Nuclear Submarines for Australia: A Hypothetical

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Abstract— As studies continue into the replacement submarine for the Royal Australian Navy, the Australian Government has clearly stated that the successor submarine will not be nuclear powered. Despite this clearly expressed position, debate continues on the issue albeit in the peripherals of the submarine community. It is therefore of interest to consider the hypothetical question,

What issues and challenges would a medium naval power such as Australia face, were it to decide on a nuclear propulsion option for its replacement submarine?

In addressing the question, the author has drawn on freely available sources of information to discuss a number of issues:

The paper pre-supposes that Australia will have embraced a civil nuclear power programme for the low carbon generation of base load electrical power, which the author considers to be an essential prerequisite for a naval nuclear propulsion programme.

I. Introduction

This discussion paper owes its origins to one written in 2006 to assist in the nuclear submarine debate. The question the Author set himself then was:

"Discuss the issues that would need to be addressed to enable the first of a number of nuclear submarines to be accepted into service by the Royal Australian Navy (RAN) in 2020."

That debate subsided with the Government's clear statement that the successor submarine would not be nuclear propelled. However it did not go away completely. For example, recent blogs in The Australian on recent Air Warfare Destroyer (AWD) problems made the mental leap from the AWD's production problems back to the Collins Class successor and concluded that rather than building conventional submarines in Australia with all the risks that involved, we should instead lease some Virginia Class submarines! A similar theme was also taken up by Greg Sheridan in the Weekend Australian of 23 July 2011.

Rather than re-ignite that debate, the Author has converted the paper into a hypothetical which discusses the issues that might surface with any attempt to establish a nuclear submarine programme in Australia. The new question therefore is:

"What issues and challenges would a medium naval power such as Australia face, were it to decide on a nuclear power option for its replacement submarine?"

The issues that need to be addressed are:

- What are the advantages and disadvantages of nuclear submarines?
- How many might be required to constitute a valid force?
- What is available?
- Where would they be built?
- How would they be crewed?
- How would they be supported?
- How would they be disposed of?

- How much would all this cost?

In answering these questions the Author has inevitably drawn on his Royal Navy (RN) experience, although all data had been obtained from open sources. However, RN and United States Navy (USN) nuclear submarines reactor plant operating and support cultures are broadly similar, not least since RN nuclear power operating practice in the early days owed much to the USN procedures which came with the purchase of a "Skipjack" Class nuclear propulsion plant for HMS DREADNOUGHT to accelerate the UK nuclear submarine programme. Indeed after many decades of separate development, the two programmes seem now to be coalescing with the British Government's decision in March 2011 to select a US design for the reactor plant for the Trident replacement, at a cost of about £3 billion.

II. THE CASE FOR NUCLEAR SUBMARINES

A. Overcoming the Tyranny of Distance

Clearly the ability to transit to an operational area at dived speeds continuously in excess of 25 knots is a unique attribute of the nuclear submarine. Two excellent examples of this were the Falklands crises of 1977 and 1982 when nuclear submarines went non-stop to the Falklands at high power virtually all the way. HMS DREADNOUGHT's deployment to the Falklands in 1977 was a classic example of successful power projection in a sub-conflict situation. Clearly this is of great interest to any Australian strategist who has in mind the long transit distances between support bases and likely operating areas.

B. Indiscretion or the Lack of It

Total independence of the surface except for command-initiated activities ensures that the properties of a true submarine can be used to maximum benefit. This is most clearly demonstrated by the strategic missile submarine's primary patrol aim of remaining undetected, an aim that is only made possible by nuclear power.

C. Unlimited Electrical Power

Not unlimited, but as far as what is required, this is virtually so. A nuclear submarine is capable of generating about 4 MW of AC power and while a substantial amount of it is required for reactor and propulsion auxiliaries such as main coolant pumps, it still leaves a lot for ship and combat systems. It also enables power to be allocated to other traditionally under-resourced systems such as ventilation and cooling systems. When the Author joined the New Submarine Project from a nuclear programme, the need for tight management of power budgets had to be re-learnt

D. Space

The additional space available in an SSN is invaluable in respect of weapons load. HMS ASTUTE can carry up to 38 weapons. USS VIRGINIA has 12 vertical missile launch tubes for Tomahawk SLCMs and four 533mm torpedo tubes. There is capacity for up to 26 Mk 48 ADCAP heavyweight torpedoes and Sub Harpoon anti-ship missiles to be fired from the tubes. Mk 60 CAPTOR mines may also be carried.

