nothing is Rickover known as "the person who has most influenced the development of civilian nuclear power in the United States" (Ref.13; 1). Three key results of the building of the "Nautilus" can be identified: all of which contributed to Rickover's unique career.

The project "helped create a nuclear equipment industry", as the "fuel elements, pressure vessels, pumps, tubing and the like could also be built for nuclear power plants". Secondly, "new standards of precision in manufacture and products" were established, that could also be applied to civilian power generation. And last but not least, the thousands of officers that Rickover had personally selected "provided a personnel base for the nuclear industry" in the USA (Ref 9), (Ref. 13).

Rickover had a career spanning sixty-three years, during which he designed nearly all the engineering codes, standards and designs on which nearly all the western world's reactors are based. He also motivated the construction of some 200 nuclear-powered submarines, aircraft carriers and cruisers. It is therefore not surprising that pressurised water reactors and boiling water reactors built to carry out his requirements should have enjoyed commercial success.

Shippingport and thorium: Rickover's last experiment

"At 12:30 am, on August 26, 1977, the operators at the Shippingport Atomic Power Station began lifting the central modules of the experimental breeder reactor core into the blanket section" (Ref. 21: 1).

Very few people today know that a particularly important experiment was carried out at the Shippingport Atomic Power Station between August 1977 and October 1982. Only recently is the importance of that experiment for power generation and the safe disposal of plutonium being realised.

The experimental core that was fitted on 26 August differed from the two cores that had previously been used at Shippingport in two ways. Firstly, it was designed to "breed" fuel (that is, produce more nuclear fuel than it consumed). And secondly, unlike the first two cores (that used highly enriched uranium (consisting of more than 90% uranium-235) surrounded by natural uranium (that is more than 99% uranium-238), the third core contained mixed oxides of uranium-233 and thorium 232 (Ref.22: 3-5). The basic architecture of all three cores, the so-called "seed and blanket" model, will not be discussed here as this is a topic in its own right.

Why thorium? Like uranium-238, thorium 232 (and virtually all thorium is made up of just that one isotope), can be converted by bombarding with neutrons into another element that undergoes fission far more easily. Uranium-238 is transmuted to plutonium 239, while thorium changes to form uranium-233. Like uranium-235 and plutonium 239, uranium- 233 is a good, fissile fuel for nuclear reactors.Like uranium-235 and plutonium-239, it can be and has been used to make nuclear weapons, but for technical reasons is far more difficult to use uranium-233 for this purpose.

Rickover's last experiment was a success. After five years of operation (producing heat for the reactor), during which it had generated "about 2,5-billion kWh of electrical power", the core "contained approximately 1,3% more fissile material" than when it had started (Ref. 21:3), (Ref. 22:6). Unlike other breeder reactors, which used liquid sodium as a coolant and high-energy neutrons to produce and fission plutonium, the Shippingport experiment proved that an ordinary pressurized water reactor, with relatively minor modifications, could also be used as a breeder. Moreover, the "waste" produced (that is thorium with uranium-233) could then be stored until such time as the uranium-233, a valuable potential future fuel, could be extracted.

According to some, Rickover's last experiment needs to be reexamined anew.More modern thorium-based reactors, such as the RTH (see below) would be "highly relevant to the world's energy potential and a viable alternative as a PWR replacement in future generations of nuclear reactors" (Ref. 22:6). As "the abundance of thorium in the earth's crust is about 3 times that of uranium…the thorium cycle thus ensures a long-term supply of nuclear fuel" (Ref. 23: 25): something particularly attractive to countries with large reserves of thorium, like Canada and India. And, because "the thermal conductivity of thorium dioxide "is about 50% higher than that of uranium dioxide] over a large temperature range, and its melting point is 340°C higher" than that of [uranium dioxide: nuclear fuel elements are typically in the form ofuranium dioxide ceramic pellets in long, thin zirconium alloy tubes], this makes for lower fuel operating temperatures, less diffusion of fission gas products (Ref. 23:25), and greater safety: in short, "an added margin of safety in the event of a temporary power surge [as in Chernobyl] or loss of coolant [as in Three Mile Island] (Ref. 24: 4). Others are more critical of thorium-powered reactors. Kazimi points out that, despite numerous countries (the USA, France, Japan, Russia, Canada, and Brazil) having tried thorium, previous "work on thorium elsewhere in the world did not lead to its adoption, largely because its performance in water reactors, such as the first core at the Indian Point power station (in New York) did not live up to expectations". He also notes that cost is a major and uncertain factor, "that thorium-based fuels could cost anywhere from 10% less to about 10% more than conventional nuclear fuels" (Ref. 24: 5-6,12).

But power generation is not the only area where thorium-powered reactors are being reexamined. In recent times, it appears that a modern development of Rickover's experiment can actually be used to dispose of a particularly dangerous type of radioactive waste: the many tons of plutonium that have been accumulated in the USA and the former Soviet Union during the Cold War.

According to an agreement between the USA and the Russian Federation, each have agreed to dismantle "a large number of excess intercontinental ballistic missiles and each dispose of 34 tons of the resulting plutonium" (Ref. 27:81).

