HM Government

Trident Alternatives Review

16 July 2013

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This review is not a statement of government policy. For the purposes of assessing potential alternative approaches to deterrence, officials have had to develop theoretical threats, capabilities and postures as part of their methodology. The inclusion of these theoretical propositions should not be taken as an endorsement from the Government.

The report is structured in two parts. Part 1 sets out an analysis of the alternative systems and postures which might be available to the UK in mid-late 2030s and which could be expected to cost no more to procure than a like-for-like replacement of the current Trident-based submarine deterrent. Part 2 addresses the deliverability of the shortlisted options, including detailed costs, risks and timescales associated with the various alternative systems and postures.

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This information is also available on the Cabinet Office website:
www.gov.uk/government/organisations/cabinet-office

Alternative format versions of this report are available on request from the Cabinet Office, 70 Whitehall, London SW1A 2AS.

Contents

Executive Summary

1. Deterrence rests on the notion of 'unacceptable loss' - the ability to inflict a level of damage that a potential aggressor would judge outweighed any benefit they might gain by a particular course of action. It is not unique to nuclear weapons but nuclear deterrence has a unique role in deterring extreme threats to the UK's vital interests which cannot be countered by other means.

2. The credibility of the UK's deterrent is crucial; a potential aggressor needs to believe that the UK has the capability and resolve to deliver 'unacceptable loss' in response to an actual or imminent attack.

3. The UK Government's nuclear posture and commitment to the Trident system is clear and this review does not affect it. However, the Coalition Agreement set out the terms of a Trident Alternatives review – an exercise to establish if other postures or weapons systems might deliver a credible alternative nuclear deterrent. The Trident Alternatives review was tasked to answer three questions:

- Are there credible alternatives to a submarine-based deterrent?
- Are there credible submarine-based alternatives to the current proposal, eg Astute with cruise missiles?
- Are there alternative nuclear postures, ie non-CASD, which could maintain credibility?

4. As directed, the analysis makes an assessment of alternative systems and postures (Part 1), and how they could be delivered, including operational and programmatic feasibility, cost and risk (Part 2) but does not offer recommendations. It does not produce a comparison of like-for-like capability.

Deterrence: Role and Credibility

5. The review considered the timeframe out to 2060. The UK's deterrent was assumed to remain a political tool of last resort rather than a war fighting capability. For the purposes of the review, the requirement, which is **explicitly not** a statement of UK policy, was summarised as:

"A minimum nuclear deterrent capability that, during a crisis, is able to deliver at short notice a nuclear strike against a range of targets at an appropriate scale and with very high confidence."

6. Although only the Prime Minister can authorise its use, the UK's deterrent is made available to NATO as a contribution to the Alliance's collective deterrence. The study therefore considered situations in which the UK's nuclear weapons made a contribution to the overall deterrent effect, as well as looking at scenarios in which the UK was assumed to act alone.

7. Credibility can be summarised through five criteria: readiness, reach, resolve, survivability/invulnerability and destructive power. The UK's operational independence is also an important factor in the credibility of our deterrent. The level of damage that a deterrent needs to be capable of delivering is not absolute; it will vary depending on how critical a target the aggressor perceives the UK to be: if they judge attacking the UK is essential to their national survival, deterring such an attack is likely to require a system capable of delivering more damage than if the UK was a discretionary target. It does not depend on the scale of military capability that a potential aggressor possesses. For that reason, the study did not set a minimum necessary capability, but aimed to show what each alternative system might be capable of delivering.

Alternative Systems & Performance

8. The analysis identified specific combinations of platform (ie ship, aircraft etc), delivery vehicle (missile or bomb) and warhead design as meriting detailed consideration. Particular attention was paid to the performance characteristics of cruise missiles in order to determine the combination of stealth, speed, range and numbers most likely to overcome an adversary's defences. The final analysis was focused on two types of potential future cruise missiles: a subsonic stealthy cruise missile and a supersonic cruise missile, each carrying one nuclear warhead per missile. The ballistic missile was assumed to be Trident D5 carrying multiple nuclear warheads per missile.

9. For platforms, the analysis looked at a large aircraft, fast jets, surface ships, and three types of submarine: 'hunter-killer' (known as SSNs), ballistic missile submarines (known as SSBNs) and a variant of an SSBN that could fire either type of missile (known as an SSGN). The SSN option considered two variants: one based on the current Astute-class submarines, with horizontal launch tubes and only minimal modifications, and a new design, with vertical launch tubes and more extensive modifications. The analysis also modelled a land silo firing the Trident D5 missile, although the silo option was subsequently discounted during the review.

10. For the warhead, all the shortlisted delivery vehicles were judged able to accommodate a warhead capable of delivering explosive power comparable to the current UK warhead. Different warhead designs are needed for ballistic missiles, for cruise missiles and for free-fall bombs, which makes a very significant difference to the overall cost, time and technical risk of the different systems. Four different designs were considered according to the type of missile/platform it would deploy on.

11. The performance and vulnerability of the systems was modelled in scenarios chosen to test effectiveness against a range of targets and defensive systems. Analysis was focused on options judged likely to be affordable. Some systems were able to deter large states with sophisticated defences; others could only make a contribution to deterrence of such states in alliance with other nuclear weapon states.

Alternative Postures

12. A range of possible alternative postures was developed for the purposes of this review, noting that the inherent characteristics of the alternative systems influenced the extent to which each of them could affordably achieve or sustain a global high readiness posture. These postures therefore assumed that some warning would be likely prior to any threat or actual attack on the UK; when there is no hostile backdrop it was assumed that a no-notice surprise attack against the UK would be highly unlikely, but when there is hostility it was assumed that the warning time could be very short. The generic postures are:

a) **Continuous deterrence**. A continuous deterrent presence capable of causing the required level of damage and sustained for the life of the system, representing as close as each system can get to an assured second strike capability. For non-ballistic missile systems, limitations in range mean that this could only be focused against a specific adversary.

b) **'Focused deterrence'**. This posture would be maintained for a specific period and focused against a specific adversary, although for ballistic missile systems their inherent range would also enable near-global deterrence. At all other times, the system would adopt a reduced readiness level.

c) **'Sustained deterrence'**. Deployment of some deterrent capability would be maintained, but not necessarily close to a potential missile launch point. Deployment would be covert (submarines), ambiguous (ship) or dispersed (aircraft) to make it difficult for a potential adversary to predict when they might be within reach of the system.

d) **'Responsive deterrence'**. As for 'Sustained deterrence' but gaps between deployments would be permitted. The frequency and length of deployment would be irregular so that a potential adversary cannot predict when and for how long a gap in deployment might occur.

e) **'Preserved deterrence'**. This posture would only be adopted at low readiness. No deterrent platforms would be regularly deployed but the UK would maintain the ability to deploy if the context changed. The platforms might be deployed without nuclear weapons for training purposes and could conduct conventional duties as long as they could be made available for deterrent duties if required.

13. An operating posture has an effect on four of the five criteria relating to deterrence credibility: readiness, reach, resolve and survivability/invulnerability. These come together as an assured ability to launch a second strike (ie to respond with nuclear weapons having first been attacked by an aggressor with their nuclear weapons). A key difference between the different systems and postures is their vulnerability and, therefore, the level of assurance each has of providing a credible assured second strike capability.

14. **Ballistic missile systems:** The highest level of assurance the UK can attain with a single deterrent system is provided by SSBN submarines operating a continuous at sea deterrence posture. The range of the Trident missile allows the submarine to operate covertly from anywhere, only revealing its position when it launches a missile. Adopting a non-continuous posture introduces some vulnerability due to the potential ability of an adversary to target the UK during a period when no boat is covertly deployed. That said, a non-continuous posture would aim to have gaps in deployment only when the UK assessed the likelihood of a no-notice attack to be extremely low. The possible (but unquantifiable) risks are that the UK could miss indicators and warnings of hostile intent or face a very extended period of high tension, forcing a gap in deployment. A ballistic missile silo is significantly more vulnerable simply because its location will be known by an adversary, although this can be partially mitigated by having more than one silo and/or adopting a 'launch-on-warning' posture in times of hostility (ie: that UK missiles would launch as soon as an incoming attack had been detected). This vulnerability, and the risks associated with a hair-trigger launch posture, were key factors in the decision not to pursue detailed analysis of the silo option.

15. **Cruise missile systems:** For the maritime cruise missile options, the submarines are the least vulnerable because they can operate covertly until the launch of the missile. However, once it has revealed its position, the fact that the submarine will be relatively close to an aggressor's territory means it will potentially be vulnerable to attack. A surface ship is the most vulnerable because it is overt and needs to get just as close as an SSN to an aggressor's territory before launching a cruise missile, which combine to give an aggressor plenty of time to locate, track and engage it and any supporting forces. The vulnerability of the aircraft options are largely dependent on an aggressor's ability to target their location (carrier or airbase) before sufficient aircraft are launched. Some states already have that capability; others may develop it as ballistic missiles and satellite targeting systems proliferate. The risk might be partially mitigated by locating the aircraft at multiple bases (particularly if some are overseas) so that an aggressor would need to attack more than one airbase (and potentially a third party) at the same time to be confident of destroying the UK's capability.