Another reason given by the UK for making the Astute Class 30% larger than the Trafalgar Class submarines it succeeded, is maintainability. The oldest all-British designed SSNs and SSBNs were extremely difficult to maintain, largely due to the compartmental approach adopted in their machinery space design. A lot of improvements were built into the Swifttsure Class particularly in respect of the propulsion plant, with lessons learned from HMS DREADNOUGHT's American S5W plant. However Trafalgar Class submarine remained very cramped forward with accommodation particularly challenged. Trafalgar Class submarine bunk spaces were significantly less comfortable than those in the Collins Class or the Dutch Zwaardvis and Walrus classes,

III. THE CASE AGAINST NUCLEAR SUBMARINES

A. Cost

It is a given that the cost of establishing, supporting and disposing of a nuclear submarine force is extremely high; actual cost estimates will be addressed in greater detail later in this paper. However, the cost is not intrinsically unaffordable when compared, for example, with the cost of establishing the National Broadband Network: indeed the cost of each would not be dissimilar. Should the need be established, there is little doubt that the money would be found. The key question is what would have to be sacrificed in order for such a project to go ahead.

B. Structural Implications

However the cost needs to be measured not only in straight monetary terms but also in the impact that such a decision would have on the rest of the Australian Defence Force (ADF),

C. Personnel

The introduction of such a significant new arm would run a real risk of unbalancing the rest of the RAN by selecting the nuclear option as happened to the RN during the rapid expansion of the nuclear submarine force in the late 60s and early 70s. An Oberon Class crew of 65, including two engineering specialist officers, now became a crew of over 120 with up to six engineer officers. - the high propulsion plant watchkeeping load required four officers. (This figure included the Augment Watch – an additional watch of qualified watchkeepers that could be rotated within operational cycles to enable some crew members to take leave while the submarine was at sea. This helped maximise availability for sea while attempting to mitigate adverse impact on crews and their families.)

D. Support Infrastructure

Similarly support infrastructure funding became a huge drain on the naval budget; particularly as costs rose exponentially to meet increasingly stringent safety requirements combined with the extensive shore support required of a modern weapons system. As the nuclear safety requirements were largely non-negotiable, prioritisation options were limited.

E. Internal Opposition

Antagonism from within the UK Armed Forces came not only from the other two services but also from the other arms of the Navy itself. This will inevitably happen in Australia where the impact would be relatively much greater. Therefore the strategic case for a nuclear submarine force will have to be extremely strong if the case is to be won.

IV. INITIAL CONCLUSION

For these reasons it can be concluded while it is feasible that Australia could acquire and support a nuclear submarine force, it is questionable whether the ADF has the capacity to crew and support them or whether the requirement would justify the sacrifice a nuclear programme would entail.

However for the rest of this paper these doubts will be put to one side as the wider hypothetical is addressed on the assumption that the political decision to acquire a nuclear submarine force has been taken. The issues

V. FORCE SIZE

Determination of an optimal force size will inevitably results in compromise. In drawing conclusions, it is useful to look at the UK model if only because the number of submarines involved is compatible with what is likely to be a sensible outcome for Australia.

The UK needed a force of four Polaris SSBNs to ensure that one submarine would be continuously on deterrent patrol. In the early days when refit intervals were driven by core life and took place every four years this meant that at any one time:

- One submarine would be in refit
- One submarine would be working up post refit or carrying out pre-refit trials
- One submarine would be on patrol and
- One submarine would be preparing to go

When Polaris was succeeded by Trident, the number of submarines remained at four although there was some debate as to whether a fourth submarine was required. This debate is being re-visited as the UK studies the Trident replacement

The length of an SSBN refit in the early years was 56 weeks including a refuel which appears extremely short when compared to the length of a typical Collins Class refit. However the refit was conducted with the dockyard in three shifts and was supported by the engineering departments of both SSBN crews - about 150 personnel, who not only had their own refit work packages but were an integral part of the set-to-work, test and trials programme that took up nearly 50% of the refit. When the priority was less, as in the case of SSN refits, the timescale doubled.

For an SSN force an equivalent operating profile might be:

- One in refit
- One in mid cycle docking
- One in maintenance
- One preparing for patrol
- Two on patrol

This has remained a fairly standard profile for many years. For example, at the start of the Falklands War, the operational status of the five submarines of the Valiant and Churchill classes was as follows:

- COURAGEOUS Operational
- VALIANT Operational, about to enter a Mid cycle docking
- CONQUEROR In maintenance; at 47 hours' notice for sea
- CHURCHILL In refit
- WARSPITE Completing refit; about to re-enter service

VALIANT, CONQUEROR AND COURAGEOUS were all deployed before the end of the War.

