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Admiral Hyman G Rickover USN and the UK Nuclear Submarine Propulsion Programme

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SYNOPSIS

For 30 years Admiral Rickover served the USA both as the Director of the Division of Naval Reactors in the Department of Energy and as the Deputy Commander for Nuclear Propulsion in the Naval Sea Systems Command, heading up the Office of Naval Reactors. He is universally recognized as the Father of the Nuclear Navy and his forthright, abrasive style and his promotion of excellence in engineering are legendary. Less well known is the influence he had on the UK naval nuclear propulsion programme, resulting from his friendship with Admiral Earl Mountbatten when he was First Sea Lord.

This paper covers aspects of Rickover's remarkable career up to *USS Skipjack* with its S5W reactor and describes where the UK propulsion programme had got to by 1956, when the two great men first met. It describes their relationship and what resulted from their meeting. Those events still affect the programme today, while Rickover's principles are timeless.

INTRODUCTION

1. At 2315 on 3 August 1958 the United States nuclear powered submarine *USS Nautilus*, crossing the polar ice cap under the ice, reached the North Pole. Leaving the ice cap the next day, as the submarine emerged into open water, 2 foot seas and brilliant sunshine, the historic signal was made: "NAUTILUS 90 NORTH". To mark the historic event, the Commanding Officer, Commander William R Anderson USN, signed letters; one to the President, one to Mamie Eisenhower[1] who had launched the submarine, and doubtless many others. One was to the UK, to the First Sea Lord and Chief of the Naval Staff, Admiral of the Fleet Earl Mountbatten. It said:

> Dear Admiral Mountbatten
>
> At Admiral Rickover's request I am writing to tell you of the transpolar voyage of the USS NAUTILUS. On 3 August we crossed the North Pole submerged beneath the Arctic ice pack on our way from Pearl Harbour to Europe. This is the first time in history that any ship has transited from the Pacific to the Atlantic via the polar route. It is also the first time in history a ship has reached the North Pole.
>
> Knowing of your keen interest in nuclear power and the NAUTILUS I hope you will accept this letter as a memento of one of the greatest accomplishments of both.
>
> I hope that I may again have the pleasure of giving you a ride on NAUTILUS.
>
> This letter was signed at the North Pole.
>
> Very respectfully,
> (signed) W R ANDERSON
> Commanding Officer [2]

2. The submarine, already on her second reactor core, had sailed from Hawaii in the Pacific and after transiting the North Pole she arrived in Portland, Dorset to an "overwhelming welcome"[3] by the Royal Navy, no doubt arranged by Mountbatten. After six days being visited by senior naval and Admiralty civilian officers and by politicians, who learned first hand of her remarkable capabilities, *USS Nautilus* made a record breaking North Atlantic crossing to New York: 3350 miles in six and a half days, an average speed of 21 knots[4]. She was greeted by an armada of tugboats and fireboats and later the ship's company were given a ticker-tape parade at which Admiral Rickover was the President's representative.

3. Not only was USS Nautilus the world's first nuclear powered submarine, it also represented the first use of nuclear fission to generate power as opposed to make bombs. The nuclear power plant was conceived by Rickover and designed by him and his team of talented engineers of the Office of Naval Reactors in Washington, together with the Bettis Laboratory operated by Westinghouse.

4. In the UK, work on nuclear propulsion began in earnest in 1955, the year Nautilus went to sea. Rickover visited the UK from 20 - 31 August 1956, when he visited all the organizations involved in the programme. He was introduced to Mountbatten. Their meeting was an immediate success. "The introvert iconoclast from the Ukraine .... fell under the spell and aura of Queen Victoria's grandson" wrote the Proceedings of the US Naval Institute in 1981[5].

THE AIM OF THE PAPER

5. This paper aims to describe Rickover's influence on the UK submarine nuclear propulsion programme. It traces aspects of his own career up to *USS Skipjack* with its S5W nuclear propulsion plant and describes, in outline, the early stages of the UK nuclear propulsion programme. Admiral Mountbatten had been influential in getting this moving and the 1956 meeting between the two great men appears to have been crucial in Rickover's decision to help the UK. Business involving Rickover was seldom if ever straightforward and his perception of how work should be organized and who should do it caused a fair degree of frustration, notably within the UK Atomic Energy Authority.

6. Unlike US/UK cooperation in the nuclear weapons field, which was authorized by the 1958 Agreement between the two countries and continued thereafter, US assistance in nuclear propulsion was similarly authorized by the same agreement but it only lasted for the duration of the initial contract between Westinghouse and Rolls Royce. Rickover specifically rejected any further exchange thereafter. This paper explores the circumstances and the reasons.

7. The paper concludes by summarizing Rickover's views on engineering and personal standards which heavily influenced those in the nuclear submarine programme in the Royal Navy and which are as relevant today as when he decided to help us nearly half a century ago.

RICKOVER'S EARLY CAREER [6]

8. Rickover's Naval career up to the time when he espoused the neutron as the particle through which the US Navy would dominate the seas and win the Cold War, was not particularly remarkable. However, it was enormously zealous, competent and tinged with the obsessive behaviour and single minded determination to excel, even in the smallest of tasks, that subsequently characterised and forged the nuclear programme itself.

9. To gain entry to the US Naval Academy at Annapolis he received the support of a local congressman from Chicago where the family lived on the fathers meagre income as a tailor, supplemented by a variety of part time jobs that he himself was able to get.

10. In 1922 he graduated 107th out of 540 midshipmen, having excelled in some academic subjects through sheer hard work, while doing little else to acquire good scores for what the Royal Navy would call "officer-like qualities". He spent the next 5 years in a destroyer and then the battleship Nevada. Still something of a loner, albeit with some good friends, he concentrated on studying engineering. He did not in the least welcome those social aspects of naval life which distracted him from his work, although he recognized that not to be seen to participate would itself lead to time-wasting explanations. His solution was simple. Put in an appearance, and at the first convenient opportunity slip away, having arranged a boat to get him back to his own ship and study.

11. He then returned to Annapolis for study prior to gaining a master's degree in Electrical Engineering at Columbia University.

12. From there he joined the submarine service and after 3 years was recommended for command by his Commanding Officer and by the Submarine Division and Squadron Commanders. However, his Commanding Officer endorsed the commendation with the comment that S-48 had lost too many officers lately and could not afford to lose another. This was picked up by the Bureau of Navigation who turned down the request "at the present time". After a short spell in the Office of Naval Material he returned to surface ships. The next 3 years in the battleship *Mexico* had a major effect on the course of his career. His work was outstanding: the fleet engineers took notice and set about interesting him in specializing in engineering. First, however, he was appointed to command a minesweeper, the *Finch*, used for target towing and, like all those on the Asiatic station, it was in a pretty poor state. He ran a tight ship, but his real interest lay in engineering and in 1937 he became an ED - an Engineering Duty officer.

13. Throughout most of World War 11 Rickover headed the Electrical Section of the Bureau of Ships in Washington. The Dictionary of American Military Biography says of this period:

> He directed improvements in the design of obsolete electrical equipment, and through demanding aggressive management he overcame critical wartime supply shortages by extensive contracts with private industry.[7]

14. He expedited supply by by-passing procedures, and persuaded industry into taking on work way ahead of the formal contracts. In one case it involved analyzing some British magnetic minesweeping cable, doing some reverse engineering on it, and ordering up cable and diesel generating capacity, all without authorization and in blatant disregard (by his own admission) of British patents and US procurement procedures.[8] There is a view that in fact he could have saved himself and everyone else a lot of trouble by simply asking for details, because there was a free and wholesale transfer of technological data on radar, nuclear science, and virtually every other technology with war-winning potential. But it was not Rickover's way to be beholden to anyone.

15. The skills and experience he acquired in the Electrical Section were later applied to excellent effect in getting nuclear power to sea long ahead of everyone else's expectations. But seldom were there concessions to people's feelings. "He'd rather arouse a guy by saying something nasty than make a friend" said his senior engineer.[9] Other habits he acquired too. He employed people to do what he thought they would do best, regardless of cloth (naval or civilian), regardless of age, regardless of rank. This led to some pretty irate people. He worked prodigious hours, and expected everyone else to do the same. He had an interesting management style. He avidly read the internal carbon copies, the so called "pinks" of all internally generated papers to see exactly what his own people were doing. He did this all his life, pouncing on anything he didn't like. He delegated everything, kept close watch on what was happening, questioned and challenged, and when he identified people he could really trust he heaped them with authority and responsibility.

16. In the Electrical Section he developed what two other biographers describe as "the patriotic grudge" that years later he summarised in these words :

> Most of the work in the world today is done by those who work too hard. They comprise a 'nucleus of martyrs'. The greater part of the other workers' energy goes into complaining.[10]

In the Electrical Section, also, he acquired an invaluable knowledge of much of American industrial organisations and an outspoken disdain for their motivation. He held that industry was careless, complacent, and sought only to make a profit at the expense of the Government. Contractors could not be believed, they had to be incessantly watched and harassed.[11]

17. All his life he was hugely energetic, easily made angry, shouted a lot in a high pitched voice, cursed, by-passed chains of command to talk directly at anyone he perceived as responsible for events, and was expert at verbal bullying. Small wonder he was widely feared and disliked. But everyone agrees that his engineering intuition was quite outstanding; and with his deep understanding of human character and frailty, his tireless crusading for excellence, and his essential humanity he was an exceptionally successful, if highly unorthodox, leader and manager.

> All industry disliked him. He loved to make enemies.[12]

said the senior engineer in his section. At the same time, however, he learnt how best to use and to incentivize industry and when shortfalls were revealed he would not hesitate to go straight to the top and challenge the pride and the integrity of chief executives.

18. In 1945, along with many others in the US, he received an Honorary OBE, and in 1946 the Legion of Merit, both in recognition of his contribution to the war effort.

THE US NAVAL NUCLEAR PROPULSION PROGRAMME

EARLY DEVELOPMENTS [13]

19. Independently from the Manhatten atomic bomb project, the Naval Research Laboratory was undertaking nuclear research. The leading figure was Philip Abelson who in 1941 moved to the Naval Research Laboratory to work on uranium enrichment.

20. Philip Abelson was one of a handful of people at the end of 1938 to have been within a hair's breadth of discovering nuclear fission. When the news broke, on 29 January 1939, that the atom had been split, Luis Alvarez at Berkeley leapt out of the barber's chair and ran to the Radiation Laboratory where his student, Philip Abelson, had been trying to discover what transuranium elements were produced when neutrons hit uranium.

21. "He was so close to discovering fission it was pitiful" said Alvarez, while Abelson himself said "I almost went numb as I realized I had come close, but had missed a great discovery". Within 48 hours he had found iodine as a decay product of tellerium from uranium irradiation.

22. At the Naval Research Laboratory, Abelson's first technical contribution was inventing a relatively cheap way of making uranium hexafluoride - "hex". For the nominal sum of one dollar, which he never received, the Army contracted to borrow the patented process for Oak Ridge. Abelson then proceeded to research the enrichment of uranium, because the NRL appreciated that only by using enriched uranium could a reactor be made small enough to fit inside a submarine. The process he settled on was thermal diffusion. His experimental tubes were 36 feet tall, and comprised three concentric tubes: steam at 400 deg C up the centre, liquid "hex" in the 1/10 inch annular gap, then water at 130 deg C.