16. The inherent characteristics of cruise missiles introduce further potential constraints. On targeting options, it could possibly leave geographic 'sanctuaries' that the UK, acting alone, could not reach. Also, while ballistic missile defence capabilities are likely to improve and

proliferate, air and cruise missile defences are cheaper and more easily procured internationally. Maintaining the same level of assurance that the UK deterrent can overcome an adversary's defences is therefore likely to be harder with a cruise missile-based system.

Delivering alternative capabilities

17. An assessment of the UK's ability to develop and deliver the alternative options showed that design and development of the warhead and its integration into a cruise missile or bomb would be the critical challenge. The UK nuclear warhead programme is highly optimised around producing and maintaining warheads for the Trident missile. Moving to an alternative would add technical, financial and schedule risk to the programme, not least because the Atomic Weapons Establishment (AWE) would still need to maintain the Trident warhead stockpile in parallel with designing and manufacturing an alternative.

18. Experts judge that it is likely to take 17 years to design, develop, certify and produce a ballistic missile-based thermonuclear warhead, should one be required. This is based on AWE taking a relatively well-understood concept through to the production of the first fully-certified warhead, with collaboration with the US on the non-nuclear components. Without live nuclear testing, the programme relies heavily on computer-based modelling and extensive hydrodynamic trials. These experiments take considerable time to conduct and form the critical path over the first decade or so. At this point, once the design is 'frozen', a complex series of tests is then conducted to certify its safety and performance, before proceeding to manufacture and assembly. Delivering a thermonuclear warhead for an alternative system would take longer. The starting point would be less mature, even if building upon a previous design (as assumed for this review). The AWE facilities, techniques and expertise would need to be adapted; new non-nuclear components, different from those we procure today from the US would need to be developed (in the current absence of a similar US programme, this is assumed to be mostly on our own); and developing the delivery vehicle in parallel risks extending the programme, in contrast with Trident, for which the missile and its environmental data is well-known. Consequently experts assess that, starting promptly in 2016, an initial warhead capability integrated into a cruise missile might be delivered (with some risk) by about 2040, a timescale of 24 years.

19. In theory, an accelerated warhead programme might be possible but it would come at high risk and would need to be driven as a UK national imperative. To deliver an initial capability by about 2035, non-nuclear components would need to be available by 2017 (an extremely challenging task). The overall judgment reached therefore was that delivering an initial warhead capability no earlier than 2040 was the realistic approach upon which to base the final analysis.

20. Crucially, this warhead timescale is judged to be longer than the Vanguard-class SSBN submarines can safely be operated. The third and fourth Vanguard-class submarines are planned to leave service well before 2040, after considerable planned life extensions and expert judgment is that their lives could not be stretched further without extremely high-risk re-construction of the submarines. The final stages of the review therefore focused on bridging the 'gap' by procuring a 2 boat Successor SSBN fleet until an alternative system was in service. Those options that could meet this 2040 date and which were judged to be most credible were then costed and compared against the cost of procuring 3 or 4 SSBNs with ballistic missiles: Large Aircraft with stealthy cruise missiles; fast jet with supersonic cruise missiles; SSN(Vertical Launch) with stealthy cruise missiles.

Costs

21. Cost estimates were developed to include the development, procurement and in-service support of a new system (platforms, missiles, warheads and any new infrastructure). The costs

of transitioning from the current system were also estimated, including the costs of procuring 2 x Successor SSBN until a cruise missile-based system was available. Common costs that did not vary between any of the options, such as the operating costs of AWE, were excluded from all estimates and, as such, the costs presented in this report cannot be directly compared with costs published elsewhere.

22. The costs of the cruise missile options are based on the number of platforms that could operate a 'Preserved' posture in peacetime, with the ability to surge to a 'Focused' deterrence posture and sustain it for a finite period before reverting back to 'Preserved' and recuperating. Crucially, the costs assume the use of Forward Operating Bases for crew changeover, food replenishment and minor repairs (but not for handling nuclear warheads) for circumstances in which the system might have to be deployed and sustained far from the UK. They cover: 6 x Large Aircraft with stealthy cruise missiles; 36 x JSF with supersonic cruise missiles; 5 x SSN(Vertical Launch) with stealthy cruise missiles; and an additional option of only procuring 3 x SSN(Vertical Launch) and converting the 2 x Successor boats to fire cruise missiles once they are no longer required to perform ballistic missile-based deterrence.

23. The costs of the alternative options are set out alongside the cost estimates for procuring and supporting a 4 boat fleet and a 3 boat fleet of Successor SSBNs. **This is not a comparison of equivalent constant capability**. Rather, the performance levels and vulnerability of the options differ, as do the postures that the cruise missile options could sustain compared with the continuous posture that only the 4-boat SSBN option could sustain.

24. Chart A sets out the Net Present Value for the options; these are not the costs in cash terms but are discounted to reflect the relative value of money spent at different times. This is a standard cost comparison tool and gives more weight to costs which arise earlier. The estimates are for comparison purposes only: they do not have the fidelity necessary to make an investment decision or to set budgets. The difficulty in quantifying the risks and uncertainties associated with the alternative systems means that there are varying degrees of confidence in the cost estimates.

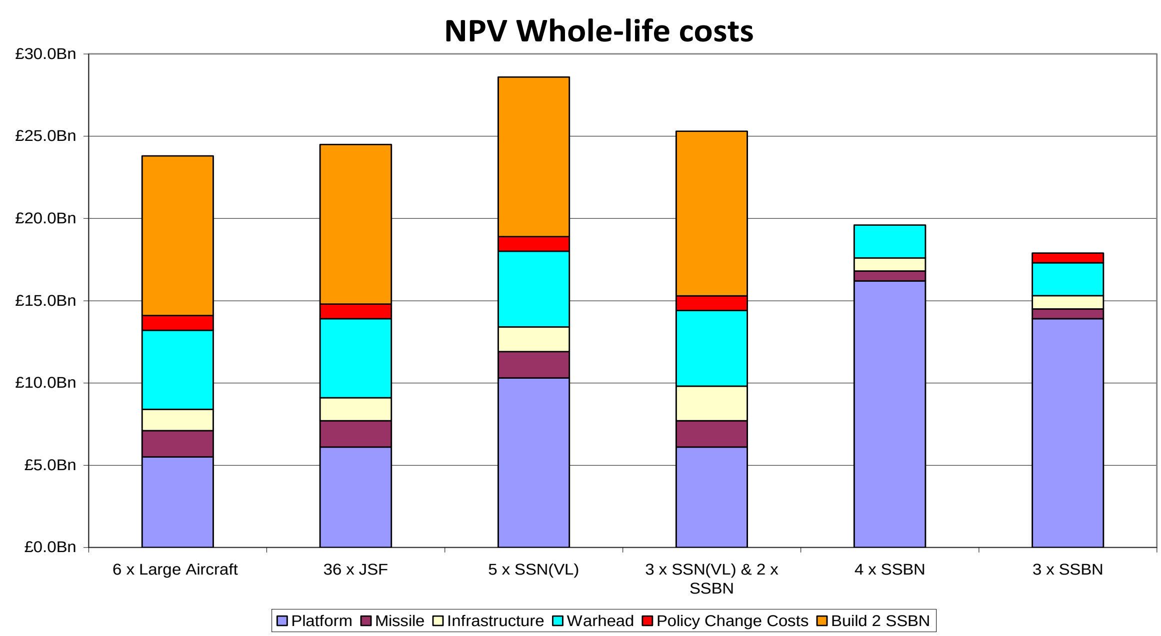

Chart A – Net Present Value comparison and breakdown (50% confidence)

25. The cost driver for the Trident missile options is the construction of the SSBN submarines: we already have the missiles and the cost of designing and producing a new Trident warhead is judged smaller and less risky than any other option. **The cost driver for all non-Trident based options is the warhead**. Not only is the cost of a new warhead for a cruise missile or free-fall bomb very considerable (£8-10Bn, compared to £4Bn for a new Trident warhead, all at 50% confidence), but the length of time it is judged to take means that 2 new Successor SSBNs need to be constructed to fill the gap before a cruise-based deterrent is available. It is the need for these 2 Successor SSBNs that makes the cost of the alternatives more expensive overall than a 3 or 4-boat Successor SSBN fleet. Even if they were not needed, all options considered other than the Successor options would require additional submarine orders to avoid the loss of the UK's sovereign capability to build future submarines.

26. **Dual-capable:** All of the options costed above assume a dedicated deterrent fleet: a larger fleet would be required for a single dual-capable fleet that is able to perform the equivalent range of conventional and deterrent tasks. Calculation of this is complex and depends on what tasks would need to be conducted in parallel and on how much risk the UK was prepared to take against each task. For example, a dual-capable fast jet fleet would probably need to be deployed and ready to conduct (or be conducting) conventional strike operations at the same time as maintaining enough platforms and crews at readiness to deliver a nuclear strike. A dual-capable SSN fleet is likely to need to conduct conventional tasks during periods of heightened tension (eg: anti-submarine warfare in support of a maritime task group). There would be very limited ability (if any) for the nuclear-armed boats to conduct these conventional tasks.