It is considered that six SSNs would be a practicable figure for an Australian force giving a fair return of availability for cost. Even when refits are no longer driven by refueling intervals, there will still be an extensive docking and refit load simply because these are steamships with complex propulsion, auxiliary and secondary systems, which are intrinsically maintenance intensive. Despite an increase in condition based maintenance, the need to ensure ongoing safety of both reactor plant and platform systems will continue to drive the refit cycle as will the never-ending need for combat systems upgrade For those reasons, the Astute Class is intended to have two major refits at one third and two-thirds of service life.

When all these factors are added to the mix, one looks at having three out of the six available for operations at any one time, with a fourth available for part of the time.

VI. What is Available: Reactor Plant Selection

The reactor plant of choice remains the Pressurised Water Reactor (PWR). Now that new generation cores such as those in the Virginia and Astute classes are capable of supporting the entire design life of the submarines, it does not seem logical to move away from PWR technology particularly as the safety criteria imposed on new plant design operation and support are vastly more stringent now than they were in those early days. Any new conceptual design would be subject to even more scrutiny as public attitudes harden against nuclear power, even given their low carbon footprint. The Fukushima reactor may have been an old plant of a different (boiling water) design but in the eyes of a sceptical public they are all the same.

There is therefore little likelihood that the development of any radically new technology would be either cost effective or practical, particularly as each of the Western nuclear navies are at the start of a new PWR based cycle, which will take them through to about 2040.

The advantages of the PWR are as follows:

- The coolant and moderator are both light water and thus readily available at sea.
- Using the same medium as moderator and coolant gives the plant a self-regulating/load following characteristic and makes it very responsive to power changes.
- The plant has a very high power density – it uses highly enriched Uranium, which along with advanced core design enables a core that is little bigger than a large dustbin to last the life of the submarine.
- It now has a long and detailed safety case, which has been refined over 50 years
- The secondary cycle is relatively low technology, ideally suited for long periods of independent operation and for maintainer intervention in the event of defects.

VII. What is available: submarine choices

The only logical potential suppliers are the USA, UK or France, each of which has a submarine or a development thereof that might meet Australian requirements:

- USA: Virginia Class
- UK: Astute Class
- France: Barracuda Class

A. Virginia Class

The Virginia Class was developed by the USN as a post-Cold War submarine that would be significantly less expensive than the highly capable but hugely expensive Seawolf Class ($2.8bn)

The US Navy's requirement is for 30 of the class. Having placed a bulk-buy contract for the first five ships, the USN then placed a multi-year contract for the following five in January 2004. General Dynamics Electric Boat Division (EB) is the lead yard and is sharing the build with Northrop Grumman Newport News. The two-yard strategy was established by the USN to ensure competition. However the two yards got together and offered the USN a joint approach that is delivering submarines early and below budget.

While the submarine is of smaller displacement than the Seawolf Class, it is almost double the displacement of the Skipjack Class, which is a measure of how SSN development has gone in all navies.

USS VIRGINIA was laid down in September 1999, launched in August 2003 and commissioned in October 2004. The eighth submarine, USS CALIFORNIA, will be commissioned in October 2011.

Given the US Navy's tradition of maintaining class continuity over a long period with an evolutionary approach to its design (the 62 submarines of the Los Angeles Class were built in three flights over 20 years), the Virginia Class will be available in an updated form to support an Australian programme. The fact that there are two build yards should ensure that there would be room in the programme.

The major problem would probably be political. The USN has in the past been fanatical in safeguarding nuclear Intellectual Property (IP), as witness its withdrawal of support to the UK as soon as politically possible after the DREADNOUGHT deal. One can only imagine the ITAR issues that such an agreement would now raise. Although US/UK collaboration has resumed, it is not known if the US would relax its position even for Australia. Clearly if General Dynamics Electric Boat Division (EB) continues to be closely involved with ASC, this will help, but nuclear IP is not within its gift.

A precedent was however set in the case of Canada in 1988 when it sought access to nuclear submarine data – see below.

B. Astute Class

Much adverse publicity has surrounded the Astute Project, most of it linked to the difficulties encountered by BAE Systems in its design processes which resulted in EB being brought in to assist, rather than any fundamental conceptual problem. It should be a good, if expensive, boat. The first of class was finally commissioned in August 2010 having been laid down in 2000 and has encountered some extremely difficult times since then, but again they seem unconnected to any design flaws. Moreover the timeline would be about right for all first of class snags to have been overcome by the time an Australian version is required.

The problem may be whether the RN retains an ongoing commitment to SSNs. Recent defence reviews, which have resulted in further reductions in the Submarine Flotilla and the cutting of key capabilities, do not engender confidence in the future. However, the British Government's continuing commitment to a submarine-borne nuclear deterrent as the successor the Trident D5 system, should ensure a continuing commitment to a nuclear option, However, should the UK Government change its position on the Nuclear Deterrent, the position of the UK SSN force would become much more problematical, with non-nuclear options re-surfacing.

