

might have been built into the submarine, but it is a small matter to cut the hull to provide access, and to re-weld it after system updating or substitution has taken place. It is all a matter of cost, and the UK government has not provided parliament the facts on which to base its decision.

Another major aspect addressed in the White Paper is the question of the manufacturing and skills base for the UK's ballistic missile submarines (SSBNs). A minimum rate, the 'drumbeat', is claimed necessary to maintain a healthy nuclear-submarine design and production base in the UK. The Royal Navy now operates the four Vanguard SSBNs and nine nuclear-powered attack submarines (SSNs; two Swiftsure and seven Trafalgar), with three Astute SSNs in the pipeline.

It is important to observe that the industry-demanded and government-accepted 'drumbeat' of every 22 months provides a steady-state submarine population of 16 submarines for a 30-year operating life, whereas for a 45-year operating life the drumbeat would yield 25 ships, and attendant higher staffing and operating requirements. If submarines were to be built with a 45-year operating life, then a replacement rate of one per three years would support a 15-sub navy, and one per four years an 11-sub navy. The industry-demanded building tempo and the government-set fleet size are fundamentally incompatible with a 45-year operating life, whatever the physical reality.

A 15-year life extension would delay the need for a decision by another 15 years, but a delay by as little as one year would be very valuable even if the life extension cannot at this point be confidently predicted. First, if parliament mandated a solid government assessment of the feasibility and cost comparison of a 15-year life extension, there is the strong possibility that such an extension would, on evidence, be deemed feasible and desirable. Second, a broader set of alternatives should be considered, rather than the strawmen set up in the UK White Paper.

In particular, it is striking that the government would propose operating the UK Vanguard-class submarines for another 20 years and then replacing them with four submarines that would each carry the same 16 Trident missiles, still loaded with only three warheads each, on average. Instead, the successor design might take advantage of the commitment of the UK government to have only 160 nuclear warheads for its submarines and consider seriously the possibility of a much smaller submarine with a much more flexible load of single-warhead missiles of the same range as Trident. In this way, there would not be the

Box 1 The real cost of replacing the Trident submarines

On 10 January 2007, three colleagues — each bringing different experience to the task — and I provided written evidence² to the Select Committee on Defence of the House of Commons for an open hearing on 23 January, well before the vote. My partners were Theodore A. Postol, a physicist who had studied basing options for the MX missile in the early 1980s (Reagan's 'Peacekeeper' intercontinental ballistic missile) and was then for some years Technical Advisor to the head of the US Navy — Chief of Naval Operations — at the time of the Trident programme initiation; Frank von Hippel, a physicist from Princeton University, who has studied nuclear power, fuel modification for nuclear submarines, and who served in the Office of Science and Technology Policy in the Executive Office of the President; and Philip E. Coyle, a mechanical engineer by training, with long experience with nuclear weapons at the Lawrence Livermore National Laboratory, who was head of operational test and evaluation for

the Defense Department in the Clinton Administration and whose responsibilities included a vast span of equipment and ordnance. As for myself, for many years I chaired for the President's Science Advisory Committee (under Presidents Kennedy, Johnson and Nixon), the Antisubmarine Aircraft Panel, the Naval Warfare Panel and the Military Aircraft Panel.

Regarding the cost associated with a delayed decision, we wrote in our written evidence: "The Prime Minister stated that the cost of building four replacement submarines would be £15–20 billion. The real discount rate used for UK indexed gilt-edged bonds by the UK Debt Management Office is 2.5 percent. A delay of this expenditure by 10–15 years would be worth about £5 billion. Alternatively, extending the lifetime of the submarines from 30 to 40 or 45 years would reduce the annual capital cost by £150–200 million per year. Obviously the possibility of such life extension is worth in-depth study."

operational inflexibility, if the need arose to use nuclear weapons, to find several targets for a given missile launch, or to waste two warheads by eliminating their nuclear yield on firing the missile. Although the displacement of the submarine would not be reduced by the full factor four implied by a comparison between the 12-warhead nominal capacity of the Trident missile and the three warheads actually loaded onto it, there would be at least a factor two reduction in displacement and comparable savings in cost.

Even though the alternatives considered in the UK White Paper included submarine-launched cruise missiles, an air-launched nuclear deterrent and ground-based nuclear missiles, the one that makes the most technical and strategic sense — submarines each with 48 single-warhead ballistic missiles — is nowhere in the list. It is not atypical of military programmes to provide such a set of seemingly exhaustive options, while not including the most attractive.

On 25 January 2007, the Minister of Defence, Des Browne, gave a public address at King's College London on the future of the UK nuclear deterrent. We had a brief public interchange at the meeting, in which Mr Browne indicated that his experts had told him that the "clock starts ticking" on the lifetime of a submarine when the

reactor first goes critical. Although this might be the case for some component of the nuclear submarine, it surely is not for most of those that experience wear-out. In considering the possibility of some system replacement, we must use a much more sophisticated approach to lifetime estimates or assessments. For instance, 'equivalent full-power hours' is a possibility for the reactor itself, embodying a measure of both fuel exhaustion and metal embrittlement.

Before the vote I touched on an approach important to the operation and renewal of the UK Trident force; I suggested a modern simulator of the Vanguard-class submarine that could be flexibly configured to represent precisely the specific submarine and its dynamic response to control inputs from the crew. Training could be more extensive and more realistic than in Vanguard itself, because the training could be extended to off-normal conditions that would be hazardous for the real submarine.

By 'modern simulator' I mean a mock-up submarine that incorporates the same appearance of consoles, gauges, monitors and control levers, knobs and wheels as the real submarine, although the entire system would be digital for economy and flexibility. Noise and vibration would be simulated as well. Not only would training be improved at reduced cost, but

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much of the at-sea training time for the actual submarine could be eliminated, together with the attendant wear and tear. Will the Royal Navy even evaluate such an approach if life extension is unacceptable because of industry pressures?

Although the House of Commons voted 409:161 in favour of renewing the Trident submarines, given the large number from his own party who voted against it, Tony Blair had to admit afterwards to the possibility of future discussions on Trident. Interestingly, that very day appeared an article by Alun Chalfont (chairman of Vickers in the 1980s, when the present fleet of Vanguard submarines was being built), entitled "Have we the skills to replace Trident?", in which he wrote:

"Although it was undoubtedly right to take the major decision now, Tony Blair was probably ultra-conservative when he wrote

in his foreword to the White Paper that, 'the present submarines will start to leave service in early 2020s'. In fact, there is no reason why the Vanguard submarine should not have a life expectancy of 45 years."

More broadly, the purpose of the UK SSBNs is evidently very different from what it was during the cold war, aside from the simplistic statement that it is to prevent the destruction of the country and to guarantee security. Against whom could the 'strategic nuclear deterrent' effectively be oriented? This is, of course, the central question, which is difficult to answer at a time of international confusion about the future of nuclear weapons. In a recent article⁵ former US secretaries of state Henry A. Kissinger and George P. Shultz, former Secretary of Defense William J. Perry, and former Senator Sam Nunn wrote, "Deterrence continues to be a relevant consideration

for many states with regard to threats from other states. But reliance on nuclear weapons for this purpose is becoming increasingly hazardous and decreasingly effective." They argue for "reassertion of the vision of a world free on nuclear weapons and practical measures toward achieving that goal..."

A decade delay in the Trident replacement decision might produce a clearer answer.

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