27. Analysis of dual-capable fleet sizes was beyond the scope of this review. However, a small study was conducted that showed that a fleet of between 10 and 18 SSNs might be required, depending on how much risk it was judged acceptable to take. This compares to the current position where the MOD has a total of 4 x SSBN and 7 x SSN. For costing purposes, dual-capable fleets of 12 x SSN(Vertical Launch) and, alternatively, 10 x SSN(Vertical Launch) + 2 x Successor converted to launch cruise missiles were analysed. In the case of the 12 x SSN(Vertical Launch) option, it was assumed that the two additional SSBN procured to bridge the gap in capability would be retired once the SSN capability was available. Chart B sets out the comparison between the cost of the dual-capable fleets and the cost of fleets of 3 or 4 SSBN plus 7 x SSN.

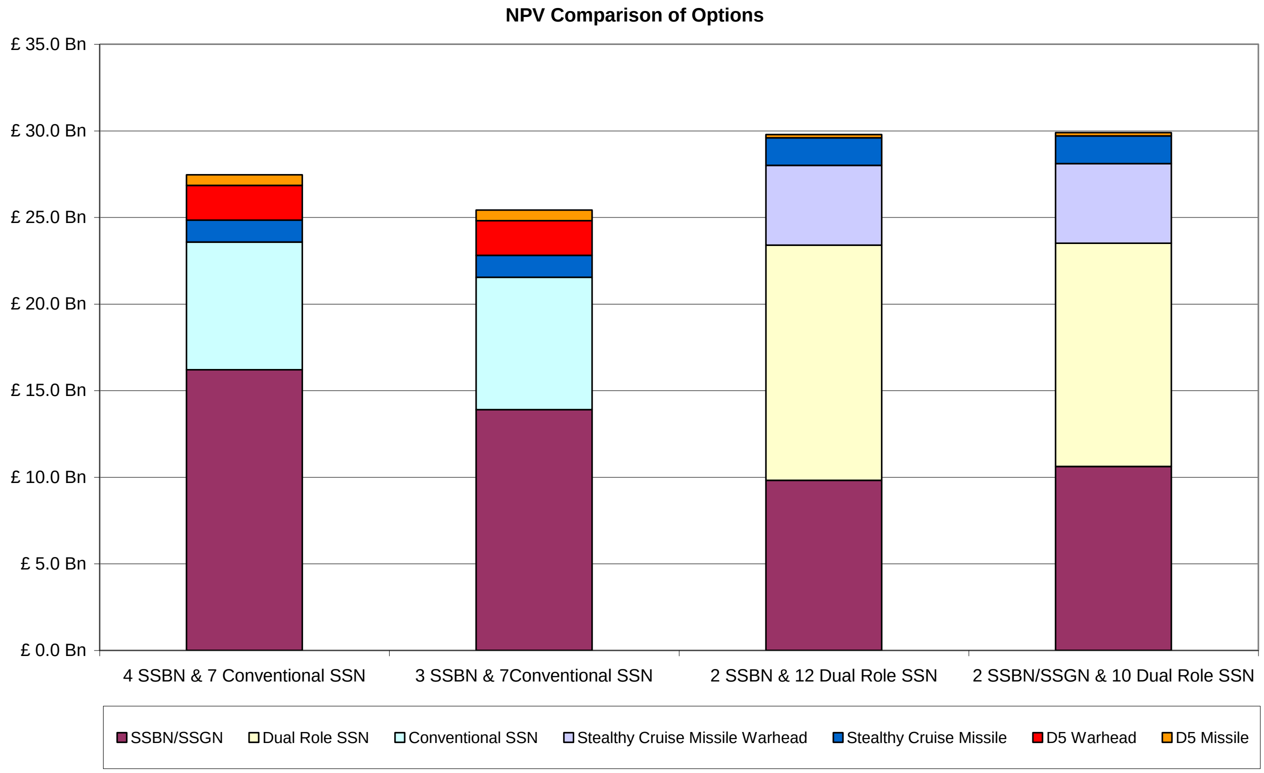

Chart B – NPV comparison of dual-capable SSN fleet vs separate SSBN and SSN fleets (50% confidence)

International reaction

28. Any change to the UK's nuclear deterrent system and/or its posture may have the potential to impact not only on the credibility of the deterrent, but also on our wider national interests and foreign relations. The precise short-term impact of how any change is received would depend on the type of new system/posture and, crucially, on whether it represented a diminution in the UK's associated level of deterrent ambition. Perceptions of the UK are driven by a broad range of factors, including the UK's economic standing, its history, cultural ties and the UK's activist role in international organisations. The level of investment in conventional capabilities (and a continued willingness to deploy them), will also be a significant factor in how we are perceived on wider defence and security issues, alongside our nuclear capability and posture. An alternative system or posture with a reduced level of assurance and/or capability may increase our dependence on allies for security and could, potentially, introduce an increased risk of miscommunication or miscalculation with an adversary during a crisis.

Legal position

29. The UK's key legal obligations in relation to nuclear weapons are set out under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and the Comprehensive Nuclear Test Ban Treaty (CTBT), although the latter has not yet entered into force. The UK's position remains that pursuit of a renewal of Trident or a new system does not breach the NPT: Article VI contains no specific steps and no timetable; the obligation is to negotiate not to disarm unilaterally and renewal/replacement is not prohibited by the NPT in view of the fact that there is no treaty on general disarmament.

30. Collaboration with another state on a nuclear-capable delivery vehicle (eg a cruise missile) would not be constrained by any UK legal obligations (the NPT does not preclude such cooperation as a missile is not a nuclear weapon) but could be covered by that state's obligations under the Missile Technology Control Regime (MTCR). Much would depend on the view of any partner on what level of collaboration would be consistent with their legal obligations and political willingness. We have not discussed alternative nuclear programmes with any state and their agreement cannot be assumed.

31. Operating a cruise missile-based system is likely to require the UK to deploy nuclear capable systems in different geographical regions than it does today, potentially requiring third party agreement. Any uncertainty about the UK's sovereign ability to use its deterrent would diminish the deterrent effect. There are no legal constraints in relation to international airspace and international waters. Forward basing is not permissible if the proposed location is within a Nuclear Weapon Free Zone.

Conclusion

32. The analysis has shown that there are alternatives to Trident that would enable the UK to be capable of inflicting significant damage such that most potential adversaries around the world would be deterred. It also shows that there are alternative non-continuous postures (akin to how we operate conventional military assets) that could be adopted, including by SSBNs, which would aim to be at reduced readiness only when the UK assesses the threat of a no-notice pre-emptive attack to be low. None of these alternative systems and postures offers the same degree of resilience as the current posture of Continuous at Sea Deterrence, nor could they guarantee a prompt response in all circumstances. Whether the cruise missile-based systems amount to a credible alternative to Trident would depend on a political judgment on whether the UK was prepared to accept:

- a reduction in whom it could deter unilaterally in all circumstances (major nuclear powers might only be deterred if UK acted with its nuclear allies);
- a significant increase in the vulnerability of any alternative system compared with an SSBN (as a result of not being able to deploy covertly and/or not being able to sustain an assured second strike capability through-life); and
- significantly increased operational complexity, especially if Forward Operating Bases were required.

33. Choosing to operate the SSBNs in a non-continuous posture depends upon the level of political confidence that:

- a potential aggressor would not launch a no-notice pre-emptive attack when the UK was at a lower posture with no boat deployed;
- that, with sufficient warning, the UK could re-constitute back-to-back patrolling before a potential period of heightened tension arises (covering the availability of equipment and suitably trained and motivated civilian, military and industrial personnel); and
- that such back-to-back patrols could then be sustained long enough to cover any emergent crisis.

34. The costs of delivering an alternative system could theoretically have been cheaper than procuring a like-for-like renewal of Trident were it not for timing and the fact that the UK deterrent infrastructure is finely tuned to support a submarine-based Trident system. In particular, the time it would take to develop a new warhead (itself a costly and high risk exercise) is judged to be longer than the current Vanguard-class submarines can safely be

operated. Bridging the resulting gap in deterrence capability would involve procuring two Successor SSBNs so that a Trident-based deterrent remains available until at least 2040. Doing that at the same time as investing in the development of a new warhead, new missile, new platform and new infrastructure means that transitioning to any of the realistic alternative systems is now more expensive than a 3 or 4-boat Successor SSBN fleet.

Part One

Part One sets out concepts for alternative systems and postures, including the potential comparative performance and number of each that might be required to meet various deterrence scenarios, alongside the associated high-level policy and legal implications.

Part Two analyses and costs the major technical, industrial and programmatic issues that could be associated with designing, developing, delivering and sustaining each of the representative systems and supporting infrastructure and personnel.

Chapter One: Credibility and Constraints

1.1 In order to help produce a shortlist of potentially credible nuclear deterrent systems, it is necessary first to scope out the role a system might play in the UK's wider defence and national security policy. To do this, the study considered from first principles potential nuclear doctrine, performance requirements and relevant legal and policy considerations.