23. Abelson built a 100 column plant at the Naval Boiler and Turbine Laboratory at the Philadelphia Naval Yard in order to be able to use the steam generated for testing naval boilers. When the other uranium separation processes being installed at Oak Ridge by the Manhatten Project ran into trouble, it was realized belatedly that enrichment by thermal diffusion could greatly speed the process of separation of bomb grade U 235. General Groves promptly installed an Abelson 100 column plant at Oak Ridge to provide the feedstock for the Lawrence calutrons as a temporary expedient until the gaseous diffusion plants at Oak Ridge were fully operational.

24. This has been something of a technical diversion, but it served to show that in the USA, as in Germany and Japan, the powering of submarines was seen to be an important application of atomic energy. It also served to introduce Oak Ridge as the Manhatten Project location for the enrichment and separation of uranium for supply to the bomb design and experimental facilities at Los Alamos.

25. In August 1944, Brigadier General Leslie Groves, Director of the Manhatten Project, appointed a five man committee to look into the nondestructive uses of atomic energy. Two of the five were naval; one of them was Rear Admiral Earle Mills who, as Assistant Chief of the Bureau of Ships, was Rickover's boss.[14]

RICKOVER'S INTRODUCTION TO NUCLEAR ENGINEERING

26. In one of the US Navy libraries there exists the translation of a 1933 paper by a German Admiral, Hermann Bauer, *Das Unterseeboot,* concerning U-boat lessons learned during WWI. Admiral Bauer had drawn the conclusion that the U-boat would have been much more effective if it could have operated submerged primarily and did not have to spend so much time on the surface. The U-boat had inadequate submerged propulsion. The translator of the paper was Lt H G Rickover.[15]

27. In 1946, Admiral Mills sent Rickover to Oak Ridge as one member of a small naval contingent. Their goal was a propulsion reactor.[16] He tasked himself and the four other members of the naval team, - Lieutenant Commanders Louis Roddis, James Dunford, Miles Libbey and Lieutenant Raymond Dick - an intensive programme of study and report writing. As well as learning nuclear theory, they would also have learnt of the many conventional but serious engineering problems encountered and overcome in setting to work the Oak Ridge installations. The massive calutrons used US Treasury silver for their magnetic windings and busbars to alleviate the shortage of copper. They had to be stripped and rebuilt to overcome problems of close wound coils being shorted out by dirt and debris in the oil cooling system. The thermal diffusion columns leaked steam so prodigiously that resort had to be made to welded joints. Also the massive gaseous diffusion installations were months late in operation, being totally depended upon immaculate quality control during production of the diffusion barriers for the full scale plant to reproduce the performance achieved in experiment.[17]

28. Right from the start of the naval programme Rickover preached that the aims would be achieved by good engineering rather than by more science, and that only the very highest standards of quality control were good enough. Significantly, he became convinced that the technology was sufficiently advanced to embark on a propulsion programme.[18]

GETTING ESTABLISHED

29. With the McMahon Atomic Energy Act of 1946, President Harry Truman signed the civilian Atomic Energy Commission into existence, but not until early 1947 did it start to take up its responsibilities and accept, from the Army, control of nuclear business. In November 1946 the AEC called for a report stating the Navy's view of nuclear power. Rickover and Roddis (one of the naval Oak Ridge team) produced a bold and provocative report predicting that in five to eight years the Navy could have its first nuclear powered vessel.

30. Early in 1947 Captain Mumma, not Rickover, was appointed as head of nuclear matters for BuShips. Later that year, with their time at Oak Ridge drawing to a close, Rickover and his team toured every centre of nuclear work and research in the USA, meeting and impressing all the big names and influential people: Dr Walter Zinn, director of the Argonne National Laboratory stressed the importance of first choosing the reactor coolant; Dr Ernest Lawrence of cyclotron and calutron fame characteristically stressed the importance of getting "real cash" in order to attract good people and big companies; Dr Edward Teller was enthusiastic and supportive.[19] By the end of the year the group had been dispersed and Rickover had only the patronage of Admiral Mills, his erstwhile boss when he ran the Electrical Division, to keep him in Washington, employed as the Admiral's special assistant for nuclear matters. No staff, no responsibility, no authority. It is nothing less than incredible that eight years later USS *Nautilus* sailed on sea trials.

31. Admiral Mills' support and his role as the front man was crucial. First Rickover, with Mills, concentrated on getting naval endorsement of the principles:

- that there was a military need for a submarine with unlimited endurance and high speed submerged,
- that only nuclear power could meet that need, and
- that the Bureau of Ships was to be the Navy's agency for meeting the need.[20]

32. However, the AEC, not the Navy, was charged with responsibility for nuclear development and it was not until September 1948 that the Commission was finally persuaded to set up a division of reactor development. Lawrence Hafsted was appointed to head the Division. Admiral Mills's next two appointments were crucial. He appointed Rickover as naval liaison officer to the Atomic Energy Commission, and then in 1949 he made him Head of the Nuclear Power Branch of the Bureau of Ships, effectively replacing Mumma.[21]

33. With these two appointments Mills initiated the unique and unprecedented arrangement, which survives to this day, of a single group of engineers being both a formally recognised group of the AEC (now the Department of Energy) responsible for development of naval reactors, while also having a formal existence within the naval Bureau of Ships, responsible for operational seagoing plants. The group was responsible to both agencies for different aspects of its business, and drew funds from both sources according to purpose. The separation extended to the group having both types of headed paper and business between the two agencies was conducted formally on paper, such that its business was fully traceable and auditable.

34. The core of the group was formed by people with whom Rickover had worked previously: the four naval officers who had been with him at Oak Ridge; Harry Mandil and Robert Panoff from the electrical section; Paul Dignan and John O'Grady from earlier naval times.

NAUTILUS

35. Rickover mobilised the Argonne Laboratory and the Bettis Laboratory, operated by Westinghouse, to develop a pressurised water reactor, while Allis Chalmers looked at helium as the coolant, and the General Electric Knolls Laboratory looked at liquid metal sodium. By the Spring of 1949 it was becoming clear that the pressurised water design offered the best prospect of success, and this was chosen for the Mark 1 submarine prototype in the Idaho desert. Lest this proved to be unsuccessful, work also continued on the sodium cooled plant by GE. This also lead to a prototype and a submarine reactor, in *Seawolf.*

36. After the choice of moderator and coolant, the choice of materials for fuel, for control rods, and for the primary loop itself, became crucial to the design of the primary plant. Rickover's Oak Ridge group had already learnt of the potential of Zirconium. Only very small quantities had been made free of the 2% of Hafnium it normally contained, but the pure form was found to have an extremely low neutron capture cross section and to be highly corrosion resistant. After a lot of effort a contract was eventually negotiated with the Carborundum Metals Co. who became successful in producing the required quantity and quality. In due course the price fell from over $300 per pound to about $5. Zirconium alloy has become the most common fuel cladding material. Similarly, hafnium production was put on a commercial production basis. How was all this achieved? "Rickover made us do it" was the Company reply.[22]

37. Hafnium has a special place in the history of atom research. It was so named by its discoverers, George de Hevesy and Dick Coster, after Hafnia, the old Roman name for Copenhagen. They did this as a mark of respect for Neils Bohr, whose visualisation of the orbital shells of electrons around the nucleus led him to predict, in the Autumn of 1922, that element 72 would not be a rare earth, like elements 57 through 71, as expected by chemists, but that it

would be a valence 4 metal like zirconium. Neils Bohr was able to announce the discovery of the metal, and the correctness of his prediction, when he accepted his Nobel Prize in Copenhagen in December that year.[23]

38. Countless other technological and engineering questions were raised, and urgent work put in hand to discover answers. The whole programme was a prime example of what would now be called concurrent engineering, with the site for the prototype being prepared before the design was established, and construction of the submarine starting before the prototype was complete, let alone tested.

39. The results speak for themselves.

August 1950	- prototype construction started.
March 1953	- initial criticality
June 1953	- achieves full power
June 1952	- President Truman lays Nautilus keel
January 1954	- *Nautilus* launched by Mamie Eisenhower
September 1954	- *Nautilus* commissioned
December 1954	- Initial criticality
January 1955	- "Underway on nuclear power"

PASSED OVER FOR PROMOTION

40. In 1953, when the tremendous achievements of designing the world's first nuclear submarine *USS Nautilus*, and building its prototype submarine propulsion plant, S IW, were starting to become widely recognized as due uniquely to his vision and determined leadership, he was passed over for promotion from Captain to Admiral. After intensive lobbying and briefing by his supporters, Congress intervened and said it was withholding approval of the 39 proposed promotions pending an investigation of the entire promotion system. Rather than let this happen the Navy Secretary overcame the problem by a device which kept Rickover eligible, then required the July 1953 Selection Board to select for promotion one Engineering Duty Captain experienced and qualified in the field of atomic propulsive machinery for ships. Despite being faced with only one eligible candidate it took the Selection Board more than two hours to fulfil this remit from the Navy Secretary.[24]

SKATE

41. Nowadays, *USS Nautilus* would be called a "technology demonstrator". For its first production class of nuclear submarines, the Navy said it wanted a smaller submarine. Debates also took place over responsibilities for the various aspects of the design and placing contracts. The outcome was the decision that submarine design and procurement would be the responsibility of the departments of the Bureau of Ships (BuShips) normally responsible for such matters, while Rickover's Office of Naval Reactors would be responsible for reactors and the entire propulsion system through to the propeller, drawing upon relevant Buships expertise. The opportunity would also be taken to introduce other shipbuilders to the demands of building nuclear submarines. Electric Boat had built *Nautilus* and *Seawolf* (initially powered by the sodium cooled reactor) and would build the lead ship *Skate* herself. *Swordfish* and *Seadragon* would be built at the Navy yard at Portsmouth; and *Sargo* at the Navy yard Mare Island.[25]

42. Two reactor designs based on the *Nautilus* were produced by Naval Reactors and Westinghouse, designated S3W (*Skate* & *Sargo*) and S4W (*Swordfish, Seadragon*). While the reactor was sufficiently similar to *Nautilus* to be judged not to need a new shore prototype, the plants developed rather less power. *Nautilus* had a submerged displacement of 4,100 tons and was 320 feet long; *Skate* was 2,850 tons and 268 feet long. With less power, *Skate* had a somewhat slower top speed.[26] Like *Nautilus, Skate* had twin shafts and propellers with a hull design still based on traditional conventional submarine designs. All these facts were relevant in the context of Rickover and the UK programme. The S3W plant was also fitted in the one-off *USS Halibut*, a submarine designed to take the Regulus guided missile for use against shore targets.

43. The submarines of the *Skate* Class became famous for being the first US submarines to surface through the Arctic ice and when *Skate* herself did so in 1958, shortly after the Nautilus polar voyage, the Commanding Officer also wrote to Admiral Mountbatten. This is a two page letter in the Commanding Officer's own handwriting.