Access to UK nuclear IP would have to be approved by the US because of the UK's continuing obligations under the US/UK agreement for technology transfer following on from DREADNOUGHT. However a precedent of sorts was set in 1988 when Canada was considering purchasing Trafalgar Class submarines. The US Government made the following statement, “After careful review of the views of his senior advisers, the President has determined that, if the Canadians select the Trafalgar design, the interests of the United States are best served by agreeing to the British request. We have so informed both the British and Canadian Governments.

“I should stress that the President's determination was made only because of the unique circumstances involving the United Kingdom and Canada, two of our oldest and closest allies. U.S. policy remains opposed to the transfer of nuclear submarines to other nations.”

One would hope that a similar approach would be taken by the US Government in respect of Australia, unless of course the US wishes to exclude the UK from working with Australia for commercial reasons.

Certainly the increased level of co-operation between the UK and the USA would seem to indicate a more flexible attitude to allies in this regard. (In May 2011 the UK Ministry of Defence announced that a US design had been selected for the PWR3 to be installed in the successor SSBN, at a cost of about £3 billion.)

If the Astute Programme stays on track, the submarine is a possibility for Australia. However with only one yard the UK would only be able to match the requirement if there were a gap in its own programme. More generally, it is of concern that the size of the remaining UK programme may no longer provide the necessary critical mass necessary to support a new entrant to the field.

C. Barracuda Class

The submarines of the French Rubis/Amethyste Class are the smallest SSNs ever built and suffer from poor endurance and insufficient combat system capability as a consequence – for example it can only carry 14 weapons. They will be replaced by the Barracuda Class, as part of the French Navy’s force structure model for 2015. At approximately 4500 tonnes and with a derivative of the reactor used on the Triomphant Class SSBN and the FNS CHARLES DE GAULLE, they will bring France closer to the mainstream of SSN construction. Unlike the Rubis/Amethyste, which has turbo-electric propulsion, the Barracuda will have direct drive turbines as well as turbo-electric drive so they presumably intend to make this a fast boat.

However just as the Barracuda is approaching the size of the earlier Swiftsure Class, British and US designs are increasing in size to meet increased combat system and improved maintainability requirements with both new designs coming in at 7800 tonnes submerged displacement. The Barracuda is quoted as having a likely weapon load of only 18 weapons.

It remains to be seen if Barracuda will be big enough to pack the kind of punch that one would expect of an SSN for the price. There is a risk that the RAN would move from the top flight of SSK operation to the bottom flight of SSN.

However the boat is within the size envelope that would be attractive to the RAN. Crew size is also significantly down on the US/UK designs and it was almost half the price although this price advantage has now been eroded.

D. Parent Navy Support

It will be essential to have a close relationship with the parent Navy of the country of origin, not only during the acquisition phase but also through life. The support provided to the UK during the acquisition of HMS DREADNOUGHT was stopped by the USN after the submarine was delivered. The rules then forbade any exchange of information or even discussion of nuclear matters between the two navies far less any other countries. While this was a serious setback, the RN survived because its own programme was up and running by then. If it had not been so, it would have in been in serious trouble when, later, generic plant problems were encountered. It is essential that Australia has a permanent relationship with whichever government and navy it decides to partner with. Without such a relationship it will be impossible to maintain a valid through life nuclear safety case.

D Combat Systems

The Author is not qualified to comment in any depth on the capabilities of the various weapons and combat systems likely to be on offer except that the weapon carrying capacity of both Virginia and Astute Classes is greatly superior to the proposed Barracuda Class, which appears to be less than a Collins. Also the go-it-alone attitude of the French in weapon technology could be a problem for Australia, although on the other side of the equation the French, British and Australians all use Thales sonars. Big is definitely beautiful in this context.

J Best Fit

Conclusions are:

- The most capable submarine undoubtedly will be the Virginia Class, followed by the Astute Class with the Barracuda third. It is arguable that the Virginia Class is over-capable for what Australia needs.
- The size of the USN programme would ensure the security of the Australian programme.
- The Astute Class will provide the combat systems equivalent of a fully capable nuclear Collins Class.
- The Barracuda will provide a more limited yet acceptable capability with a submarine not significantly bigger than a Collins Class boat and a much smaller crew.
- However there are other issues that must be taken into account other than capability, such as interoperability and cost.
- From a platform perspective there will not be much to choose between the UK and USN platforms. Where the USN will score is the RAN's close involvement with USN in combat system development and ASC's mature relationship with EB.