1.2 The study looked out to 2060 because any system to replace the current Vanguard-class submarines needs to enter service in the 2030s if we are to avoid a complete gap in capability, and needs to remain effective for 25-30 years to be a reasonable return on the investment. While it is impossible accurately to predict what the future will look like out to 2060, the UK's future policy and doctrine for its nuclear deterrent will reflect the political, security and legal context at the time.

Nuclear Doctrine

1.3 The fundamental and enduring premise is that **the UK deterrent will remain a political tool of last resort** rather than a war fighting capability; its use is only to be considered in the most extreme circumstances.

1.4 For the purposes of the review, the UK's deterrent is assumed to have two roles:

- Deterrence. To deter extreme threats to the UK and to its vital interests, including those of its allies, including the UK being coerced or blackmailed to act against its strategic interests and where such coercion cannot be countered by other means; and, in the context of the 'grand bargain' underpinning the nuclear Non-Proliferation Treaty, to deter large-scale conflict and thereby to contribute to maintaining global stability.

- Restoring deterrence. As a last resort where deterrence has failed, the employment of UK nuclear weapons to prevent a situation escalating to the point where national survival is at stake.

Deterrence Credibility

1.5 Deterrence rests on the notion of "unacceptable loss" - the ability to inflict a level of damage that a potential aggressor would judge outweighed any benefit they might gain by a particular course of action. The concept is not unique to nuclear weapons. The credibility of the UK's nuclear deterrent is crucial; the potential aggressor needs to believe that the UK has the capability to deliver such damage, having overcome any defensive systems and that the UK has the political and military resolve to employ its nuclear weapons in response to an actual or imminent attack. It is also important that a deterrent system is safe and secure and can be afforded in the long term. Communicating the UK's policy intent and capability is vital.

1.6 The level of damage that the UK needs to be capable of inflicting is not absolute; it will vary depending on how critical a target the UK is perceived to be: if attacking the UK is essential to achieving an adversary's goal, deterring is likely to require a system capable of delivering greater damage than if the UK was a discretionary target. It does not depend on the scale of military capability that a potential aggressor possesses. For that reason, the study did not set a level of damage that a system must be able to cause in order to be 'credible'. Rather, the analysis aimed to show what level of capability could be delivered by different systems that are likely to be affordable.

Extended and Collective Deterrence

1.7 Although only the Prime Minister can authorise its use, the UK's deterrent is made available to NATO as a contribution to the Alliance's collective deterrence. This complicates a potential adversary's calculations by providing more than one centre of nuclear decision-making. The study therefore considered situations in which the UK's nuclear weapons made a contribution to the overall deterrence effect, as well as looking at scenarios in which the UK was assumed to act alone.

Legal Considerations

1.8 The UK's legal obligations in relation to the ownership of nuclear weapons are set out under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and are described in Chapter 4. There is no special legal regime that applies to the use of nuclear weapons. Although the first Additional Protocol to the Geneva Conventions only applies to conventional weapons, customary international law of armed conflict applies to nuclear weapons and, as a consequence, the main legal principles governing the use of nuclear weapons are not materially different from those governing conventional warfare. The main principles regulating the use of force and the conduct of hostilities are military necessity, humanity, distinction, and proportionality. It is difficult to predict what the future legal framework might look like or how, in extreme situations, political judgements might be made. For the purposes of this study, it is assumed that the fundamental principles of current international law endure.

Assumptions and Constraints

1.9 The factors described above were distilled into a set of baseline assumptions, performance requirements and constraints. The key overarching requirement, which did not aim to replicate existing policy, was:

> **"A minimum nuclear deterrent capability that, during a crisis, is able to deliver at short notice a nuclear strike against a range of targets at an appropriate scale and with very high confidence."**

The study deliberately did not define "minimum", "short notice", "scale" or "very high confidence" as that could have overly-constrained the list of system options for analysis.

1.10 The study did not set a strict date by when the capability needed to enter service, as to do so would pre-judge other factors to be assessed by the review, including the potential to adopt postures other than Continuous At Sea Deterrence. However, technologies that could not be ready for a nominal in service date of around 2035 were excluded.

Scenarios

1.11 In order to assess the effectiveness of the systems in deterring potential adversaries, a range of scenarios was developed. These recognised that systems with a lower level of capability might require an alliance with other nuclear weapon states to enable the UK to contribute to the overall deterrence effect against the most capable potential adversaries. An operational analysis model was then used to calculate the probability that the given level of damage would be achieved. The number of missiles/platforms required was also sensitive to the distance between targets within each scenario: each cruise missile carries a single warhead; a Trident missile has multiple warheads which it can deliver either all on the same target or on a range of targets. A range of distances between targets was therefore modelled to assess the effectiveness of each system against differing geographic constraints.

Chapter Two: System Options

System Options

2.1 The Trident Alternatives study reviewed the options generated for the 2006 White Paper and filtered them against the assumptions and constraints derived from the work set out in Chapter 1. This filtering included the following key exclusions:

a. Space-based platforms and fixed maritime options tethered to the sea-bed were excluded based on legal (international treaty) considerations.

b. Hand-delivered systems were excluded as they would not meet several constraints, including in particular credibility and absolute range.

c. Short-range delivery vehicles launched from fixed platforms were excluded as they would not meet the absolute range requirement.

d. Unmanned Air Vehicles were excluded due to concerns about maintaining positive political control and about potential legal issues surrounding the development of unmanned nuclear weapon systems.

e. Helicopters and dirigibles were excluded because of technical feasibility and credibility issues.

f. Large aircraft with either ballistic missiles or hypersonic glide vehicles carried by ballistic missiles were excluded due to the likely costs and risks associated with integrating those missiles with the platform.

g. Ships with ballistic missiles or hypersonic glide vehicles were excluded as the required size of vessel and of its escort force was likely to cost as much as submarine-based options, but to be significantly more vulnerable.

2.2 This process resulted in a shorter list of platform and delivery vehicle options discussed below, some of which were set aside during subsequent iterations of performance and technical risk analysis.

Platforms

2.3 **Large aircraft:** Initially, a modified civilian aircraft or a military stealth bomber were considered. Subsequent analysis showed that attempting to modify a civilian aircraft was likely to be a very high risk option: such aircraft are designed to hold cargo/passengers safely and are unlikely to be able easily to accommodate the insertion of a bomb bay, let alone the sudden change in centre of gravity when firing missiles. A stealth bomber was judged to be significantly more expensive and the potential need for (and cost of) supporting aircraft to defend it would need to be considered should counter-stealth technology develop over the life of the system. These specific options were therefore set aside. Instead, analysis focused on a generic military aircraft. In reality, were this option to be pursued, much more work would be required in partnership with industry to determine how to deliver the most cost effective platform.

2.4 **Fast Jet:** Joint Strike Fighter (JSF) and the French Rafale aircraft were considered, but Rafale’s incompatibility with UK aircraft carriers would have been a significant cost driver so only JSF was taken forward in the later modelling.

2.5 **Low-orbit vehicle:** Several future concepts were considered to see if they would be suitable platforms/delivery vehicles: potential commercial space ventures ; a Fractional Orbital Bombardment System (a concept designed by the Soviet Union as a ballistic missile system that achieves orbital trajectory before de-orbiting the final stage of the missile); and a future trans-atmospheric bomber concept . Each of these concepts was considered to be too risky and expensive for conversion to a nuclear weapons platform to merit further detailed consideration.

2.6 **Maritime surface vessels:** Initially, a Type 45 Destroyer was modelled as a medium-sized ship. Later analysis used the Type 26 Frigate on programmatic grounds (if aiming to deliver platforms in the early 2030s it would be more feasible to integrate nuclear-capable features into the future Type 26 programme than attempting to retro-fit what, by then, would be ageing Type 45 platforms). The Queen Elizabeth class carrier was modelled as the platform for the Fast Jet option.

2.7 **Submarines:** For the purposes of the review, three broad categories of submarine were considered: ‘hunter-killer’ (known as SSNs), which have several military roles, one of which is the ability to fire small numbers of cruise missiles; ballistic missile submarines (known as SSBNs), whose only role is to fire ballistic missiles with nuclear warheads; and a hybrid (known as SSGNs), which are SSBNs modified so that they can fire large numbers of cruise missiles (either instead of or as well as ballistic missiles). Two variants were considered for the SSN option: one based on the current Astute-class submarines, with horizontal launch tubes and only minimal modifications; and a new design with vertical launch tubes and a more extensive range of modifications. The horizontal launch variant was assumed to fire cruise missiles that fit the existing torpedo tubes, while the vertical launch version was assumed to be able to accommodate larger missiles (which can therefore be faster and/or have a longer range). The SSBN option is the Successor submarine currently undergoing its assessment phase before the main investment decision in 2016. An SSGN option was also considered, that is Successor but with modifications to allow it to fire Cruise Missiles from the Common Missile Compartment. The wholly SSGN option was subsequently discounted on cost grounds (building Successor SSBNs, then modifying them to fire cruise missiles must cost more than just building Successor to fire the existing Trident missiles). A mixed Successor/SSGN option was subsequently considered as an option to facilitate the transition to a fleet of dual-capable SSN submarines with vertical-launch cruise missiles.