> August 17, 1958
>
> My Dear Admiral Mountbatten,
>
> Admiral Rickover thought you would enjoy having this letter written as we cruise under the ice near the Pole.
>
> This is our second visit - the first on August 12. Since then we have surfaced the *Skate* six times within 300 miles of the Pole - 3 times within 50. Although it is ticklish business working up in these small openings, I think this is the most significant part of our work up here and worth the risk. Since entering the pack on August 10, we have covered about 1800 miles, and I am becoming convinced that in the summer we can come up here and stay as long as we like.
>
> One of the most pleasant memories in *Skate's* history is her visit to England this Spring. Every one of us, from Captain to seaman, felt as though we were among friends with whom we had much more in common than in difference.
>
> I have recently been reading the collected correspondence of your Admiral Jack Fisher. What a splendid man he was - and what enthusiasm. Obviously he was controversial, but I don't think either of our navies has seen anything like him since.
>
> The performance of the *Skate* on this cruise has been flawless, but the finest experience of the cruise for me has been watching these officers and men of mine rise to the challenge of this new environment. They've been magnificent.
>
> Very truly yours
> (signed) James F Calvert
> Commanding[27]

SKIPJACK AND THE S5W PLANT

44. With further development of the *Nautilus* power plant to maintain the horsepower while reducing the size of the propulsion plant, Rickover's team and the Westinghouse-Bettis engineers evolved the S5W plant. Having a single, centreline propeller shaft and single propeller, the first S5W propulsion plant was installed in a "tear-drop" hull design, thus marrying two of the most significant submarine developments of the post war period.[28] Built by Electric Boat, the *Skipjac*k turned out to be the fastest US submarine to go to sea for the next two decades. The S5W power plant was fitted not only in the US navy's fast attack submarines (SSN) but also in the nuclear submarines carrying the Polaris ballistic missile (SSBN). In all, 98 US Navy submarines were powered by S5W, with a variant, the S5Wa, fitted in the *USS Glenard P Liscomb* which had a turbo-electric drive.

45. The S5W was the last submarine reactor and power plant designed by Westinghouse. All subsequent designs of submarine for the US Navy were designed by General Electric. For their part, Westinghouse turned their attention to civil nuclear power, building on the success of the Shippingport nuclear power station.

SHIPPINGPORT [29]

46. In the early 1950's the only work towards nuclear power generation, as opposed to weapon development and production, was that under the control and direction of Rickover and his team. When the AEC therefore sought to make a start on civil electrical power generation it had the choice of making a fresh start with a new team or capitalizing on the naval programme.

47. In April 1953 the Commission proposed to President Eisenhower that an infant aircraft carrier nuclear power plant project, recently cancelled as a cost savings measure, be redirected to civilian power production. A strong lobby favoured putting the design and development out to industry, in part at least to avoid adding to Rickover's empire. However, the opposition was overcome and in July the civilian project was allocated to Rickover and the naval nuclear propulsion organization, with Westinghouse the leading industrial designers. The result was the world's first full scale nuclear power station devoted solely to civilian use. In the UK Calder Hall came on line sooner, but its main role was to produce weapon material.

48. Shippingport, unsurprisingly, shared many characteristics with the naval plants under design and construction, but incorporated many new and different features also. In this design, as in the naval plants, Rickover showed his immense talent for correct decisions. The design philosophy emphasized safety, design conservatism, reliability, and the redundancy needed for good availability.

49. It was a pressurised water reactor (PWR), whereas in the UK we were concentrating on graphite moderated, gas-cooled plants. The design incorporated the principle of layers of defence against the release of radioactivity and fission products in accident situations, recognizing the loss of coolant accident as the one causing greatest consequence for a PWR. It would be a 4 loop plant, albeit full power could be achieved with only 3.

50. Major decisions concerned the fuel. Submarine reactors needed and could justify very expensive highly enriched fuel, to achieve a small reactor plant. For a civil plant, provided pressure vessel size did not create a constraint, low cost rather than small size was the driving feature. A novel "seed and blanket" design was decided upon, in which the seed would be highly enriched fuel as for naval plants, and the blanket would be natural uranium. But what form should it take? Existing knowledge favoured uranium-molybdenum alloy, but Rickover opted for the lesser known alternative of uranium dioxide in zircalloy cans. This inspired choice proved so successful that it became widely used in the civil power industry.

51. In December 1954 the AEC chose the Dusqesne Light Company as the utility to own and operate the plant. Work on site commenced in September 1954, and the station went critical on 2 December 1957 achieving full power on 23 December 1957.

52. Many years and some cores later, Shippingport again explored new concepts, becoming a light water breeder reactor. Each fuel module had a moveable seed of uranium 233 dioxide, stationary blanket also of uranium 233 dioxide, and reflector of thorium dioxide. Operation of this unique core was entirely successful, and Shippingport finally shut down having successfully launched the world's most successful generic design of civil reactor, the PWR, having also proven the light water breeder technology.

53. Thus the naval programme provided the basis for the commercial development and exploitation of nuclear power. Rickover's methods and standards set a benchmark for the industry. His trained people emerged from the naval programme to man the utilities, bringing with them his outlook and standards, while the practices and procedures developed by the naval programme for quality control and for operator training could be adopted without need for significant change. Thus Rickover's principles began to pervade the entire industry throughout the USA.

THE UK NUCLEAR PROPULSION PROGRAMME

THE UK ATOMIC ENERGY AUTHORITY

54. In 1945 the Atomic Energy Research Establishment (AERE) Harwell was established under Sir John Cockroft. The British Manhatten Project team under James Chadwick returned from the USA "with pockets full of secrets".[30] The following year, the McMahon Act was passed in the USA, severely restricting the exchange of technical information from the US to people from other nations, including former allies that had been part of the project. In the UK, as in the USA, work was mainly focussed on atomic weapons and with the UK determined to develop its own atomic bomb, Christopher Hinton set up his production group at Risley, while an intensive power research programme began at Harwell. In 1947, the first graphite-moderated research reactor went critical. The decision was taken that gas cooling would be used for the civilian power plant.

55. The UK Atomic Energy Authority (UKAEA) was created in 1954. Its main business concerned graphite moderated, gas cooled systems, with work on the Calder Hall site having started in 1953. Calder Hall was commissioned in October 1956, ostensibly as a civil power station, but also acting as a key source of fissile material for the weapons programme. Research was also being undertaken into water reactors. However, this work was cancelled in 1955 to allow the AEA to concentrate on gas cooled plants. Thus work on water cooled plants continued only for naval purposes.

THE NAVAL SECTION

56. In the early 1950s, the success of the programme in the USA and the increased availability of enriched uranium in the UK persuaded the Admiralty, in 1954, to commit more resources to nuclear propulsion, the early post war work having been devoted to high test peroxide (HTP).

57. At AERE Harwell a Naval Section was established under Captain (E) Harrison-Smith, and in 1955 this was expanded with more naval officers, and officers from the Royal Naval Scientific Service, the Royal Corps of Naval Constructors, as well as engineers from Vickers Armstrong Ltd and the Yarrow Admiralty Research Department (the organisation which evolved into YARD Ltd). The Naval Section was tasked with the design of a complete nuclear propulsion plant prototype. No information was available from the USA except the timescales of the Nautilus programme.

58. Earlier in the decade, work by the Admiralty, AEA and Vickers had explored the design of a uranium thermal reactor, graphite moderated, gas cooled, but the size of the plant was seen to be impractical for a submarine. A liquid metal cooled design had also been considered. However, by 1955 it was recognized that the pressurized water (PWR) design was best suited for submarines. The AEA advice was to concentrate on this design, with a target date of criticality of January 1960 for the shore prototype and mid 1962 for the first submarine.[31] Considerable effort had to be put into defining and carrying out the necessary experimental work into all the aspects of such a plant. The experimental programme, involving many rigs, was extensive and costly and continued on a large scale until the end of 1958.[32]

ROLLS ROYCE

59. Rolls-Royce Ltd was involved from the beginning. The company's declared business was "propulsion on land, sea and in the air" and soon after the Admiralty greatly increased its investment, the Chairman, Lord Hives, learning that the Admiralty was looking for a major engineering company to design the nuclear side of the submarine power plant, also decided to commit a significant forward design effort to nuclear energy. The Company sent people to join the Naval Section at Harwell, while having a small design team at work within the company.[33]

THE SUBMARINE PROJECT

60. It was recognized from the outset that in view of the novel and experimental nature of the proposed submarine propulsion plant, a shore prototype would be essential. Thus, in January 1956 The Secretary of the Admiralty wrote to The Secretary, UKAEA as follows:

> Sir,
>
> I am commanded by My Lords Commissioners of the Admiralty to inform you that They intend to investigate the application of nuclear power to marine propulsion and in the first instance to construct a nuclear propelled submarine. They are entering into agreement with Messrs. Vickers-Armstrongs as the main contractor for the submarine project as a whole.
>
> 2. It has been agreed that this firm will work in conjunction with Messrs. Rolls Royce, Messrs. Foster-Wheeler and other such contractors as may be considered necessary.
>
> 3. In view of the magnitude of the project and the need for early completion the main contractors will be required to place sub-contracts in agreement with the Admiralty with a view to expediting the work.
>
> 4. The reactor for the submarine will be of the pressurised light water moderated and cooled type and of approximately 80 megawatts of heat output.
>
> 5. Subject to the agreement of the Authority it is proposed to construct a complete prototype installation and it would be

appreciated if facilities could be provided for its erection and test on one of the Authority's sites in order that the general services available thereon can be made use of.

6. It is hoped that the Authority will be able to offer technical advice and assistance, in the design, experimental and testing stages, to My Lords' representatives and the firms concerned, together with the use of experimental facilities at Harwell and elsewhere.

61. The letter continues by giving the target dates for commencement of trials of the prototype as late 1959 and of the first "experimental submarine" as 1962; and names Captain S Harrison-Smith as the official representative of the Admiralty. The letter concludes:

10. My Lords will be pleased to receive the Authority's comments on this proposal and to discuss the terms and conditions of an agreement.[34]

62 The UKAEA agreement to contribute R&D effort as well as experimental facilities was not concluded until February 1957, but this did not preclude much valuable assistance being given in the meantime.[35]

63. In April 1956, a paper presented to the Marine Propulsion Committee, Panel E - Special Propulsive Systems, titled "The Importance of Nuclear Propulsion to Naval Power":

a. Gave a brief history of marine propulsion, and included the phrase

"... it is by no means certain that the gas turbine alone will ever replace steam in large warships ...."

b. Gave the advantages of nuclear propulsion

c. Concluded with a summary of the current work:

Detailed work is in hand on the design of the reactor core in relation to various possible fuel materials and fuel element designs. More general work is proceeding on heat exchangers, general machinery layouts and hull designs, ... Present thought is being centred round a single shaft installation as it seems likely to give a higher reasonably silent speed. Installations employing all geared drive, all electric drive, and hybrid systems are being considered.[36]

64. The organisation and coordination of the activities of the many groups involved in the programme involved a fairly complex committee structure. The three firms formed Vickers Nuclear Engineering Ltd; the Deputy Engineer-in-Chief of the Fleet ran a steering committee covering the propulsion plant; the Director of Naval Construction ran a committee to coordinate progress on the submarine as a whole; while the Senior Naval Representative at Harwell, Captain Harrison-Smith, chaired a Main Project Committee with several sub-committees covering the scientific and engineering experimental work.[37] The R&D work and the coordination between the Admiralty, the UKAEA and the various organisations was the responsibility of the senior Admiralty scientist, Dr Jack Edwards, who subsequently established the Department of Nuclear Science and Technology at the Royal Naval College, Greenwich. The theme of organization is picked up later in the paper.