VIII. BUILD OPTIONS

When Mountbatten and Rickover were discussing how best to accelerate the UK programme Rickover asked Mountbatten whether the British Admiralty wanted to satisfy its pride or whether it wanted to get a nuclear submarine as soon as possible. Mountbatten answered that he wanted to get a submarine as soon as possible. The result of that discussion was the Dreadnought Agreement whereby a Skipjack S5W reactor and propulsion plant were provided for installation inside a British designed hull and with a British front end of what became HMS DREADNOUGHT. It is of note that 50 years after the Dreadnought Agreement, the UK has again gone to the US for its future PWR design.

The Australian Government will have to consider its priorities in much the same manner in deciding where the boats should be built.

To build a submarine in Australia, particularly to install, set to work and test a nuclear plant would be a monumental undertaking. The question then becomes not whether Australia could do it but whether it would want to.

The least risky way would be to build in the country of origin as part of the build sequence of that country's own programme. The crew would then be trained with the parent navy much as in the Australian Oberon Programme.

But the disadvantages are the same as in the Oberon Programme; there would be no means of involving Australian Industry in the build programme in order to develop the skills required to support the programme.

A Australian Build

However, assume that an American design has been chosen and agreement is reached on access to US nuclear technology. Also assume that ASC has retained its links with EB and that the design relationship between the two organizations has flourished. The possibility of a Dreadnought Option or a version of it becomes more attractive. For example:

- The reactor and propulsion plant would be a proven Virginia Class design, procured in the US with EB taking the lead.

- The complete reactor compartment would be built at EB with as much initial testing of reactor systems as possible done there. Reactor systems outside the reactor compartment would be manufactured at EB for installation in the appropriate hull section in Australia.

- The core would be loaded at EB. As it is a once-in-ship lifetime, the details of the load out are not essential in-country skills for Australia.

- The secondary propulsion plant would be assembled and tested in a US land based test site.

- Platform systems and hull design would be a joint effort between ASC and EB

- Combat Systems would be a joint effort between ASC and a combat systems house.

- The submarine would be consolidated at Osborne with the reactor compartment delivered as a complete hull section.

- The submarine would then be launched on the new Osborne Shiplift. Note: Nuclear safety issues on the use of a shiplift will be less stringent with a clean core that has not been taken critical and therefore has no fission fragment inventory.

- Propulsion and Primary Plant testing would then take place at Osborne (subject to the site receiving a licence for critical operations, see below).

There are many permutations of the above including building the First of Class overseas.

This predicates a US solution but realistically that is probably the case given the growing ties between Australia and US in defence matters. A similar solution might be possible with an Astute derivative, particularly given EB's involvement in that programme but it lacks the economies of scale of the US option. Theoretically it could also apply to a French option, however, the practicability of such a project is less certain.

IX. CREWING

Nuclear submarines are manpower intensive. Both Virginia and Astute will have a crew of about 100 plus trainees, not much less than their predecessors. Propulsion plant watchkeeping is demanding and will continue to be so in the US/UK options. Nuclear propulsion plants require three watches of qualified watchkeepers with typically eight in a watch, including an Engineer Officer of the Watch (EOOW) and Nuclear Chief of the Watch (NCOW). It is not permissible for trainees to stand a watch unsupervised therefore propulsion trainees are embarked, additional to complement.

Although mention is made in literature of personnel savings made possible by increased automation, this will not necessarily flow over into nuclear propulsion – the difficulties of justifying a nuclear safety case for operating software often prevent a radical approach to software driven control and monitoring. While it is accepted that this view may be out of date, the USN is particular can be expected to be very conservative in such matters.

The complement of the submarine forward will not necessarily be too different from a Collins Class except for an enhanced Health and Safety Complement to deal with environmental control and radiological protection.

Personnel requirements will be a very serious drain on the conventional force. In the UK at the peak of the nuclear force expansion, a very serious dilution of conventional submarine expertise took place (Artemis – the Lessons Learnt). Submariners were no longer all volunteers and a large number of non-volunteer General Service ratings ended up in submarines for a five year stint. Engineer officers went straight into the nuclear stream from RNEC Manadon for another two years of training before qualifying as an EOOW, so their "whole submarine" training was limited. With initially a mixed conventional/nuclear force Australia can expect to experience the same dilution problems as the RN did.

The Barracuda Class will have a crew of about 60, significantly down on older classes as a result of increased automation. This is very attractive to a smaller navy. Not enough is known of the planned operating profile of the plant to allow further comment.

Finally, the need to ensure that the sea/shore ratio of submarine crews is taken fully into account cannot be over-stated, to ensure that the right balance between submarine availability and personnel quality of life is to be maintained. When this balance was lost in the RN on a number of occasions in the 70s and 80s, the best people voted with their feet.