2.8 **Silo:** The 2006 analysis determined that the infrastructure and land requirements made a silo option prohibitively expensive, because it assumed that a very large physical footprint was required. To avoid this, an option was modelled based on a smaller physical footprint, rather than a very large distributed set of missile silos. This produces a reduced resilience to attack, which could be partially mitigated by having two or more sites at distance from each other.

2.9 **Mobile ballistic missile launcher:** The UK has no previous experience of such systems and there are none in service in the US or in France. The option was therefore discounted due to the high technical and cost risk associated with an indigenous development programme as well as the operational risks associated with protecting, basing and moving such a platform within the UK.

Delivery Vehicles

2.10 A number of future cruise missile concepts were considered, each of which carry a single warhead. These ranged from subsonic options, similar to the existing Tomahawk Land Attack Missile and Storm Shadow missile, through to concepts for stealthy subsonic, supersonic and hypersonic missiles with better performance (but much higher technical risk). Analysis considered how the various designs could be adapted to fit the various platform options; the most significant space constraints were posed by the torpedo tubes in the existing Astute submarine design and the internal weapon bays in the fast jet. In addition, a number of non-cruise missile options were considered, including free fall bombs, ballistic missiles and hypersonic glide vehicles that are boosted by ballistic missiles.

2.11 **Cruise missiles (CM):** Cruise missiles are 'air breathing' missiles that are designed to fly at fixed altitudes and speeds, thereby enabling their fuel consumption to be minimised, and, by extension, significantly increasing their operational range. Three speed ranges were considered: subsonic (slower than the speed of sound); supersonic (faster than the speed of sound); and hypersonic (more than five times faster than the speed of sound). In order for a cruise missile's engine to function, it needs to be travelling at/near its design speed, which means that if launching from a static/slow platform a rocket booster is required to get the missile up to speed, which is then discarded. The faster the cruise missile, the larger the booster (i.e. a hypersonic CM would need a much larger rocket booster than a subsonic CM). The subsonic, supersonic, and hypersonic CMs considered are set out below.

2.12 **Subsonic cruise missiles:** A number of subsonic cruise missiles were modelled, each with varying degrees of stealth that it might be possible to deliver in the 2030s. In particular a modernised stealthy Tomahawk-like weapon was modelled with all of the platform options. Modern 'low observable' missile concepts were also modelled, representing what industry might be able to produce within the 2035 timeframe. However, the stealthy shaping of the design limited its ability to be scaled to fit torpedo tubes and the fast jet's internal bays without sacrificing considerable range and/or sufficient space for a viable nuclear warhead. Following extensive modelling of these missiles with the platforms in various configurations of stealth and range, the review focused on a single very stealthy concept for all platform options with the best range deemed to be achievable, albeit with considerable technical challenge, by 2035 (referred to as Stealthy Cruise Missile (SCM) throughout this report).

2.13 **Supersonic cruise missiles:** Several supersonic missiles were modelled, representing, broadly, what it might be possible to develop. While their dimensions had the advantage of allowing integration with all platform options, subsequent analysis confirmed that the range would place the platforms in particularly vulnerable positions close to any adversary that they were seeking to deter, and in some circumstances out of range of any targets. As such, a supersonic missile was taken forward to the final analysis with the fast jet only, due to that platform's assessed ability to penetrate defensive systems.

2.14 A much larger concept, Boosted Supersonic Missile (BSM), with considerably greater range, was also considered but was found to be unsuitable for the maritime platforms and the fast jet. Subsequent technical analysis concluded that the UK could not feasibly deliver this missile concept integrated with a large aircraft before the 2040s, let alone consider the integration of a nuclear warhead to this timescale. It was therefore parked from the final analysis.

2.15 **Hypersonic cruise missiles:** The review also considered the concept of a boosted hypersonic cruise missile (BHM). After scaling, two missiles might have been able to fit within the large aircraft but, regardless of the extreme technical challenge involved in the UK developing a hypersonic missile, this was discounted due to the considerable number of platforms (and therefore cost) that would be required to provide the necessary levels of damage.

2.16 **Hyper Glide Vehicles (HGV):** HGVs are arguably the most advanced strategic delivery systems currently under development. HGVs are boosted into space by the same type of rocket boosters used by a ballistic missile, but are powered back towards the atmosphere before being released, and then gliding through the upper atmosphere at extremely high speed. They then 'dive' onto their target with very high accuracy. For modelling purposes a range of concepts were considered but discarded from further analysis due to the technical challenge of the UK developing one for nuclear use.

2.17 **Ballistic Missiles (BM):** Ballistic missiles perform a guided rocket boost into space before releasing their payload onto a ballistic trajectory early on in flight (i.e. letting the payload 'fall' through space). This 'throwing' of the payload onto a high arc gives ballistic missiles long range (circa 10000km). The re-entry vehicles (the payload) then fall through the atmosphere at high speed, requiring advanced defences to neutralise them. Given current UK-US arrangements for the Trident D5 ballistic missile and our knowledge of and experience with this system, it was decided only to model the D5 in this review.

2.18 **Free Fall Bomb:** For modelling purposes a solution based upon the WE177, updated to modern safety standards, was used (see below for discussion on warhead options).

Warhead

2.19 Having eliminated those missile options that could not safely accommodate a nuclear warhead, the remaining delivery vehicle options were all judged able to carry a warhead that could generate explosive power (ie nuclear yield) comparable to the current Trident warhead. However, the different environment and stresses experienced by different types of delivery vehicle mean that different designs of warhead are required for ballistic missiles, cruise missiles and free-fall bombs respectively. For example, a ballistic missile warhead will spend many years in a relatively cosseted environment in a launch tube but, if launched, would then experience extreme vertical acceleration, followed by a predictable flight profile, a period of time transiting through space, before finally returning into the atmosphere at hypersonic speeds, experiencing extreme vertical deceleration. In contrast, an air-launched cruise missile might be handled more frequently by weapon engineers, would spend time being buffeted while underslung on the aircraft (if on a fast jet) and would then need to be able to withstand transit through much thicker atmosphere as the missile routed from the aircraft to the target, all at sub-sonic or supersonic speeds. There are design solutions to both that ensure the warhead is safe, survives its journey and can still explode at the designated point (and not before), but they are quite different: a warhead designed for a ballistic missile is very unlikely to survive life in a cruise missile, and vice versa.

2.20 In addition, given the UK's commitment to the principles of the Comprehensive Nuclear Test Ban Treaty (CTBT), as we await its entry into force, we would be unable to conduct any live tests of a new warhead to assure its safety and performance. Any design must therefore be based very closely on existing designs that can draw upon test data from previous live tests. Four representative designs were considered:

- **UK bomb:** based on that used in the previous UK free-fall bomb (the WE177), but incorporating modern safety features. This design would only be suitable for free fall bomb use.
- **Cruise missile warhead:** this uses a design based on work done in the early-90s for a cruise-missile 'Future Theatre Nuclear Weapon'. This design would only be suitable for the cruise missile role.
- **Cruise missile warhead (low radiation):** this warhead is one designed to use material that emits lower levels of radiation whilst carried or embarked and therefore is more suitable for deployment alongside personnel for sustained periods. It would theoretically be suitable for both cruise missile and free fall bomb use.
- **UK Trident warhead:** this design is based on what a potential future UK warhead for the Trident D5 missile system might look like. This design would only be suitable for ballistic missile use. This does not pre-judge a decision on whether or not to replace the Trident warhead.

2.21 For the cruise missiles, there is a choice between the two warhead designs. The key difference between the two is that the low radiation design reduces the risk to nearby personnel; something that is needed in an SSN(Horizontal launch), where the crew routinely occupy the same space as the missile for months at a time. For other cruise missile options, the risk from radiation is more easily (and cheaply) mitigated in other ways. The review therefore assumes that a design based on the first design would be used for all cruise missile options apart from SSN(Horizontal launch), which would use the low radiation design. In terms of free fall bombs, we have assumed that it would be based on the UK bomb design.

2.22 The shortlist of system options taken forward to the final iteration of modelling was therefore:

Platform	Delivery Vehicle	Warhead design
Large Aircraft	Stealthy Cruise Missile	Cruise missile warhead
Fast Jet	Stealthy Cruise Missile	Cruise missile warhead
	Supersonic Cruise Missile	Cruise missile warhead
	Free-fall bomb	UK bomb
Surface Ship	Stealthy Cruise Missile	Cruise missile warhead
SSN(Horizontal launch)	Stealthy Cruise Missile	Low radiation cruise missile warhead
SSN(Vertical launch)	Stealthy Cruise Missile	Cruise missile warhead
SSBN	Trident D5 ballistic missile	UK Trident
Silo	Trident D5 ballistic missile	UK Trident

Table 1 – System options shortlist

Chapter Three: Postures

3.1 In accordance with the Terms of Reference, the review developed a range of possible postures for each system, avoiding concepts judged to be tantamount to disarmament. In doing so, we made the following key assumptions:

a. that the UK will retain the ability to change to a higher posture from a lower posture, if required, and that it could do so in accordance with its legal obligations;

b. that a period of warning is likely prior to any threat of attack or actual attack on the UK, although the length of warning will depend upon the situation - when there is no hostile backdrop a no-notice surprise attack against the UK is highly unlikely but when there is hostility the warning time could be very short;

3.2 The process explored ways in which the postures might reflect the strategic context by defining how each system might be configured for 'high', 'medium' and 'low' readiness. It also considered the likely time it would take for each system to change readiness, as well as how communication of the UK's nuclear policy and doctrine (our 'declaratory posture') might help to enhance the deterrent effect of each system.

a. The highest state of readiness is when the system is able to launch a nuclear response at short notice. This readiness could be continuous or be adopted only in a period of heightened tension or conflict and is designed to provide the highest level of insurance against a pre-emptive no-notice attack.

b. Medium readiness is how the system would operate when there is no heightened tension and the probability of a no-notice attack is sufficiently low to allow us to relax the readiness of the system such that it needs the ability to attain high readiness within months (not years).

c. The lowest readiness state describes the way in which the system operates when no tension or hostile backdrop exists and the probability of a short-notice attack is sufficiently low to allow us to relax the readiness of the system such that it needs the ability to attain high readiness within years (not months).