65. By the end of 1956 it had been decided on the recommendation of the UKAEA that the shore prototype would be at the Authority's site at Dounreay. It therefore became known as the Dounreay Submarine Prototype (DS/MP). In an effort to strengthen the organization, Rear Admiral Guy Wilson was appointed Rear Admiral Nuclear Propulsion. In March 1957 the Admiralty announced that the submarine would be called HMS DREADNOUGHT.

RICKOVER, MOUNTBATTEN AND THE UK PROGRAMME

66. Since 1949 pressure had been building in the USA for amendments to the McMahon Act of 1946. With the formation of NATO and the perceived need to deploy nuclear weapons within friendly nations, it was clear that some disclosure of non-technical information would be needed. The USA Atomic Energy Act of 1954 allowed, but severely limited, assistance to other friendly nations, so the US were constrained in what information could be passed. Specifically, the Act did not allow the transfer of nuclear reactors or their fuel.

INITIAL EXCHANGES

67. Under the aegis of the Act, Rickover's first visit to the UK was from 20 - 31 August 1956, when he visited all the organisations involved in the programme. When he visited London, he was introduced to Mountbatten. Their meeting was an immediate success. In a letter to Admiral Sir Michael Denny, the Chiefs of Staff representative in Washington, dated 4 September 1956, Mountbatten wrote:

I have just had a long final talk with Elkins [Vice Admiral R F Elkins] before he leaves to join you so that he will come out to you really up to date. He will tell you in confidence of the extremely friendly and helpful attitude which Rickover has shown during his visit here. I know you will realise how very carefully one has to treat any dealings with Rickover in discussion in the Pentagon where his very success appears to have made him the more disliked. Nevertheless he could not possibly have been more friendly to us and I am hoping for great things from our contact.[38]

68. Lord Hood wrote from the Embassy in Washington that Rickover's readiness to help the Royal Navy was the decisive factor in the subsequent co-operation, and it arose largely "by the personal efforts of the First Sea Lord".[39]

69. Rickover visited again in May 1957, when a limited exchange of information began, and shortly afterwards a British delegation was given a two week tour of US facilities. These events are described by Mountbatten in a 1957 First Sea Lord's Newsletter:

The way was at long last cleared early in May for the exchange of information on submarine pressurised water reactors. In anticipation, I had already sent a personal invitation to Admiral Rickover to pay a short visit to England as soon as he was free to talk, to tell us about the American programme and see how far we had got. In the event, this proved to be a wise move, for Rickover is the virtual dictator of the whole of the U. S. Navy's Atomic Propulsion Programme; and, no matter what the scope of the official agreement, it was pretty clear that the information we received would be largely dependent on our getting his goodwill and active help.

He arrived at the end of May and spent four days with us giving a good talk in the Admiralty Cinema to members of the Board and other high ranking officers (both Admiralty and A. E. A.) This was followed by lunch at my house and visits to Foster Wheelers, Rolls-Royce, Ltd., and Harwell. He subsequently cancelled the arrangements officially made with Washington for the visits of our technical missions and re-planned the whole tour to suit what he thought would be our advantage.

A combined team of Admiralty, Atomic Energy Authority and Contractors' representatives (led by Wilson, the Rear-Admiral Nuclear Propulsion, and totalling nineteen in all) subsequently went to the U.S.A. for about 2½ weeks in June for discussions in Washington and visits to Westinghouse, the prototype test site at Arco, the Electric Boat Company (which built NAUTILUS), the GEC laboratory and Portsmouth Navy Yard, which is now actively engaged in building nuclear submarines. Rickover was as good as his word and laid on an extremely good series of presentations at all these places. From what I hear, no questions were barred. The general opinion is that the visit was of great value in corroborating that the lines on which we have been working in the design of our plant have been basically sound and the extent to which our calculations line up with theirs is very reassuring. Nevertheless, we have learned a great deal from their experience, particularly in installational design and we now need time to collect our thoughts and to take a number of decisions on possible changes which could do much to improve the final ship at the expense of some delay.[40]

70. The nature and flavour of the first visit of a UK team to US nuclear submarine programme facilities is vividly captured by the following account, contained in a private letter to the author of this paper, by Professor Jack Edwards, previously mentioned in paragraph 64 above:

My own personal contacts with Rickover stem from our first information exchange visit when Rickover tried to run us into the ground by arranging a series of visits that covered about 30,000 miles, with a typical visit beginning at 10pm, and finishing at 3.30am to enable us to get 2 hours sleep before going off on another trip, continuing in that vein for some 3 weeks. We stood the strain quite well but Rickover had taken an innate and unfair dislike to our naval team leader and took every opportunity to expose any weaknesses in his detailed nuclear knowledge. He also made several attempts to undermine the competence and authority of Dr J Dunworth of the AERE who was senior Atomic Energy Authority representative on the mixed team of Naval, Atomic Energy Authority, Rolls Royce, Vickers and Royal Naval Scientific Service members. We had several occasions when Rickover tested our stamina and nuclear knowledge and explored our national resources and abilities, but these were just demonstrations of his raw and innate determination to expose any weaknesses in our nuclear programme and personnel, and determine whether or not the UK could be trusted to observe both secrecy and advance the state of the art of nuclear propulsion in the UK.

One example of Rickover's style at meetings occurred when we had a fairly intense session set up for a wash-up after a prolonged visit to the Electric Boat Company: the meeting was scheduled to last most of the day and Rickover was in the chair casting a beady eye over his mixed British and American audience. Around lunch time and in the middle of a fair old grilling by Rickover, he suddenly broke off the technical discusssion, called for silence and beckoned a USN WAVE Officer to his side, and then commanded her to sing some arias and extracts from various light operettas to us all, quite unaccompanied too! This took us all by surprise as we were then well into our working lunch of chicken legs and chips from a basket which we had all been given. Knowing Rickover by then, the British contingent were all anxiously trying to avoid catching his eye in case he called us up to join the WAVE Officer in a duet - and this was not something to which we had become accustomed in all of our normal UK MoD meetings.[41]

71. In a further letter Jack Edwards wrote:

It seemed to me that he never did things spontaneously, but worked always to a carefully thought out advanced plan (in matters concerning individuals as well as in all of his technical and political activities). When I mentioned Captain Harrison-Smith as being the target for many of Rickover's public jibes, this is true enough, but he also showed his dislike for John Dunworth as the ARER's senior physicist, and of course he also objected to Guy Wilson, Rear Admiral Nuclear Propulsion - it was not difficult to offend the man. In the case of Harrison-Smith, I remember that what particularly riled Rickover was Harrison-Smith's public objection to Rickover slanging off another member of the British Team and of H-S's stout defence of our compatriot. We all greatly admired Harrison-Smith's performance that day.[42]

72. As well as taking a dislike to the British senior officer sent over, Rickover got the impression that the British were trying to play off the Navy and the AEC against each other in order to get information, and he and his team were spending altogether too much time on the matter. The UK team had indeed acquired vital information which led to decisions to change some key aspects of the UK design, notably the fuel embodiment and the closely related electromechanical control rod drive mechanism.

73. A letter from the British Embassy in Washington to the UKAEA, dated 25 June 1957, reads:

As you will know from Dunworth's telegrams and his report now that he has returned, the submarine reactor party are extremely pleased with the extent to which information was made available.

and later

Our own present design has stainless steel fuel elements while the Americans use zircalloy. The latter is very interesting for two reasons. (a) It would considerably reduce the U-235 requirement. Even if this might not be a financial economy, it would be replacing U-235 which we cannot buy with zirconium which we probably can. (b) We learned during this visit that with zircalloy the primary circuit becomes so little radioactive that maintenance is very greatly simplified. We do not know whether this would also be the case with stainless steel elements.[43]

74. And that is where it might have rested. But in October and November 1957 the Soviet Sputniks went up, greatly impressing the world, and indicating a clear lead in this field of technology. In what other fields might they not be ahead? Prime Minister Macmillan went to Washington. With him went Sir Edward Plowden of the AEA and Sir Richard Powell of the MOD and these two held discussions with Lewis L Strauss, Chairman of the Atomic Energy Commission, and Donald Quarles, Deputy Secretary of Defense, with a view to pooling nuclear science resources.

75. Much of the business concerned cooperation in nuclear weapons, but in the case of nuclear propulsion, where the US held such a marked and impressive lead, the four men agreed that maybe the UK could procure a complete submarine propulsion plant, and perhaps a submarine. The Atomic Energy Act would have to be amended to let it happen.[44]

76. Shortly afterwards, Rickover again visited the UK.

RICKOVER'S THIRD VISIT - JANUARY 1958

77. Following the discussions in Washington, the Admiralty, UKAEA, Rolls Royce, Foster Wheeler and all parties involved in the programme held high level meetings to discuss the turn of events and to decide what scale of assistance to accept from the USA. The several options were considered, from acquiring a complete submarine down to accepting further limited help in the areas where the work in the UK was still in difficulty. It was recognized that the greater the amount of help, the more the UK would be beholden to the USA and constrained in its future use of the technology. It was decided to accept limited help, mainly in the field of reactor core design.

PREPARATIONS FOR THE MEETING WITH RICKOVER

78. On 22 January 1958, a meeting was called in the Admiralty of what Mountbatten later refers to as the special nuclear committee[45]. It was chaired by the Secretary to the Admiralty, Sir John Lang, and was attended by Lord Weeks of Vickers, Mr Denning Pearson and Mr Barman of Rolls Royce, Mr Hopewell of Foster Wheeler, Rear Admiral Sir Edward Rebbeck of Vickers Nuclear Engineering (a new company formed by Vickers Armstrong, Rolls Royce and Foster Wheeler as partners to prosecute the programme), Sir Edwin Plowden and Mr Strath of the AEA, Mr Hainworth from the Foreign Office, and from the Admiralty: the Controller (Vice Admiral Sir Peter Reid), Admirals Power, Wilson (Rear Admiral Nuclear Propulsion), Mr Rowland Baker, Mr Nairne and Mr Pritchard. Significantly, Mountbatten was not present. The Chairman said at the start of the meeting that he had hoped to attend, but was prevented by a prior engagement. Perhaps, being a consummate politician, he was keeping his powder dry.

79. This meeting completely misjudged Rickover's opinions and his intentions. From the detailed minutes of the meeting[46] it seems that Rolls Royce were feeling bruised by the past few months' fruitless attempts to conduct information exchange in the USA and the conclusion from this was drawn that Rickover was adamantly opposed to firm-to-firm business. At the same time, the AEA were clearly enjoying excellent relations with the AEC and could not understand why there were any problems in the nuclear propulsion quarter. In everyone's eyes Rickover was the obstacle and a very difficult meeting with him was anticipated.

80. Lord Weeks wondered whether it would be possible to get round Rickover by making commercial arrangements with American firms who were willing to co-operate, bearing in mind that the AEC had said they saw no legal difficulties in the way of normal commercial exchanges of information. Mr Pearson

doubted whether Westinghouse would be prepared to negotiate such an agreement if they knew Rickover was against it. Rickover had already barred visits by Rolls Royce technicians to the Westinghouse factories where he had a measure of control and would not allow Rolls Royce to station people permanently at such factories, although this was a normal feature of an exchange of technical information.