Disposing of 34 tonnes of plutonium is not a simple matter. The Kurchatov Institute in Moscow is currently evaluating the use of an updated version of the Shippingport thorium core to dispose of plutonium. The advantage of using thorium is that the product, which includes uranium-233, is then particularly unattractive to any terrorist group wanting to steal it and attempt to make nuclear weapons. While "burning" pure plutonium can actually produce even more weapons-grade plutonium, "the potential weapons material produced in an RTR (Radkowsky Thorium Reactor, this term defined later) is difficult to handle and fabricate into weapons…and has a significantly lower explosive "yield" (Ref. 25: 250).

Radkowsky was "the original chief scientist for the US Naval Reactors Program for Admiral Hyman G Rickover" (Ref. 26:1), and also headed the design team for Shippingport. When asked by his former professor, Edward Teller, the father of the American hydrogen bomb, if he could find a way to reduce the chances of nuclear weapons getting into the wrong hands, Radkowsky turned again to the final experimental core he designed for Shippingport.

With some variations, this is now the basis is the Radkowsky Thorium Reactor (RTR), currently being evaluated at the Kurchatov Institute in Moscow as a most promising means of "burning" the 34 tons of plutonium that needs to be destroyed. Ironies abound. Radkowsky, who recently died aged 86, was most amused at the thought of working with his former enemies. After all, Rickover, his former boss, had motivated and presided over building the American nuclear navy, one of the greatest arms races in history, largely to counter the Russian threat.

Another irony is that the metallic core of the reactor being tested in the Kurchatov Institute consists of a special alloy of highly enriched uranium: proven through years of use in Soviet nuclear-powered submarines (Ref. 24:11)!

But perhaps the crowning irony is that it is Rickover's former arch-enemies, the Russians, who recognize and value most highly the results of his last experiment. One of the main reasons so few people even today know of this work is that it was considered Rickover's pet project, and the many enemies he had made during his incredibly long career were only too happy to stop his programme once he was forced into retirement.

By the time the experimental thorium core was shut down in October 1982, the US Secretary of the Navy had announced that Rickover was to retire. And, by the time a report was issued on the results of the experiment, Admiral Rickover was dead and "many of his strongest political supporters were either retired or dead" (Ref.21:2).

Limitations of water-cooled nuclear power plants

"Today's [water cooled PWR and BWR] nuclear power plants typically discharge 30% more waste heat per kilowatt-hour of electricity generated than conventional [coal-powered]plants" (Hogerton, 1968;30).

However, despite their worldwide success in the nuclear power industry, PWRs and BWRs have two limitations.

One is that their operating temperatures are not high enough, resulting in a lower thermodynamic efficiency. As Hogerton puts it, nuclear power plants "employing these systems are thus obliged to operate with low-quality steam and as a result are not as efficient in converting heat to electricity as the more modern conventional plants". In other words, "today's nuclear plants typically discharge 30% more waste heat per kilowatt-hour of electricity generated than conventional plants" (Hogerton, 1968:30)". Even though the article was written nearly 40 years ago, this still rings true, because there has been no large-scale building programme to replace nuclear power stations built then.

A second limitation Hogerton points out is that PWR reactors "are not efficient users of nuclear fuel". Essentially, this is because, like all thermal reactors, PWR reactors rely on the minute proportion (0,7%) of uranium that occurs naturally as uranium-235, and which has to be artificially enriched to higher percentages for reactor fuel.

While a typical commercial reactor uses uranium-235, it can also make some limited use of the uranium-238 which makes up making up ca 95% of its fuel (currently, an enrichment of5% is common). By the time three years are up, most of the uranium-235 in the fuel has been "burned", and the reactor needs to be refuelled. But during that time a small fraction of the uranium-238 in the fuel has been transmuted into Pu-239, which, like uranium-235, releases energy when fissioned.

In fact, just before a typical commercial reactor is shutdown for refueling, some 30% or more of the power generated by the reactor may be due to the fission of Pu-239 (Ref.17, 2). Fast neutron breeder reactors are far more efficient at using uranium fuel than normal PWR (and indeed, any thermal reactor), and can extract about 70 times more energy from uranium fuel than thermal reactors. This is because they can use the uranium-238 far more efficiently, producing plutonium from it. Fast neutron reactors are also called breeder reactors, as they can produce more fuel than they consume.

The much-publicised accident at Three Mile Island in 1979 did involve a PWR, but the design and system were not at fault: like most crashes involving modern aircraft, it was a classic case of "operator error". There, inadequately trained operators misunderstood what was going on, and turned off the emergency cooling systems which, until then, were working perfectly. The result was a core meltdown: an undesirable accident, but nowhere near the disaster caused by the explosion at Chernobyl. No one was injured or exposed to excessive radiation in the Three Mile Island accident.

The incident at Three Mile Island in 1979 and the later disaster at Chernobyl in the Ukraine on 26 April 1986, drastically affected the building of nuclear power plants in the West. But, ironically, this has not happened in the Russian Federation. While the discredited RBMK reactors are no longer produced (those in service were altered and made safer to operate), the Russian Federation has continued to build PWR reactors (known as VVER reactors in Russian terminology), both for local use and for export (Ref. 8).

Clearly, while the PWR and the BWR have enjoyed spectacular success, a new type of reactor that can run at a higher operating temperature without compromising safety, and achieving better thermal efficiency has a bright future. One such reactor is the fourth generation gas-cooled reactor. But to begin to understand how such a reactor could come about, we will first need to understand how and why its ancestor, the Magnox reactor, came into being in the United Kingdom, at roughly the same time that the pressurised water reactor was being developed for the "Nautilus". This is the topic of the next article in the series, entitled "From MonteBello to Magnox Reactor".

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