3.3 We also considered ways in which a system might be able to respond to a surprise event quickly despite being at a lower overall readiness state. This involves minimising the vulnerability of the system to attack and thereby maximising the probability of a credible capability surviving if it was attacked. For instance, we considered combinations of: physical protective or security mechanisms; measures to reduce detectability either through covert, irregular or ambiguous deployment; and the geographic spread of assets (posing an adversary the challenge of multiple and concurrent targeting if they wished to attack the system). For some systems holding a proportion of the capability at a higher readiness might be possible, while for others it might be a case of maintaining contingency processes for re-constituting a deployable system very quickly.

3.4 **Alternative Postures:** The generic postures examined in the study are set out below. They vary slightly for each system due to the differing characteristics of the air, maritime and land options.

a) **Continuous deterrence**. A continuous deterrent presence, aiming to cause the required level of damage and sustained for the life of the system, representing as close as each system can get to an assured second strike response capability. For non-ballistic missile systems, limitations in range mean that this could only be focused against a specific adversary.

b) **'Focused deterrence'**. This high readiness posture would be maintained for a specific period. At all other times, the system would adopt a reduced readiness level to recover its ability to sustain high readiness in the future. Again, some systems would have to focus on a specific threat.

c) **'Sustained deterrence'**. A visible deployment of some deterrent capability would be maintained, but the number of platforms could vary and nor need they be at high readiness. This demonstrates capability and resolve and reduces the response time if the situation deteriorated. Depending upon the nature of the platforms, their deployment would be covert (submarines), ambiguous (ship) or dispersed across bases (air) and aims to make it extremely difficult for a potential adversary to predict whether and when they might be within reach of the system.

d) **'Responsive deterrence'**. As for 'Sustained deterrence' but gaps between deployments would be permitted. The frequency and length of deployment would be irregular so that a potential adversary cannot predict when and for how long a gap in deployment might occur.

e) **'Preserved deterrence'**. This posture would be adopted at low readiness. No deterrent platforms would be regularly deployed but the UK would maintain the ability to deploy if the context changed. The platforms might be deployed without nuclear weapons for training purposes and could conduct conventional duties as long as platforms could be made available for deterrent duties if required.

Credibility criteria

3.5 A credible and effective nuclear deterrent is underpinned by five criteria: readiness, reach, resolve, survivability/invulnerability and destructive power. The operating posture has an effect on all but the destructive power criterion.

3.6 **Readiness:** To act as a deterrent, a potential adversary must believe that the UK's nuclear weapons are available and ready for use. The longer the perceived time it would take the UK to prepare its weapons (warhead, missile, delivery vehicle, platform and associated suitably-trained military personnel) and then to locate them in a suitable launch position, the greater the risk that an aggressor will judge that they have an opportunity to attack with sufficient force to achieve their objectives and prevent or evade a nuclear response from the UK. The readiness of UK nuclear forces becomes more critical as hostilities rise. Changing the readiness of forces during a crisis can be challenging. Whether intended or otherwise, an adversary could perceive changes in posture or readiness as a sign of firm hostile intent. As a result, changes in posture in a crisis could contribute to miscalculation. Because of the fear of how changes might be perceived by an adversary, a government could find itself inhibited. This is not unique to alternative systems, however. This problem applies to all non-continuous postures.

3.7 **Reach:** Likewise, a potential adversary must believe that the UK's nuclear weapons have the ability to reach them and to overcome any defences they are likely to have deployed. There is a close link with readiness: if a potential adversary judges that it would take the UK a significant length of time to manoeuvre its weapons into a launch position, they might judge that they had time to evade or frustrate an attack. There is also a close link to survivability: the shorter the range of the delivery vehicle (missile/bomb), the closer UK forces would need to be to a potential adversary for them to be able to reach specific targets and, therefore, the more vulnerable those forces would be to attack, especially if they were not able to operate covertly.

3.8 **Survivability/invulnerability:** To act as a deterrent, a potential adversary must doubt his ability to prevent the UK from launching a nuclear attack through a pre-emptive attack on our nuclear forces and/or critical supporting infrastructure. For covert forces (eg submarines), their invulnerability depends upon protecting their acoustic and electro-magnetic signatures through life. For fixed infrastructure or overt forces, survivability is about having the ability to withstand an attack and/or sufficient fall-back options to provide the necessary resilience.

3.9 **Resolve:** Finally, nuclear weapons only deter if potential adversaries think the UK's political and military leadership would actually be prepared to use them. Deterrent messaging is therefore important at all times but especially so as tensions increase towards hostility. To avoid sending mixed messages, this needs to be matched with an appropriate posture. On the one hand, a non-continuous posture could be misinterpreted by a potential adversary as meaning that the UK did not have the resolve, (or was not sufficiently ready) to use its nuclear weapons. On the other hand, a posture that evolved to match the wider security environment gives the UK the option of making overt posture changes if it was judged that it could help underline our resolve and thereby de-escalate hostilities, but there is an unquantifiable risk that a potential adversary will react to this by increasing their own military preparedness, leading to an inadvertent escalation. With a continuous posture, potential adversaries know that the Prime Minister has directed that our deterrent is always available (and potentially in a position that could target them), which they could perceive as a sign of our resolve.

Assured second strike: system analysis

3.10 The five criteria come together as an assured ability to launch a second strike (ie to respond with nuclear weapons having first been attacked by an aggressor with their nuclear weapons). A key difference between the options is their vulnerability to a pre-emptive first strike or to pre-emptive asymmetric action and, therefore, the level of assurance each has of providing a credible assured second strike capability. The vulnerability of the platform is influenced by the posture adopted, the visibility and mobility of the platform and its proximity to an adversary's forces which, in turn, is highly dependent on the range of the missile.

3.11 Only the silo and 4-boat SSBN options are capable of sustaining a continuous deterrence posture for the 25-30 year life of the system within the cost parameter of the study (ie the 4-boat Successor submarine programme). Continuous deterrence would be prohibitively expensive for all other options because of the number of platforms and delivery vehicles required. **For costing purposes**, we assumed that such systems would routinely operate a 'Preserved deterrence' posture, but with the aim of attaining a 'Focused deterrence' posture within a few years and then to sustain it for a finite period. In addition, in order to keep fleet sizes broadly affordable we have assumed that forward operating bases (land or Carrier-based) would be available if required for all the non-ballistic missile options. Such bases potentially require third party agreement. Any uncertainty about the UK's sovereign ability to use its deterrent would diminish the deterrent effect. The key judgements therefore revolve around how long a future crisis that engaged the UK's nuclear deterrent might last and *in extremis* whether it would be acceptable to rely upon collective deterrence in any situation in which the UK's deterrent was not available.

3.12 **Ballistic missile systems:** For the UK operating a single deterrent system, the highest level of assurance is provided by SSBN submarines operating a continuous at sea deterrence posture. The missile's range and the platform's design, with appropriate procedures and supporting forces to help protect its signature, enable it to operate safely and undetected at a significant distance from a potential adversary's forces. An aggressor would know that an attack on the UK risks provoking a retaliatory response from the deployed submarine. For the silo, the review examined a concept of two silo bases maintained at separate sites within the UK, each using Trident D5 missiles. However, a silo system would be significantly more vulnerable to pre-emptive attack (at any state of readiness) due to its permanent overt fixed location. When at high readiness, the UK might have to adopt a 'hair-trigger' launch-on-warning posture, in which the UK missiles would launch as soon as possible after an attack was detected. This in turn introduces higher risks of instability/miscalculation during a crisis.

3.13 Adopting a non-continuous posture for an SSBN-based deterrent introduces some vulnerability due to the potential ability of an adversary to target the UK during a period when no boat is covertly deployed. Several nations are likely to have the ability to target the UK mainland, including the locations of SSBNs in port, with conventional or nuclear weapons but the likelihood of this happening while the UK was at a low state of readiness is less certain. The aim would be that a non-continuous posture would have gaps in deployment only when the UK assessed the likelihood of no-notice attack to be extremely low. The posture would aim to be adjustable given a warning period prior to any threat of an attack emerging, allowing the UK to increase the readiness of its nuclear deterrent, including more frequent covert patrols and, ultimately, dependent on circumstances, a resumption of back-to-back patrolling for a finite period of time. The residual risk is either that the UK (and its allies) could miss vital indicators and warnings of hostile intent or was unable to sustain high readiness during a long period of raised tension.