81. It seemed that the main difficulties were associated with Rolls Royce and the reactor core, so the meeting decided to propose to Rickover that the exchange should be fronted by Vickers Nuclear Engineering and should address all aspects of the propulsion plant.

82. On the subject of cores and fissile fuel, Mr Pearson said that Rolls Royce's first impression was that there would be no difficulty in using the American cores in our reactor nor would there appear to be any difficulty in increasing the loading in order to provide the greater shaft horsepower. Sir Edwin Plowden suggested that it might be a good plan to ask for his assistance in buying the first set of fuel elements so that we would be able to speed up progress on DREADNOUGHT.

83. As a result of this discussion it was agreed that Mr Pearson should attend the forthcoming meeting with Rickover, indicating that this had not been the initial intention. There could be no clearer indication of people's complete unpreparedness for what was to come!

84. The meeting then discussed what response should be given "if the UK were pressed to acquire a nuclear submarine or parts of it with Rickover's help". The Chairman gave three reasons why this should be refused: lack of dollars; it wouldn't accelerate the DREADNOUGHT timetable; and in Rickover's own words we should lose all the advantage of having to work out the design of the reactor for ourselves. It was agreed that this last argument would be the one to use, as it was Rickover's own.

85. Finally, the meeting discussed whether it would be necessary to break with Rickover if he did not show some sign of co-operating. Sir Edwin Plowden said that if Admiral Rickover continued to refuse to allow visits to the United States, then he was in default in the agreement which had already been reached between the AEC and the Authority. After some discussion it was agreed to avoid acrimony in the course of the meeting, but that at a later time "we might have to say that we were sorry that he was not being co-operative but that we must have these arrangements with contractors in the United States and that we shall have to obtain such information through the AEC".

THE MEETING ON 24 JANUARY 1958

86. The special nuclear committee gathered for the meeting with Rickover and the First Sea Lord, Admiral Mountbatten. Before going into the meeting, the two men met in private. Mountbatten's official biography describes the occasion.

> I asked Mountbatten, wrote Rickover, "whether the British Admiralty wanted to satisfy its pride or whether it desired to build a nuclear submarine as quickly as possible. He replied that he wanted to get a nuclear submarine as quickly as possible." Within five minutes the deal was done; Britain would acquire a ready-made propulsion plant from the Americans. The two men went straight into the meeting at which all the most senior members of the British project were assembled. Mountbatten explained at some length why he considered it was essential to buy American. "This produced a deathly hush of disapproval" recalled Denning Pearson of Rolls Royce, but he and Lord Weeks of Vickers both backed the First Sea Lord's decision. Opposition crumbled. Rickover's executive assistance could scarcely get over his admiration of the handling of the meeting.[47]

87. Theodore Rockwell's description is almost identical:

> Rickover and Mandil were touring nuclear facilities in England and Scotland, and they concluded that the British nuclear submarine program would not bear fruit for many years. "England has been a real friend and ally of America for generations" said Rickover. "We should help them".
>
> "But how do we do that?" asked Mandil.
>
> "By giving them outright a submarine reactor plant and the supporting technology" was the reply.
>
> But it appeared that the proud British might be reluctant to accept an American reactor plant for one of their warships. Rickover resolved that question in typical fashion. He met alone with the First Sea Lord, the famous and colourful Lord Mountbatten, and asked him bluntly "Do you want a working reactor plant now, or would you rather preserve British pride?" Mountbatten emerged from that meeting and announced - to the amazement and consternation of his admirals and other officials - that he was prepared to accept Rickover's offer to provide an American plant'. [48]

88. Admiral Mountbatten's account, written twenty-one years after this momentous day, is interesting for his version of events. It illustrates his political and negotiating skills as well as his determination and decisiveness.

> The great day was the 24th January 1958. Rickover was going to come to meet the special nuclear committee in the Admiralty. At 1000 I saw Baker [Mr Rowland Baker RCNC, recently appointed to head the DREADNOUGHT Project Team, who had been present at the meeting of the special nuclear committee two days earlier, on 22 January 1958] the naval constructor formerly on my staff in Combined Operations and now in charge of the nuclear submarine design for the British. I was a great believer in him and was gratified to find that he actually thought it would be better to take the American SKIPJACK nuclear propulsion unit complete with the steam turbine as well. However he warned me that the rest of the committee would be against this.
>
> At 1030 Rickover arrived in my office to see me. I told him that I understood that this powerful nuclear submarine propulsion committee was going to advise strongly against accepting the steam propulsion plant. We spent the next hour going into this in very great detail. He absolutely convinced me that this would be a mistake. He told me that whereas the nuclear reactor was a reasonably straight forward job as they knew what they were doing, the problem of the heat convertor and the steam turbine was one that gave them the most trouble. They had had endless little failures and unexpected difficulties and now at last they had got a homogenous whole in the SKIPJACK. He now had the authority to offer us the whole propulsion plant and he thought we would be absolutely crazy to cut out the steam propulsion unit.
>
> At 1130 I met the entire committee in full session, but without Rickover. I listened to their arguments, I then said I had had an hour with Admiral Rickover and had heard his arguments. I was convinced he was right and they were wrong. I was going to bring him in now and tell him so and I warned them that I was going to see the First Lord and get him to back the proposals to acquire a complete SKIPJACK propulsion plant and put that up to the Government for approval. I may say this caused consternation. I do not think I have ever seen top class people quite so horrified and so hostile at the attitude I took up.
>
> However I told them that I was quite determined to persist in this attitude and then went personally and called Rickover in.
>
> I told him that the committee's views were that we should not take the steam propulsion plant but should confine ourselves to the nuclear reactor. I told them that he was opposed to this and I now asked Admiral Rickover to give his reasons. He was very calm and lucid and made an absolutely firm case to take the whole of the SKIPJACK unit complete with the steam propulsion plant.[49]

89. In fact, as the official notes of the meeting describe, it was the *Skate* plant that Rickover offered. Interestingly, the notes of the meeting available in the Public Records Office provide only an account of Rickover's words to the committee, with no mention of the First Sea Lord's backing or the committee's reaction. Given what ensued, the key parts are:

> Admiral Rickover said that he was out to help as much as possible and if eventually the United Kingdom decided to go ahead with the DREADNOUGHT project on present lines he would assist as much as he could, including firm-to-firm contacts. He would, however, most strongly advise that the

easiest and cheapest way in which the Royal Navy could achieve its aim of having a nuclear submarine was for the Admiralty to designate Rolls-Royce Ltd. as their representative with intent that the firm should place a contract with Westinghouse of America for a complete machinery propulsion plant for a submarine. What he had in mind was that the United Kingdom should acquire a complete plant, including everything in the way of drawings, spares, training and so on including such facilities from other contractors like Electric Boat Company and also facilities to have representatives of the contractors watching the manufacturing processes of tile machinery including the nuclear cores. Admiral Rickover emphasised that he was not making a proposal from America to England, he was speaking for himself and it would be for the English Government to put forward a request to the United States Government. He would, however, do his best to ensure that the answer of the American Government was favourable to such a request. He emphasised that every part of the nuclear machinery was tied up with every other part and that you could not change one thing in a nuclear machinery plant without taking account of its effect on others.

He suggested that the United Kingdom should decide on the type of submarine to aim for and thought that the best choice would be the U.S.S. "Skate". This was a proven type and was a ship of high performance with a speed of over 20 knots - admittedly less than 'Nautilus" and also smaller than "Nautilus", but nevertheless a very satisfactory ship. He estimated that about 18 months to two years would be taken in building the machinery unit, but the United Kingdom could go on with the hull in the meantime.[50]

90. At a stroke, Rickover defined his terms, confounding all that the special nuclear committee had discussed. There would be firm-to-firm exchange and Rolls Royce would take the lead for the UK (not Vickers Nuclear Engineering for whom Rickover had no time). A complete nuclear propulsion plant would be provided, including the core, with full supporting documentation and training. The UK could choose which plant to accept. The deal was to be initiated by a request from the UK. He didn't say that this was the full extent of the help the UK would get from the USA in the field of nuclear propulsion but, as it transpired, that was clearly his intention.

91. Admiral Elkins in Washington, who accompanied Rickover on this visit to the UK and attended the 24 January meeting, had assessed the position rightly. In a personal letter to the Admiralty's Chief Scientific Advisor just two weeks earlier, he said:

He [Rickover] is being very truculent & having great success with Congress, being regarded as about the one man who has delivered the goods before schedule, & he is standing no nonsense (as he calls it) from anybody. He is likely to suggest to us (a) that we buy a reactor on very favourable terms, which he will arrange & (b) that we go on with our own development causing as little interference as possible with his.[51]

92. Treasury approval to accepting Rickover's offer was signified in a minute from the Chancellor of the Exchequer to the Minister of Defence on 5 February 1958.[52] There were four understandings:

a. The overall cost would be about £8M

b. The total expenditure over the next three years would not exceed what was already planned for the nuclear programme.

c. Everything possible should be done to keep the dollar cost down.

d. The Admiraly and the AEA should have access to the know-how. Rolls Royce should not be allowed a monopoly of R&D in the field.

93. Mountbatten's decision to accept the offer initiated a period of intense activity on both sides of the Atlantic. In the UK a great deal had to be decided:

a. How would Rolls Royce set itself up to spearhead the deal?

b. Would future reactor cores be procured from the USA, or would the UK acquire the expertise to make them. If the latter, who would do it?

c. Which propulsion plant should be sought, *Skate* or *Skipjack*? Rickover recommended *Skate*, as the plant proven in operation, but might not *Skipjack* be a better bet?

d. What should happen to the shore prototype DS/MP?

e. Should the submarine continue to be called DREADNOUGHT, or should this illustrious name be reserved for the first all-British submarine?

ROLLS ROYCE AND ASSOCIATES

94. A November 1958 paper by the First Lord of the Admiralty to the Defence Committee describes what transpired:

With the agreement of the United States Government, the Admiralty nominated the Westinghouse Electric Company as the firm from which they would wish to purchase such machinery and one of the firms already engaged on the development of the plant for the first British nuclear submarine (DREADNOUGHT) - Rolls Royce Ltd. - was invited to act as the Admiralty's agent in negotiation with them. It had been understood from the start that one British firm should be the point of contact with the US firm and subsequently the Americans stressed the desirability that the contract should be between Rolls Royce and Westinghouse. Rolls Royce, recognising that the engineering technique required for the design and production of a submarine propulsion plant extends beyond the scope of their normal activities, are in the process of setting up a new subsidiary company - Rolls Royce and Associates Ltd - to assist in the procurement of the machinery unit which is to be purchased from America (inspection etc) and to develop and design# future plants for naval and, possibly, other uses. This new company, who will not itself undertake manufacture, is being formed in collaboration with Vickers Armstrong and Foster Wheeler, with whom Rolls Royce have been associated on the DREADNOUGHT project.