This therefore requires that shore support activities need to be fully integrated so that the submariner on his/ her shore cycle has a useful and fulfilling role to play.

The industrial base (both civil and military) required to support a nuclear submarine force will be very substantial. The Clyde Naval Base in the UK is reported to have 3,000 service personnel, 800 of their families and 4,000 civilian workers, while the Devonport nuclear submarine refit

X. SUPPORT INFRASTRUCTURE

A nuclear submarine programme can only succeed if it takes place in a country with a mature civil nuclear power programme. Therefore it must be assumed that a debate over the establishment of a civil nuclear power programme will have taken place and will have been successfully resolved in favour of nuclear power and a civil Pressurised Water Reactor programme. Selection of a different reactor technology e.g. boiling water or gas cooled would appear to go against the logic of history in the development of nuclear power over the past fifty years and would make the task of any naval programme team more difficult but not impossible.

The existence of a mature civil programme is considered to be essential in order to ensure that there is an industrial base on which to build the required support infrastructure and also to ensure that there is sufficient in-country regulation to satisfy the general public that the programme is safe.

Nuclear submarine shore support infrastructure will be subject to the full rigour of a civil nuclear installation licensing regime wherever it is has the potential to impact on reactor safety and hence on the safety of the general public. This basically means that any installation which is used in any way to support a nuclear submarine propulsion plant has to be licensed for the task in hand and will therefore be subject to a full safety assessment as will the shore based personnel who operate it. Pleas of a lack of funding will fall on deaf ears!

This is similar to modern submarine safety cases in that it is numerically based both in the determination of probability and the assessment of consequence of any accident. The priority is the safety of the General Public with the two key factors being prevention of radiation release and the containment of any release that does occur i.e. the prevention of core damage and the effectiveness of reactor containment should it occur. However it also includes the prevention of accidents surrounding the handling of radioactive material outside the primary containment.

Reduction in routine radiation doses to levels that are as low as are reasonably practicable (the ALARP principal) remains the objective, a concept that is difficult to justify to a suspicious public as has been shown by the Fukushima accident.

This is where the problems are encountered most often with the anti-lobby. “Not in my backyard” (NIMBY) plays a big part in this. Naval authorities have to move outside their comfort zone and deal with local government in the preparation of accident response procedures where the responses are likely to include, “How can you say they are safe if you need accident procedures?” or “If you cannot guarantee that a nuclear accident is impossible, I don’t want your submarine anywhere near my town”.

At least one senior RN officer’s promising career has come to a shuddering halt as a result of his inability to deal with such attitudes, which are often supported by the more sensationalist end of the media (“ Royal Navy to Replace Submarines ‘Fukushima type’ Nuclear Reactors”.) However, the issues are substantive and need to be addressed carefully.

Some of the issues that would have to be fully assessed and found acceptable for any submarine berthing and/or docking facility are:

- Time at risk i.e. the number of hours nuclear plants are present in the facility
- Distances from inhabited buildings and from the local populace
- Services required to support critical and shutdown reactor operation eg power; cooling water; nuclear effluent;
- Operation and repair activities permitted in the facility
- Qualification and training of all shore based personnel involved in nuclear submarine support
- Radiation monitoring and accident procedures
- Management of the facility to preserve the safety and security of the berth or dock
- Ability of facility to withstand external events eg earthquake; wind; fire; terrorism etc.

XI. DECOMMISSIONING

Decommissioning was barely addressed in the early days of the nuclear submarine programme when cold war requirements were of higher priority. As a Ministry of Defence spokesman admitted to a House of Commons Select committee in 1988,

"The Admiralty decided - God bless it - to go into nuclear propulsion for submarines in the early 1950's... There were quite enough problems to contemplate at that time without thinking too much about what on earth we should do with it when we were finished with it."

That is no longer acceptable and decommissioning must be included in the total cost of ownership, which will in turn determine the overall affordability of the capability. It will also contribute significantly to the political and environmental debate on the acceptability of a civil as well as a military nuclear reactor programme, since the legacy of the programme will undeniably exist long after each submarine’s operational life is over.

There are three main sources of radiation within a nuclear submarine that have to be considered when considering the scrapping of a nuclear submarine:

- The core
- The radioactive corrosion products within the primary circuit
- The irradiated steel of the pressure vessel and primary circuit

A. The Core

Even after the core has reached the end of its design life there will still be a substantial quantity of unused fuel as well as long life fission fragments. These long life fission fragments continue to decay and generate heat long after shutdown and fuel modules must therefore continue to be cooled throughout the decommissioning process. There must then be a place “somewhere” that will store the fuel until the fuel can be processed to recover the useable uranium. This would be similar to Sellafield in the UK.