3.14 **Cruise missile systems:** The inherently shorter range of a cruise missile system could impose significant constraints upon the UK's options, possibly leaving geographic 'sanctuaries' that the UK acting alone could not reach. Also, while ballistic missile defence capabilities are likely to improve and proliferate, air and cruise missile defences are cheaper and more easily procured internationally. Maintaining the same level of assurance that the UK deterrent can overcome an adversary's defences is therefore likely to be harder with a cruise missile-based system.

3.15 On readiness, the inherent range of a ballistic missile means that almost every country can be held at risk from a single UK site/patrol area. The inability of non-ballistic systems to do this (other than, arguably, the large aircraft[1]) means that at higher readiness levels the system could only be focused against a single country/region. If detectable (eg with an overt aircraft carrier/JSF deployment), this would send a clear signal about who the UK was and was not attempting to deter. Also, should the system's readiness need to be raised during a crisis or should assets need to be redeployed to hold at risk targets elsewhere, this could be interpreted by an aggressor as a significant escalatory step. In some circumstances, there could be pressure not to deploy the UK system in order to avoid increasing tensions.

Vulnerability

3.16 The vulnerability of the platform is influenced by the posture adopted, the visibility and mobility of the platform and its proximity to an adversary's forces which, in turn, is highly dependent on the range of the missile.

3.17 The least vulnerable system is the SSBN, as the range of the Trident missile allows the submarine to operate covertly only revealing its position when it launches a missile. Even then, only a very sophisticated adversary is likely to be able to locate, track and engage the SSBN. The ability to track a submarine may improve over time but it is still likely to be significantly harder to do than for ships or fixed sites such as silos or air bases.

3.18 A ballistic missile silo is significantly more vulnerable to attack simply because its location will be known by an adversary, although this can be partially mitigated by perimeter

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[1] A large aircraft with air-to-air refuelling can reach distant targets by flying from airbase(s) in the UK or abroad.

security, by having more than one silo and/or adopting a ‘launch-on-warning’ posture in times of hostility.

3.19 For the cruise missile options, the submarines are the least vulnerable because they can operate covertly until the launch of the missile. However, once it has revealed its position, the fact that it will be relatively close to an aggressor’s territory means it will then be comparatively vulnerable if the adversary has the capability to track and engage it, potentially preventing it from firing sufficient missiles to complete the attack. The surface ship is the most vulnerable because it is overt, relatively slow moving and needs to get close to an aggressor’s territory before launching a missile, all of which combine to give an aggressor plenty of time to attack it and any supporting forces.

3.20 The vulnerability of JSF is largely dependent on the vulnerability of the Carrier/Forward Operating Base where it is based. The stealth of the JSF aircraft itself enables it to penetrate even sophisticated defences, although this level of effectiveness may reduce as counter-stealth technology improves. For aircraft launched from a Carrier, the range of the JSF/missile combination is crucial as it determines how close to the target the Carrier Task group must be. Some states are likely to be able to attack a Task Group at ranges beyond which aircraft could be launched without requiring air-to-air refuelling in order to reach their targets.

3.21 For aircraft (JSF or Large Aircraft) launched from airbases, the vulnerability depends on an aggressor’s ability to target the base before sufficient aircraft are launched. Some states have that capability; other states may develop it as long range ballistic missiles and satellite targeting systems proliferate. The risk may be partially mitigated by locating the aircraft at multiple airbases (particularly if some are hosted by allies) and adopting an ambiguous/covert deployment so that an aggressor would need to attack more than one airbase (and potentially a third party) at the same time to be confident of taking out the UK’s capability. Nonetheless, there would still be vulnerability to attack by a major power – and this vulnerability could be de-stabilising by allowing pre-emptive strikes against the UK.

Destructive Effect

3.22 The damage caused by an attack is dependent on the survivability of the delivery vehicle (the more missiles/warheads that get through an aggressor’s defences, the higher the confidence in achieving the necessary damage). For each of the scenarios, the operational analysis modelled a range of fleet sizes for each of the platform/delivery vehicle combinations, taking into account their range/speed/stealth and the effectiveness of the adversary’s likely defences.

3.23 Analysis was subsequently focused on those systems judged likely to be affordable within the cost constraints of the study but which the model indicated had the ability to achieve the desired level of damage in at least one scenario. This gave an ‘operational fleet size’ needed to achieve that level of damage. Some systems were able to deter large states with sophisticated defences with such operational fleet sizes; others could only make a contribution to deterrence of such states in alliance with other nuclear weapon states.

Force Generation

3.24 The operational fleet size was then analysed to estimate the total number of platforms – ‘the whole fleet size’ – that would need to be procured and maintained through-life in order that the UK could make available during a crisis the appropriate number of operational assets. This approach took into account maintenance, training, manning and readiness requirements. The whole fleet size is sensitive to the length of time the system might need to be held at high readiness and, crucially, where the system might need to be deployed for that period. For all cruise missile options, apart from in some circumstances the large aircraft, the whole fleet size is critically dependent upon the availability of a forward operating base to sustain the deployed force at distance from the UK, potentially requiring third party agreement. Any uncertainty about the UK's sovereign ability to use its deterrent would diminish the deterrent effect. The fleet size also varies depending on whether the platforms are procured as a dedicated deterrent fleet or if they are required to act as a dual-capable fleet able to conduct both conventional and deterrent duties.

3.25 The resulting whole fleet sizes that were used in the cost analysis for the cruise missile-based systems are set out in Table 2. They represent the total number of platforms that would need to be procured as a dedicated deterrent fleet. Following a period at high readiness ('Focused') the fleet sizes would allow the system to recuperate ready to sustain high readiness again. In this recuperation period, and at all other times when there is no heightened tension, the system would adopt a lower posture (eg 'Preserved') and would not attempt to sustain a presence close to a specific adversary.

Costed Fleet Sizes - Cruise Missile Systems
6 x Large Aircraft with Stealthy CM
36 x JSF with Stealthy CM
36 x JSF with Supersonic CM
36 x JSF with Bomb
4 x Type 26 with Stealthy CM
5 x SSN(H) with Stealthy CM
5 x SSN(V) with Stealthy CM

Table 2 – Whole-Fleet Sizes with Forward Operating Bases

3.26 The resulting whole fleet sizes that were used in the cost analysis for the ballistic missile-based systems are set out in Table 3. Given the range of the missile, the geographic location of a potential adversary does not influence the number of platforms needed. Instead, the whole fleet sizes are influenced by the posture adopted. For the SSBN, the four boat fleet represents the number that could sustain a CASD posture, while the three boat option could only sustain a non-continuous posture. With 24/7 manning the silo could be operated continuously; the number of silo sites is influenced by the level of risk the UK might accept against not having a guaranteed second strike capability. For the purposes of this review, two was chosen as the minimum number that would ensure that an adversary's calculations would have to take into account its confidence of successfully destroying multiple sites before a UK counter-attack could be launched.

Costed Fleet Sizes - Ballistic Missile Systems
4 x SSBN
3 x SSBN
2 x Silo

Table 3 - Whole-Fleet Sizes for Ballistic Missile systems

Note: No new Trident missiles were included in the costs as it is judged that the UK has sufficient missiles. Only life extension of the current missiles and new warheads were included in the costs.

Geographic constraints

3.27 The analysis highlighted the complexities associated with operating each of the cruise missile-based systems in a nuclear role at distance from the UK. While situation-dependent, the examples below illustrate the challenges that would be faced by the UK and the potential diplomatic issues that would arise from deploying nuclear assets into a region and from establishing a forward operating base.

3.28 For the maritime options, 'choke points' become a critical factor in determining the route nuclear-armed platforms might take. There would be significant force protection and diplomatic challenges with attempting to pass through them and, therefore, they would probably need to be avoided. Similar constraints for replenishing supplies/crew in overseas ports would be faced, unless an ally or third party was willing to permit entry to their territory. As such, routing and basing becomes difficult for nuclear-armed platforms, particularly at a time of heightened tension. These constraints have a considerable impact on the logistical and maintenance burden associated with sustaining a nuclear presence at distance from the UK. The diplomatic impact of creating a Forward Operating Base to help ease the burden and its vulnerability to disruption or attack would need detailed consideration.

3.29 For the air options, JSF could not reach distant scenarios without deploying either to a secure forward airbase, with the facility to hold UK nuclear weapons, or with the carrier and its task force. The large aircraft is able to deploy long distances either by travelling from the UK and relying on air-to-air refuelling from a number of tanker aircraft that would need to be pre-positioned or by forward deploying to an operating base in the relevant region. Routing would take account of access to foreign airbases and territorial airspace. Multiple crews would be required for each platform to sustain a high alert state.