The extent to which this Company will undertake machinery design outside the reactor is undefined.[53]

CORE MANUFACTURE

95. The subject of core manufacture became one of the most contentious issues. Up until January 1958, the UK programme had been taken forward under close collaboration between the Admiralty and the UKAEA. Naturally, the Authority had taken the lead in aspects involving fissionable materials and the testing and evaluation of core materials. The proposal that all technical information should be transferred to Rolls Royce who would thereby be enabled to manufacture future cores for the naval programme appeared to elbow the UKAEA out of the picture entirely.

96. Following Rickover's visit and the momentous decision to take a ready-made product from America, the first stage of the process was agreed to be a letter from the UK requesting a nuclear propulsion plant and describing the proposed process for its transfer to the UK[54]. In a letter to the Admiralty dated 4 February 1958, Sir Edwin Plowden of the Authority protested strongly to the part of the draft letter concerning fuel.

...if the words mean and imply what they seem to mean and imply, the Authority must dissent strongly from one passage in the draft. ..... where it is stated that "in addition and specifically only the Rolls Royce personnel would be trained by the U S Company (outside U S Government facilities) in the manufacture of the nuclear core." This passage seems to us to imply that the Rolls Royce personnel would not be permitted to pass on the detailed information they had acquired during their training. This in turn seems to imply that the intention is that Rolls Royce should manufacture the fuel elements for the nuclear submarine.

If this is what the letter means it would, of course, run counter to the agreement between the Admiralty and the Authority on the submarine project. It would, moreover, represent a fundamental change in the policy, which has been pursued by all responsible for atomic energy in this country ever since the end of the war, of having the facilities for fuel element fabrication (in so far as those involve fissionable materials)

concentrated in one organisation: first the Ministry of Supply, now the Atomic Energy Authority. This is a major point of policy and has been followed both in the nuclear power programme and in the submarine project hitherto. We could not possibly agree to this policy being set aside as a by-product of the arrangements being made (presumably with public money) between a British firm and an American firm.[55]

The letter continues with all the arguments against setting up new and additional facilities, outside the Authority, for core manufacture.

97. However, that Rolls Royce should have exclusive access to the knowledge required for core fabrication and for quality control was exactly what Rickover intended; and as negotiations and the drafting of agreements and contracts proceeded through 1958 it is what he achieved, blocking and delaying American consents until this point was achieved.

98. In a brief to the Prime Minister, Harold MacMillan, about to be called on by Rickover on 2 February 1959, the First Lord, Lord Selkirk, wrote:

> Discussions with Rickover ..... were made more difficult by his insistence that Rolls Royce should be the main UK contractor for the nuclear core ..... and that the AEA should not be given manufacturing information about fuel elements.
>
> and
>
> ..... Rickover declined to have the drafts passed formally to the US Navy Department until HMG had agreed that RR would be permitted to manufacture fuel elements for subsequent machinery using this Westinghouse information.[56]

99. It is not clear from UK documents why Rickover was so obdurate that the UKAEA should be excluded from any part of core manufacture or inspection. However, two themes emerge:

a. He was at great pains to ensure that, on both sides of the Atlantic, the deal would be company to company and would not directly involve Governments, lest they become implicated if anything went wrong and there was a nuclear accident. By this argument, as a Government organisation the UKAEA would have to be excluded.

b. He was made highly angry and frustrated by UKAEA's refusal to allow him to visit Calder Hall and to pass over full technical information. His line appears to be that given his generosity in giving a submarine plant to the British, we should give him access to Calder Hall information.

100. The UKAEA saw things rather differently. In separately briefing the Prime Minister prior to Rickover's call in February 1959, Sir Eric Plowden wrote:

> Admiral Rickover is a remarkable man, of great technical ability and great achievements, especially in carrying to success the NAUTILUS project, ...
>
> Nevertheless his status in the US Atomic Energy Commission is that he is a member of the staff. He is Assistant Director of the Naval Reactors Division.
>
> Because of his subordinate position in the US Atomic Energy Commission, he has no part in the wider policy-making of the Commission either in the weapons field, apart from naval matters, or in the civil field. He is, however, a prominent critic of the UK Atomic Energy Authority's commercial policy on the civil side, arguing within the commission and to Congress, as well as to the Authority, that in return for the submarine and other military information from the United States the Authority should make all their civil information freely available to the United States.
>
> There are, however, some areas of work of immediate commercial value (such as the advanced gas-cooled reactor) where we are not willing to give all our information to the Atomic Energy Commission, who would be bound by their law to pass it on to the American industry, the principal competitors of British industry in the nuclear field.[57]

101. It is puzzling why the Authority did not connect Rickover with Shippingport which had gone critical a year earlier.

102. In any case, in trying to get information about Calder Hall, Rickover was not supported in the USA. The Chairman of the Congressional Sub Committee, Senator Pastore, said "..reciprocity under our bilaterals .. does not include Calder Hall which has to do with another thing. That comes under another field. ...I do not think we should confuse the two (ie Calder Hall and submarine) because if we do we may be in trouble"[58]

SKATE OR SKIPJACK?

103. Shortly after Rickover's visit, on 29 January 1958, the Controller of the Navy, Vice Admiral Sir Peter Reid, chaired a meeting to discuss the American offer[59]. The main topic was whether to ask for the *Skate* power plant, or the newer untried plant in *Skipjack*. The main arguments were:

a. The *Skate* plant is tried and tested, probably cheaper, and in any case the Americans have promised to keep the UK informed of further developments. On the other hand, it is a lower power plant, suited to a smaller submarine than DREADNOUGHT, and drives two propeller shafts.

b. The *Skipjack* plant is of the same order of power as DREADNOUGHT and drives a single shaft and hence is much more suitable, albeit not yet fully proven. Furthermore, it is the plant the US intend to use for their Polaris submarines and would therefore be suitable for ours.

104. Flag Officer Submarines's representative spoke firmly in favour of *Skipjack* and he was supported by Rear Admiral Nuclear Propulsion, Rear Admiral Guy Wilson.

105. The extract from the Admiralty Board Minutes for Thursday 13 February 1958, records that "subject to the concurrence of the Minister of Defence and the sanction of the Treasury, the *Skipjack* propulsion unit was to be preferred."[60]

WHAT'S IN A NAME?

106. The same Board Minutes record that

> The Board decided that the name should not be transferred to a later vessel, if only because of the criticism which would arise on account of the inordinate time which would then apparently elapse between the inception and completion of the submarine bearing the name 'Dreadnought'.[61]

DS/MP

107. The purchase of a nuclear propulsion plant from Westinghouse was predicated on the assumption that the cost could be contained within the £8M allowed by the Treasury for the nuclear submarine project. Initially, it was thought that to contain the cost within this sum it would be necessary to halt virtually all work at Harwell and significantly delay work on DS/MP. In the event it was found that stopping all virtually all work on core design allowed DS/MP to proceed. The question was, to what design?

108. Detailed studies by Rolls Royce showed that the DS/MP reactor pressure vessel (RPV) would accommodate the S5W design of core and by adopting this and the control rod drive mechanism as S5W, the rest of the prototype, primary and secondary, could continue as designed in the UK.

REDIRECTION

109. The Naval Section at Harwell was disbanded in 1959. Dr Jack Edwards went to the Royal Naval College Greenwich to establish there the Department of Nuclear Science and Technology (DNST), taking with him the JASON zero power nuclear reactor. Rolls Royce and Associates (RR&A) took over the activities of the Combined Derby Team. New premises for RR&A and a Rolls Royce fuel element and core fabrication factory were built at Raynesway, Derby. The Admiralty's zero energy reactor for testing fuel channels, NEPTUNE, was dismantled in Harwell, redesigned and rebuilt as part of the new RR&A premises. All this was complete by 1963.

110. Writing many years later, Professor Jack Edwards said:

> I suppose some would regard him as a sort of foster father of the British nuclear fleet. Personally I am still convinced we

would have built our nuclear submarine entirely on our own efforts - it would not have been as good as *Skipjack*, and it would have taken us some 2 years longer to get to sea. But it would have been entirely our own design and would not have made us so dependent on the whim of the US Congress on the passage of further information to us. However, it probably assisted in the subsequent Polaris conversion.[62]

MEANWHILE, IN THE USA

AMENDING THE 1954 ATOMIC ENERGY ACT

111. In January 1958 the necessary legislation was introduced on the floors of the House and the Senate, and hearings began in the Subcommittee for Cooperation. It met opposition, and the Commission was accused of acting in bad faith in having earlier given information to the British. Rickover testified on 27 February, having recently returned from his third visit to the UK. Until it was certain that the Russians had nuclear submarines he advised caution: the greater the number of nations having access to the technology, the greater the risk of its ending up in the Kremlin. Nevertheless, he spoke in favour of amending the Act to help the British:

> When I was there about a month ago I suggested to them, and they have bought, the idea that they would make a commercial arrangement with one of our companies to buy a complete submarine propulsion plant from an American company in a purely commercial arrangement, and install it themselves in a submarine they are building in England. They are currently spending about $7 million a year on their submarine development, and at that rate it will take many, many years before they are ready. [63]

112. President Eisenhower signed the legislation on 2 July 1958. The amendment established an elaborate procedure which ensured that cooperation with other countries would not be easily approved. The Commission and the Department of Defense had to negotiate the agreement and submit it to the President. The two organizations had to state that they had received a guarantee that any material or any sensitive atomic-energy information would not be transferred to unauthorized persons. The President had to determine in writing that the proposed agreement would **"promote and ... not constitute an unreasonable risk to the common defense and security..."** He then had to submit it to the Joint Committee. That group would have sixty days while both Houses were in session to consider and deliberate. It was clear that any agreement on nuclear propulsion would be scrutinized with great care.

THE 1958 US/UK AGREEMENT

113. To give it its full title, "Agreement between the Governments of the United Kingdom of Great Britain and Northern Ireland and the Government of the United States of America for Cooperation on the uses of Atomic Energy for Mutual Defence Purposes" Washington July 1958. Cmnd 537. Published in the UK by Her Majesty's Stationery Office, price sixpence net. It is commonly known as "The '58 Agreement".

114. The agreement covered weapons and nuclear propulsion and put tight security constraints on all information exchanged. No information of US origin could be passed to any other nation without the express permission of the USA Government.

115. The agreement allowed the supply of further cores for the DREADNOUGHT reactor from the US until 1968.

THE ROLLS ROYCE - WESTINGHOUSE AGREEMENT

THE DRAFT AGREEMENT

116. With the 1958 Agreement signed, Rolls Royce and Westinghouse began urgent discussions to devise the means of giving effect to the offers made by Rickover. These had been expressed in a memorandum setting out the details of the Admiralty proposal and were accepted in principal by Mr Dulles in a letter of 2 June 1958.[64]

117. Rolls Royce kept the UK Government fully informed and in the later stages were assisted by an Admiralty contract officer, since it was known that both Governments would need to approve any contracts which emerged. The draft agreement between the two companies was in two parts. The first part was a Supply Contract which covered

a. The sale of the nuclear propulsion machinery for DREADNOUGHT.

b. The training of Rolls Royce, RR&A, Vickers Armstrongs and the Admiralty, in the installation, operation, repair, engineering design principles and design philosophy of the machinery.

c. The training of Rolls Royce and RR&A in the detailed design and manufacture of the nuclear steam generating plant, including the reactor core.

d. Lead yard services from the Electric Boat Company for the complete ship.