It is not clear if the processing of submarine reactor spent fuel is ongoing in the West. The emphasis still seems to be on secure safe storage. For example the Ministry of Defence (UK) has recently awarded a 36-year contract worth £230m to British Nuclear Group for the receipt and storage of reactor fuel. Re-processing would itself generate significant quantities of high-level waste.

Managing spent fuel and high-level active waste is a highly sensitive issue, which the nuclear industry has yet to address in a way that will answer all critics. One can expect the NIMBY principle to be vigorously applied in this area.

B. Primary Circuit

Before the reactor can be defuelled, a safe working environment has to be established, which requires the activity within the primary circuit to be addressed. Stainless steel is prevented from further corrosion by a very fine layer of corrosion products, which adhere tightly to the surface of the metal. These corrosion products become irradiated and are known as crud, which is reputed to derive from the acronym for “Chalk River Unidentified Deposit” after the site where the deposits were first encountered. They do not present a problem in service unless they become detached by thermal or hydraulic shock when they contaminate the primary circuit in what is known as a crud burst causing general radiation levels to rise sharply.

During normal operations, personnel will be protected from this background radiation by shielding however it will contribute to the exposures which personnel working in the reactor compartment during defuelling will receive unless action is first taken to remove these deposits. Achieving exposures that are as low as reasonably practicable (ALARP) for these personnel will require the primary circuit to be chemically decontaminated. This is turn will result in a highly active residue that also has to be stored.

C. Steel

Even after the core is removed and the primary circuit is removed, there remain the many tonnes of stainless steel forming the reactor pressure vessel, the primary loops and primary system pipework. Although it should not now be contaminated with radio-active material, the steel itself will have become radioactive from the neutron bombardment of its cobalt. Cobalt 60 is a gamma emitter, which has a half-life of 5.27 years. One solution to this radiation is therefore to allow time for natural decay to reduce the Cobalt 60 gamma emissions to acceptable levels, hence the long-term lay up of UK submarine reactors in Plymouth and Rosyth and the burying of US reactor compartments in the Department of Energy's Hanford Nuclear Reservation in Washington. Reactor compartments are sealed at both ends and shipped by barge and multiple-wheel high-capacity trailers to Handford to be buried. The burial trenches have been evaluated to be secure for at least 600 years before the first pinhole penetration of some lead containment areas of the reactor compartment packages occurs, and several thousand years before leakage becomes possible.

D. Australia

Defuelling requires most of the skills required for re-fuelling and is more complex than initial core load because of the radiation levels and decay heat that do not exist in a new submarine core. It will be essential for Australia to have its own nuclear power industry to provide the expertise and facilities for handling spent fuel and high-level nuclear waste. If this is to be done in Australia, a nuclear defuelling facility will require to be built within a secure dockyard environment with much of the capabilities of a re-fuelling facility including: a dock area which would contain:

- a defuelling building including core module handling equipment
- an effluent treatment plant,
- a core pond,
- an active waste facility for Intermediate and low Level Waste
- high integrity services to ensure that core cooling is never disrupted.

High security would be required at all stages of the process because of the enriched nature of the fuel. All facilities will be subject to stringent safety analysis.

If core initial load were not done in Australia, these facilities would not be required until end of submarine life. Even if core load was done in Australia, it is unlikely that the technology would stand still over the life of the core so that a further spend on decommissioning facilities would be required.

On the plus side of the ledger, it is possible that the process will be much better understood and more effectively managed by then, although this argument has already been used in the past to little effect. Also the fact remains that a capability will be required to deal with any problem that may arise during core life, as it would be highly unlikely that the supplying country would wish to deal with such an eventuality, even if it were in a position to do so.

This is not a short term solution and is the single greatest weakness in the case for nuclear power whether for civil or military use. It is suspected that proponents of a lease option see this as a way of circumventing the decommissioning issue; this may be more difficult to achieve than it appears at first sight. Populations may just about accept their own radiological waste – they will be much less keen to accept that of others.

XII. COST

A. Submarine Unit Cost

USS VIRGINIA is understood to have cost about $US1.8 billion, compared to USS SEAWOLF at $US2.8 billion, and the average cost of Los Angeles class submarine of around $US1 billion.

It estimated that each of the first three Astute Class submarines will cost about £1.3 billion or $US1.8 billion. There is therefore little or no price differential.

The estimate for the Barracuda is now 1.45 billion Euros, or $A2.0 billion, having increased significantly as the development has proceeded. Given the continuing close involvement of the French State in the programme real costs may not be as visible as in UK or US but they can be expected to rise. As delivery of the first of class approaches this cost can be expected to rise.

It would appear therefore that a unit price of $A2.0 billion is around the mark. Note that this would not be the price for an Australian build as these overseas builds are taking place in facilities that have been largely funded for previous projects.

B. Acquisition Logistics

The Acquisition Logistics package for the Collins Class Project was equivalent to the cost of an extra submarine, so a valid figure in this case would be $A2.0bn

C. Infrastructure and Support

The cost of supporting a nuclear force is very large. To give an indication, this quote is included from the UK National Audit Office in December 2002 on the construction of nuclear refitting facilities in Devonport,

"Sir John Bourn, Head of the National Audit Office, told Parliament today that the costs of this project had risen from £650 million to an estimated £933 million. Although the Ministry of Defence originally considered that it had transferred the risk of cost overruns to the private sector, in the end it funded most of the cost increase itself and will pay an estimated £849 million at 2001-02 prices." (£1.6Bn in 2011 prices)

Even allowing for the inefficiency of that procurement process, this gives a rough order of magnitude of the type of sums involved in procuring such facilities. Similar costs were encountered at the Clyde Naval Base re-development for platform support of the Trident Programme. The massive cost increases in both sites came partially from the need to design the facilities to more stringent safety standards that were just being introduced into the civil programme including the need to design against a seismic event well beyond those ever experienced in UK but which had been derived from statistical extrapolation. With Australia's more active seismic environment, one would not imagine that we could get away with anything less.

While a civil nuclear power industry will be essential to support a naval programme; it does mean that the RAN will have to conform with all civil standards right from the start of the programme, unlike the USN and RN whose programmes began in a relatively more benign regulatory environment.

The introduction of nuclear power into Australia will be very controversial. One can imagine the most detailed safety arguments being presented (both for and against). The facilities will have to meet the highest international standards. This particularly applies to docking an in-service nuclear submarine. For example, no drydock on the Eastern Seaboard is likely to meet the seismic criteria for docking a nuclear submarine. Similarly any shiplift that has not designed ab initio with this in mind is not likely meet the standard. Also the UK figures quoted above only covered a refit capability to which would have to be added the very large costs of a nuclear submarine operating base such as the UK's base on the Clyde. To this must be added the costs associated with decommissioning. A conservative estimate would therefore be to assume that the shore facilities would cost about **$A4.0 billion.**

The UN quotes annual operating costs as $US21 million per submarine – no fuel costs. This figure will benefit significantly from economies of scale and can be expected to be considerably higher in Australia. Even without refuelling, each submarine would need a mid-life modernisation which might cost a further $A200 million. Adding another $A250 million per boat for decommissioning and disposal would give a total life cycle cost per boat over a 30 year life excluding acquisition of about $A1.2 billion. An alternative method would be simply to assume that procurement is 50% of the LCC which would give a figure of $A2.0 billion per submarine.

D. Final Costs

With such woolly figures, it is necessary to apply a large contingency of 30%. It is emphasised that the figures are quoted purely to give an indication of the scale of investment that would be required.

- Six submarines @ $A2.0 bn $A12.0bn

- Acquistion logistics package $A 2.0bn
- Infrastructure $A 4.0bn
- Through Life Costs $A 12.0bn
- Contingency @ 30% $A 10.0bn

Total programme cost <u>$A 40.0bn</u>

XIII. CONCLUSIONS

The following conclusions are offered for further debate:

- A nuclear submarine force would be so expensive and have potentially such a de-stabilising effect on the rest of the ADF, that its selection will need to be justified on the grounds of the highest possible strategic need.
- Should that need be established, the force size should number six submarines.
- The acquisition and through life costs of six submarines plus infrastructure would be in the order of $A35 and $A40 billion: these figures are indicative only.
- A proven overseas design should be selected.
- The new French design concept for the Barracuda Class is attractive from displacement, price (possibly) and crew size. However it can be expected to be less capable than the US/UK designs.
- The long term commitment of the UK to nuclear submarine propulsion may come under financial threat.
- The Virginia Class would be an attractive nuclear option for Australia
- Relations with the overseas reactor plant designer, parent navy and safety regulator would need to be maintained throughout the life of the programme.
- Relationships between the US and Australian Government and between ASC and EB could lead to an Australian/US nuclear agreement.
- The least technical risk would be to build the submarines overseas.
- The submarine could be consolidated at Osborne with the reactor compartment and secondary plant procured and supplied as complete packages in an otherwise Australian build.
- The infrastructure requirements will be very demanding and will involve working very closely with nuclear regulatory authorities and state and local government.
- Concerns within the general public will have to addressed carefully with full acceptance of an Australian nuclear power industry an essential prerequisite.