118. The second part was a Licence Agreement under which Westinghouse would licence Rolls Royce to use the information to manufacture or (with certain reservations) to have manufactured the equipment in question. Rolls Royce were to be permitted, inter alia, to grant a sub licence to RR&A. Provision was made for the continuing of design and manufacturing information.

119. As drafted, The Licence would run until the end of 1968, with the possibility of extensions for periods of five years thereafter, "insofar as each has the right to communicate such information to the other".

120. The draft agreement also included express provision that after three years Rolls Royce would be permitted to grant sub-licences to such persons as may, from time to time, be designated by the Admiralty.[65] This provision was specifically to allow the UKAEA to be brought back into the business so that Rolls Royce would not continue to have a monopoly of the manufacture of cores.

121. The First Lord's paper to the Defence Committee describing the draft agreement [66] reported that the overall cost would be about £10M as compared with the £8M approved by the Chancellor of the Exchequer in February 1957, the increase being caused by the cost of fissile fuel (incorrectly assumed to be within the earlier estimate); the decision to purchase the *Skipjack* rather than the smaller *Skate* set; the charges for technical assistance and training; and the cost of lead yard services.

122. The paper, taken and agreed by the Defence Committee on 26 November 1958, recommended that:

a. The Admiralty should agree in principle to the draft Supply contract and Licence Agreement.

b. HMG should endorse the terms and be prepared to countersign the Agreement.

c. Rolls Royce should be permitted to manufacture fuel elements.

RICKOVER'S SPANNER IN THE WORKS

123. But Rickover rejected the terms. In a Minute to the Prime Minister dated 28 January 1959, the First Lord sought agreement to change the draft Rolls Royce - Westinghouse Agreement, just approved by the Defence Committee, saying:

> At that time I was under the impression that the terms were likely to be acceptable to the United States Navy. In further discussion, the latter have insisted on the excision of large parts of the licence agreement, under which much of the information would have been channelled in future to the United Kingdom.[66]

124. The enclosure to the Minute explains that, except in one respect, in the Admiralty's view the scope of the Licence Agreement did not go outside the scope of the 1958 Agreement.

> The US Navy do not, however, share this view. They ... consider that the section relating to the continued exchange of information on future military reactors should not form part of an agreement framed under Article III of the Bilateral as this information could not pass without the prior negotiation of a further agreement on the extent and means between the two Governments. It is the US Navy view that even the passage of

information relating to later marks of this machinery cannot be provided under the agreement presently under negotiation between the two firms.[67]

125. The solution to the issue was to drop the entire Licence Agreement and include in the Supply Contract those terms which remained unchallenged. Those were:

a. The passage of information under the Supply Contract to continue for a period of one year beyond the time when the reactor first operates (estimated as mid 1962) and to include information on any modifications incorporated during that period relevant to DREADNOUGHT's plant.

b. RR&A and Vickers rights to manufacture or have manufactured propulsion plants or parts thereof using information supplied by Westinghouse and Electric Boat.

c. HMG's right, after three years, to designate other parties to receive information and to undertake manufacture. [ie. the clause affecting UKAEA's right to information]

126. There was a silver lining. The fixed price of the contract was reduced by $700,000 and although Rickover was not able to reduce Westinghouse's fee, he secured the agreement of Electric Boat to a reduction of $50,000 in their fee. Furthermore, the dropping of the Licence Agreement meant that Rolls Royce did not have to pay any royalties, saving $600,000 per set of machinery and $150,000 in respect of Dounreay.[68]

127. Rickover agreed to the changes.[69]

VIEWS OF RICKOVER

128. The Admiralty's brief for Rickover's call on the Prime Minister, Harold MacMillan, in February 1959 is a wonderfully succinct account of Rickover's achievements, his position in America, his relationship with the Admiralty and the events described above, ascribing much of the delay to "Rickover's own refusal to look at the documents before HMG had given their provisional approval". It concludes:

> Admiral Rickover has throughout his dealings with the Admiralty been a strange mixture of helpful and hindering. He is always careful to restrict help which he gives to the strict letter of bilateral agreements, and is only willing to help if things are organised in his way. With these qualifications he can be and sometimes is very helpful. It would certainly have been very difficult for the Admiralty to get as far as we have done without his assistance.[70]

129. In the covering letter, the First Lord writes:

> Rickover is a complicated character with a chip on both his shoulders and accordingly easily flattered, and also quite likely to be sharp and even rude in his remarks. .....
>
> We have been at pains to keep him sweet and on the whole this has worked. At the same time, in my opinion, his object is to keep under his own control the extent of the flow of information on naval reactors, so that we remain mainly dependent on him for any benefits we get from the USA. .....
>
> I hope it will be possible for you to say that you appreciate what he has done for us, but I do not think it is necessary to carry your thanks too far.
>
> Signed: Yours, Selkirk [71]

130. Admiral Mountbatten was also preparing for this visit by Rickover to the UK and wrote to the man about to succeed him as First Sea Lord, Admiral Sir Charles Lambe:

> One very important point is that stormy petrel of the American Navy, Vice-Admiral Hyman G Rickover, arrives next Sunday on a visit to our nuclear propulsion activities.
>
> As we virtually owe him the ability to complete DREADNOUGHT two or three years ahead of time with a saving of millions of pounds on R&D we must all keep in with him.
>
> In his unbelievable, egotistical way, he has always regarded the First Sea Lord as his opposite number, and went so far as to tell Geoffrey Thistleton-Smith that he had begun to doubt whether the British Government were taking nuclear propulsion sufficiently seriously, since they were allowing me to leave the Admiralty before the project was properly through!
>
> At all events I am sure you will enjoy his extraordinary company and would like to meet him on his last day in London on Friday 13 February and perhaps you could keep luncheon free or some other time that day depending on how the programme works out.[72]

131. It is appropriate to end this section with a quotation from Rickover himself. Given his unique personality, his fierce individuality and his protectiveness towards the US naval nuclear propulsion programme, how did it come about that the United States of America made the priceless gift of a complete submarine propulsion plant, with full supporting information, to the UK enabling the Royal Navy to become a highly competent nuclear navy several years earlier than would have been achieved under independent development of the technology?

132. In September 1957, Rickover wrote a letter to the Commanding Officer of the *Nautilus*, Commander William R Anderson, which throws light on this most intriguing question of the nuclear submarine programme. After stating that he had gone "all out" to help the British get complete information about the American programme, Rickover wrote:

> **"I did this because of my feeling of urgency about the international situation, my admiration for the British, and particularly my great liking for Admiral Mountbatten."**[73]

THE END OF THE EXCHANGE

133. In September 1963 the Director General Ships (for by now the Controller of the Navy's departments had been reorganised, doing away with the functional heads Director of Naval Construction, Engineer in Chief, Director of Electrical Engineering) wrote a memorandum[74] drawing attention to the fact that the Rolls Royce - Westinghouse contract expired in November that year and stressing the essential need to continue to receive from USN sources supporting information, such as reactor plant change notices, changes to operating procedures and other similar information, so that safe and efficient operation might continue.

134. The paper touched on the question of whether the UK should attempt to negotiate for a further agreement or contract under the Bilateral covering design discussions related to other types of plant; and whether or not some revision of the Bilateral itself should be attempted in order to ease the restrictions it imposed. However, these were secondary to the urgent need to ensure continuation of support for DREADNOUGHT.

135. In the event, the UK request was rejected out of hand, leaving the UK naval nuclear submarine programme unable to obtain any further information from the USA and completely prevented by the 1958 Agreement from dealing with anyone else. The security constraints were very tightly maintained, to the extent that even Admiral Horlick's 1982 Thomas Lowe Gray Lecture "Submarine Propulsion in the Royal Navy" drew heavy censure from the Office of Naval Reactors.

136. Over the years there was a deal of resentment and criticism within the Ministry of Defence and the Royal Navy for Rickover's obdurate, hard line attitude which prevented the UK from talking either with his group, or anyone else, on nuclear propulsion matters. From the account given in this paper, however, it seems clear that his intention from the outset, having personally established that the UK had the ability and the determination to have a nuclear submarine force, was to give a single, time-limited boost to the UK programme. He knew that we were poor, and would become poorer; and that given half a chance would scrounge on the US rather than apply our own thought and our own resources to solving the problems that would inevitably arise.

137. Events support this thesis. In 1961 the Dreadnought Project Team (DPT) was seeking funds to enable RR&A to develop a longer life core (labelled Cordep) for the programme. Treasury approval was grudging in the extreme.

> What worries us most is the lack of firm indication of how far the Americans might be prepared to offer practical advice and help. You have told us that their preliminary reactions are favourable; from this you and the Ministry of Defence infer that Cordep is not directed on lines which have already found to be fruitless. This, however, does not get us very far; it remains possible that the Americans may later produce suggestions to

reduce the cost and improve the efficiency of the scheme. .....

In these circumstances we are prepared rather reluctantly to agree that you should start commitments on the scheme, on the understanding these are kept to the minimum until the outcome of the approach to the Americans is known; and that strenuous efforts are made through Ministerial and US Navy channels to produce a full answer as soon as possible. .....

To summarise, I should feel easier in my mind if a further determined effort were made at once to persuade the Americans to show their hand in detail. If, however, you and the Ministry of Defence are entirely satisfied that such an approach would be counter-productive and that we must make a start with your plan ..... I agree that you may proceed with the first stage of the scheme .....[75]

138. It is consistent with Rickover's frequently proclaimed views on technology and on responsibility to conclude that he decided that we would have to be made to feel total ownership and responsibility for our own decisions - or we would not be strong enough, or knowledgeable enough, or determined enough to be trustworthy users of the technology.

139. This conclusion is supported by Dr David S Mitchell, Managing Director of RR&A from 1969 to 1973 who wrote "His line was a blunt one - let the Brits stand on their own feet."[76] Also by Theodore Rockwell, one of Rickover's engineers :

Rickover agreed ... to providing support for this one ship through her first refuelling. However, he drew the line on any further significant help, because he wanted to encourage the British to develop a complete capability of their own, and not be further dependent on the United States.[77]

140. There is no doubt that at the time of the decisive meeting on 24 January 1958 Rickover made his intentions clear, because the Minute from the First Lord of the Admiralty to the Minister of Defence, written immediately after the meeting, includes the words:

Admiral Rickover made it clear that one of the important factors in his advice was that it would give us practical knowledge which would greatly facilitate our own research work in this field so that when we came to build the second and subsequent submarines we could stand on our own feet. He did not want to see us abandon our own project: indeed he hoped that his organisation might in due course benefit from us.[78]

141. Thus the special nuclear committee had been right that Rickover did not want the UK to lose all the advantage of having to work out the design of the reactor for ourselves. What the committee had totally failed to foresee was the way he would both help the British and force us to stand on our own feet.

ORGANISATIONAL MATTERS

142. Mountbatten's official biography quoting from the official tour diaries recounts that during his October 1958 visit to the USA, when Rickover was showing him round a reactor compartment, Rickover said "Admiral, I think your British set up is lousy. What you want to run a show like this is a real son-of-a-bitch" He was delighted by Mountbatten's reply: "That is where you Americans have the edge on us, you have the only real son-of-a-bitch in the business".[79]

143. Rickover was neither the first nor the only person to comment adversely on the organisation of the programme in the UK. Some 18 months earlier, on 6 March 1957, at the request of the Chairman of the AEA, Sir Edwin Plowden, Sir Christopher Hinton visited Rolls Royce at Derby, with Admiral Rebbeck of Vickers Nuclear Engineering also present, to discuss the progress of the nuclear submarine project and the organisation that existed for dealing with it. His report to the AEA executive committee starts by describing the arrangements, with:

- The hull being designed by the Director of Naval Construction at Bath;
- The prime movers being manufactured to the requirements of the Engineer in Chief: office in London, staff in Bath;
- Responsibility for construction to be placed with Vickers Shipbuilders;
- Captain Harrison-Smith, at Harwell, responsible to Rear Admiral (Nuclear), with an Admiralty organisation which collaborates [with the AEA] in experimental work and approves proposals and designs for the reactor evolved by Rolls Royce in Derby;
- Responsibility for the design and construction of the power plant placed with [Vickers Nuclear Engineering].
- Shielding under Dr Forsyth located in Barrow, with staff in Southampton;
- Heat exchangers by Foster Wheeler in London;
- The reactor itself being designed in a special office set up by Rolls Royce at Derby.

At least this team impressed him:

I formed a very good impression of the Rolls Royce team; the leading men in it are competent and imaginative and, in my view, are capable of doing a first class job.[80]

144. He continues:

The overall organisation however is such that I can see no possibility of a satisfactory submarine being evolved within a reasonable period of time. In order to do this it would be necessary to have an integrated organisation composed of suitable members of the three firms in the Vickers/Rolls Royce/Foster Wheeler consortium working together in a single office which I judge should be the Rolls Royce office in Derby. This integrated team should take full responsibility for designing and providing a reactor, heat exchangers, prime movers etc. comprising the power plant of the submarine. The design of the hull of the submarine could be undertaken by the Director of Naval Construction, but it would be necessary for him to post suitable senior members of his organisation to the main office of the consortium in Derby, so that design of the hull and design of the power plant could proceed concurrently and as a co-ordinated whole. The detailing of the hull could then be done in Bath. The fully integrated design team should be responsible to a single senior officer at the Admiralty. Only by modifying the organisation in this way do I see any hope of achieving a quick and satisfactory result.

To adopt a set-up of this sort would obviously demand an extensive change from tradition within the Admiralty, and I imagine there is little hope of such a change being made.[80]

145. He then proposes an alternative but less satisfactory re-organisation, with responsibility for designing and constructing the land based proptotype being removed from the Admiralty and placed with the Industrial Group of the Atomic Energy Authority, still with the fully integrated team at Derby. He concludes:

If the organisation is allowed to continue in its present form I feel sure the project will result only in disappointment.[80]

146. In October 1957, following a trip in *Nautilus*, Mr J RV Dolphin of the AEA was even more critical:

I am seriously disturbed about the position but I feel that unless we are extremely careful we shall carry a lot of blame for a project over which we have no control and for which the personalities are too weak, the organisation is chaotic and the co-ordination negligible.[81]

He, too, proposed a centralised organisation with a strong project leader.

147. It was not only the organisation that the UKAEA found unsatisfactory. They also had problems with the Admiralty's ways of conducting business. A letter from the Secretary, Mr Peirson to Sir Christoper Hinton begins:

I attach a copy of a letter from the Admiralty about fuel elements for the submarine reactor. Once more, the Admiralty's ways of doing business seem to be of the oddest. To write a "cocked hat" official letter on a highly technical subject and to propose a meeting which apparently ignores all the existing technical committee structure is only too typical of the Admiralty's practice of late.[82]

148. Rickover expressed his views on the organisation of the programme in the UK during his visit in May 1957. In the First Sea

Lord Newsletter of August 1957 Mountbatten writes:

> During his visit to this country, he was particularly forthright in his denunciation of our organisation for dealing with nuclear propulsion and the Controller and I had a private session with him on this subject.[83]

149. Within the Admiralty, the Dreadnought Project Team (DPT) was set up under Rowland Baker RCNC, a strong proven project director. Rickover himself did much to resolve the organisational complexity of the industries involved. By insisting on Rolls Royce leadership, he forced the creation of Rolls Royce & Associates and by insisting on commercial manufacture of cores by Rolls Royce, he eliminated the AEA from design and manufacturing activities. As the following table illustrates, he ensured to the extent that it was possible, that the UK would have an organisation that mirrored the one in the USA:

Function	USA	UK
Project Director	Rickover (dual hatted, ONR and AEC)	Rowland Baker (Single line of authority)
Project Team	Office of Naval Reactors (ONR)	Dreadnought Project Team (DPT)
Hull design	Bureau of Ships (BuShips)	Director Naval Construction (DNC)
Lead Company	Westinghouse (for S5W)	Rolls Royce & Associates (RR&A)
Submarine build	Electric Boat (for Skipjack)	Vickers Shipbuilders
Shore prototype	STR 1 Electric Boat with Westinghouse	DS/MP Vickers Engineers with RR&A

NUCLEAR SAFETY REGULATION

150. At this point it is appropriate to record that although excluded from the manufacture of cores for the naval programme, the Atomic Energy Authority, as well as continuing with some experimental work, became the Admiralty's nuclear safety regulator. Under the exchange, the Authority's Safety and Reliability Department (SRD) became recipients of the S5W safety documentation and applied considerable skill and expertise to ensuring that designers, builders and operators conformed to the safety requirements. Naval reactors, once in the submarine, become "comprised in a mode of transport" and are therefore not subject to regulation under the Nuclear Installations Act. It was seen as appropriate that The Authority should exert its authority over the nuclear programme in this role. In the USA, in contrast, the Office of Naval Reactors, being also a group belonging to the AEC, fulfilled the safety oversight function itself.

RICKOVER'S PRECEPTS

151. Rickover thought deeply about the technology he was so instrumental in bringing to the benefit of the Navy. He was a man with strong views, forthrightly expressed. Repeatedly he stressed the need for people to understand in detail the technology they were managing:

> Properly running a sophisticated technical program requires a fundamental understanding of and commitment to the technical aspects of the job and a willingness to pay infinite attention to the technical details. I might add infinite personal attention. This can only be done by one who understands the details and their implications. The phrase "the devil is in the details" is especially true for technical work. If you ignore those details and attempt to rely on management techniques or gimmicks you will surely end up with a system that is unmanageable and problems will he immensely more difficult to solve. At Naval Reactors I take individuals who are good engineers and make them into managers: they do not manage by gimmicks but by knowledge, logic, commonsense, and hard work and experience.[84]

152. He spelt out the tenets of the nuclear propulsion programme's design and engineering principles as follows:

> Because a warship must be able to perform its mission and return under combat conditions, the nuclear propulsion plant therefore must be engineered to survive battle damage and severe shock; to operate reliably and safely in close proximity to the crew; and to be repaired at sea by the crew if necessary. Standards for materials and systems are rigorous and only premium products with a proven pedigree are used in the reactor to minimize maintenance and take maximum advantage of long core lives. Building and operating effective naval nuclear propulsion plants involves many engineering and design considerations. The following are important tenets of the program's engineering philosophy:
>
> - Avoid committing ships and crews to highly developmental and untried systems and concepts.
> - Ensure adequate redundancy in design so that the plant can accommodate, without damage to ship or crew, equipment or system failures that inevitably will occur.
> - Minimize the need for operator action to accommodate expected transients. If the plant is inherently stable, the operator is better able to respond to unusual transients.
> - Simplify system design so as to be able to rely primarily on direct operator control rather than on automatic control.
> - Select only materials proven by experience for the type of application intended and insofar as practicable, those that provide the best margin for error in procurement, fabrication, and maintenance.
> - Require suppliers to conduct extensive accelerated life testing of critical reactor systems components to ensure design adequacy prior to operational use.
> - Test new reactor designs by use of a land-based prototype of the same design as the shipboard plant. Prototype plants can be subjected to the potential transients a shipboard plant will experience, so problems can be identified and resolved prior to operation of the shipboard plant.
> - Train operators on actual operating reactors at the prototypes. Simulators are not an acceptable training device for naval operators.
> - Confirm reactor and equipment design through extensive analyses, full-scale mockups, and tests.
> - Use specially trained inspectors and extensive inspections during manufacture; accept only equipment that meets specification requirements.
> - Concentrate on designing, building and operating the plants so as to prevent accidents, not just cope with accidents that could occur. [85]

[Note: the UK has found simulators to be invaluable for operator training and evaluation]

153. The crucial events this paper describes happened towards the end of 1957 and early 1958. During that period Naval Reactors was visited by Edwin L Weisl, the chief special counsel to the Preparedness Investigating Subcommittee of the Committee on Armed Services, that was considering the Polaris programme. Weisl asked Rickover how he had brought in the first nuclear submarine ahead of schedule against tremendous obstacles and odds.

154. Rickover replied that **understanding the proper roles played by government and industry was the answer. Government could not rely on industry to carry out a large scale research and development project. Doing so led to progress slower than it ought to be, costs higher than they need be, and a final product not as good as it should be. To get what it wanted, the government had to make the technical decisions. The government, therefore, had to have its own people who had to be strong in technology as well as administrative ability. The man in charge mattered more than the organisation. He had to be willing to risk his career and fight bureaucracy and inertia in government and industry.**[86]

CONCLUSION

155. Along with the S5W plant, the Royal Naval Submarine programme acquired not only an exceptional plant that achieved Rickover's aim of giving the Royal Navy a step up into the nuclear submarine age but also new standards of quality, new shipbuilding techniques, excellence in engineering, and experience of a reliable propulsion plant that was a joy to operate. Rickover also instilled in the submarine branch of the Royal Navy a concept that it understood, but had never expressed: the concept of true responsibility:

> **"Responsibility is a unique concept: it can only reside and inhere in a single individual. You may share it with others, but your portion is not diminished. You may delegate it, but it is still with you. Even if you do not recognize it or admit its presence, you cannot escape it. If responsibility is rightfully yours, no evasion, or ignorance, or passing the blame can shift the burden to someone else. Unless you can point your finger at the man who is responsible when something goes wrong, then you have never had anyone really responsible."** [87]

POSTSCRIPT

HMS DREADNOUGHT, with a nuclear propulsion plant from Westinghouse in the USA installed in a British hull, was launched by H M The Queen on 21 October - Trafalgar Day - 1960. Admiral Rickover was present. The submarine operated very successfully in service from 1963 to 1980.

The UK continued with its own design of propulsion plant (making use of the US design of core and other key reactor components) for the shore prototype DS/MP at Dounreay and for the VALIANT Class of submarines. This plant also powered the four Polaris submarines which maintained the deterrent patrol from 1969 until the duty was taken over by the VANGUARD Class of SSBN in the 1990's.

With reactor cores with ever increasing life, designed by RRA and fabricated by Rolls Royce Ltd, the propulsion plant evolved through the SWIFTSURE Class of SSN to the highly successful TRAFALGAR Class. A larger and more powerful nuclear propulsion plant, with a new shore prototype at Dounreay, was designed for the VANGUARD Class.

All this was done without further help from the USA, amply justifying Rickover's belief that given a kick start, the UK would be well able to stand on its own feet.

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