Dual-capable systems

3.30 The analysis also explored the concept of dual-capable platforms, where the platform could be switched between conventional and nuclear deterrence duties over the course of its life. Every option other than the SSBN and the silo has the ability to be dual-roled for deterrent and conventional duties, thereby maximising their potential use. When engaged in conventional military operations a clear distinction between their roles would need to be made in order to avoid inadvertent escalation (ie the risk that an adversary would misinterpret a conventional attack as a nuclear first strike by the UK) and, therefore, we have assumed that platforms would not perform conventional and nuclear roles concurrently. Where appropriate, however, we assumed that platforms carrying nuclear weapons in peacetime would be able to conduct limited, non-offensive conventional duties.

3.31 For air options, from a deterrence perspective there would be advantages in having all the aircraft known to be dual-capable: an irregular and ambiguous (eg neither confirming nor denying the presence of nuclear weapons on the aircraft/airbase) deployment pattern, sometimes with and sometimes without nuclear weapons would complicate an adversary's calculations on whether to attempt a pre-emptive attack. However, costs associated with different firing mechanisms and communications systems and crew training would affect the decision to fit some or all of the aircraft fleets for both roles, as would the impact on service life of the platforms. The impact on the wider security context and on the availability of host nation support for the aircraft when performing each role would need to be assessed, although this was managed successfully when UK Tornado aircraft were dual-capable.

3.32 For surface maritime options, given a ship's significant transit time, adopting an irregular deployment of platforms with nuclear missiles would help prevent a potential adversary from predicting where the UK's nuclear capability was at any one time. However, this deployment pattern is likely to impact upon the ability of the wider fleet of ships to enter overseas ports unless they declared that they were not nuclear-armed, thereby limiting the ambiguity. Having access to a number of strategic ports overseas that allowed for the safe and secure berthing of the UK's nuclear-armed ships and/or dock-side storage of the UK's nuclear missiles would improve responsiveness to specific threats and allow greater flexibility for ships to switch from a conventional to nuclear role after sailing from the UK.

3.33 For submarine options, the operating concept for the SSN relies upon maintaining a fleet of dual-capable platforms that allows a truly ambiguous posture to be maintained. Being able to change the number of platforms deployed with nuclear weapons would mean that an adversary could never know with absolute confidence the locations or number of deployed deterrent SSNs. This posture could impact upon the ability of the wider fleet of SSN submarines to enter overseas ports unless they declared that they were not nuclear-armed, thereby limiting the ambiguity. However, as with the surface ship option, maintaining at least one strategic port away from the UK that allowed for the safe and secure berthing of the nuclear-armed submarines would improve responsiveness to specific threats and allow greater flexibility after deployment from the UK.

3.34 Analysis of dual-capable fleet sizes for the various systems was beyond the scope of this review. Calculations depend upon which future conventional tasks might need to be conducted in parallel with deterrent tasks and upon how much risk the UK would be prepared to take against each task. However, the fleet sizes would be larger than those required for a dedicated deterrent-only fleet in order to meet concurrent demands during periods of heightened tension. For example, a dual-capable fast jet fleet would probably need to be deployed and ready to conduct (or be conducting) conventional strike operations at the same time as maintaining enough platforms and crews at readiness to be capable of delivering a nuclear response. Similarly, a dual-capable SSN fleet is likely to need to conduct a range of conventional tasks during periods of heightened tension (eg. anti-submarine warfare in support of a maritime task group) while also sustaining nuclear-armed boats in the region. There would be very limited ability (if any) for the nuclear-armed boats to conduct these conventional tasks.

3.35 For illustrative purposes, a small study focused on a dual-capable SSN fleet only. This showed that a fleet of between 10 and 18 SSNs might be required, depending on how much risk it was judged acceptable to take against concurrent conventional and deterrent tasks during periods of heightened tension. This compares to the current position where the MOD have a total of 4 x SSBN and 7 x SSN to conduct the different duties.

SSBN: 3 vs 4-boat fleet

3.36 Classified analysis about attempting to maintain continuous at sea deterrence with a 3-boat SSBN option showed that the risk of unplanned breaks relates directly to the number of submarines available for operational deployment, which in turn relates directly to the total number in the fleet. The modelling suggests that, over a 20 year period, a 3-boat fleet would risk multiple unplanned breaks in continuous covert patrolling as well as requiring regular planned breaks for maintenance and/or training. Experience to date with the Resolution-class and Vanguard-class SSBNs is that no such breaks have occurred or been required with a 4-boat fleet.

3.37 A non-continuous posture could be adopted with a 2, 3 or 4 boat fleet. In reality, rather than attempting to adopt as close-to-continuous patrolling as possible, the more likely posture is one that aims to:

a) Protect the submarine signature and preserves the size of the deterrent operating area;

b) Assure the effectiveness of the Nuclear Firing Chain;

c) Sustain sufficient trained and motivated manpower (military, MOD civilian and industry) and maintains the material state of the submarines such that back-to-back patrolling could be resumed if required;

d) Maintain sufficient conventional forces trained to provide protection for deploying and deployed SSBNs.

3.38 If the political imperative to sustain CASD was removed, the Royal Navy would need to design a schedule based on the needs of individual submarines and their crew, just as they do today for the SSN fleet.

3.39 A decision in 2016 to move away from CASD would also involve a decision on whether to retire one Vanguard-class boat from service, or to continue with the planned maintenance and life-extension programme for all four Vanguard-class boats. If a decision was taken to reduce the fleet size to only 3 boats, with the consequential risk to availability as the submarines age, in addition to reducing crews, one boat's Deep Maintenance Period would no longer be required and the overall annual maintenance cost would reduce.

Chapter Four: International and Legal issues

4.1 This chapter discusses some of the potential impacts that a change in system or posture could have on the perceptions of the UK held by other states, including our allies. However, other states' official views cannot be and should not be inferred from this analysis.

4.2 Any change to the UK's nuclear deterrent system and/or its posture may have the potential to impact on the perceived credibility of the deterrent and on our wider national interests and foreign relations. How any change is received by other states would depend on the type of new system and/or posture adopted, their understanding of why the change had been made and, crucially, on whether it represented a perceived diminution in the UK's level of deterrent ambition.

4.3 Perceptions of the UK are driven by a broad range of factors, including the UK's economic standing, its history, cultural ties and the UK's activist role in international organisations. The level of investment in conventional capabilities (and a continued willingness to deploy them), will also be a significant factor in how we are perceived on wider defence and security issues, alongside our nuclear capability and posture. An alternative system or posture with a reduced level of capability and/or assurance may increase our dependence on allies for nuclear security and could, potentially, introduce an increased risk of miscommunication or miscalculation during a crisis.

4.4 A ballistic missile-based system would continue to be seen as highly-capable and able to overcome a potential adversary's defences and to deliver more than enough damage to deter. Housing ballistic missiles within an SSBN that an adversary could not detect would reduce their confidence that they could destroy the missiles before they were launched and thus increase the deterrent effect. Housing the missiles in silos in fixed geographical locations would be widely recognised as leaving them significantly more vulnerable to attack, which could lead a potential adversary to question the credibility of the UK's deterrent in the belief that it could be disabled in a first strike or, alternatively, to judge that we may be more likely to initiate a first strike out of fear that our capability could be disabled if we do not act first (the 'use it or lose it' theory). This could create uncertainty and increase the risk of miscalculation during a crisis.

4.5 A cruise missile-based system would be perceived as being less capable than a ballistic missile system, given the reduced range and speed of cruise missiles relative to ballistic missiles. These characteristics also mean that cruise missiles would likely need to be moved closer to their targets than ballistic missiles, potentially making them more vulnerable. Any forward deployment nearer to targets during a crisis may have an escalatory or de-escalatory effect depending upon the circumstances at hand. Any use of fixed Forward Operating Bases would likely raise a range of diplomatic handling issues. During a crisis there is the theoretical risk that less sophisticated adversaries might misinterpret a UK conventional cruise missile strike as potentially being a nuclear one, leading to inadvertent escalation. Clear and unambiguous messaging by the UK in a crisis would be needed to avoid this risk.

4.6 The readiness state of the UK's deterrent would be a key consideration in any crisis. If the UK was not operating a continuous posture, any decision to increase the readiness of its nuclear forces could have a bearing on events (for good or ill) in a way that we (and our potential adversaries) have not to date needed to consider. This risks increasing uncertainty and therefore the potential for miscalculation. Operating a non-continuous posture might theoretically be an incentive to conduct a first strike on the UK aimed at preventing the UK from being able to deploy its nuclear forces, but the potential adversary would need to be sufficiently certain that the UK would have no remaining capability and that our allies would not come to our aid.

4.7 The implications of any alternative system or posture on the UK's relationship with our allies would depend upon the specific approaches adopted, on what they meant for potential technical collaboration with allies, and on how they may affect their perceptions of the UK's continuing commitment and contribution to collective deterrence.

4.8 The UK is committed to the long-term objective of a world without nuclear weapons. Since the ending of the Cold War successive governments have reviewed and reduced the UK's nuclear holdings and actively pursued international progress on multilateral disarmament. The UK is also at the forefront of international efforts to stop the proliferation of nuclear weapons. Depending upon the nature of the change in system or posture, it may have a positive impact on perceptions of the UK's commitment to multilateral nuclear disarmament and counter proliferation; that said, it may not.

International legal considerations

4.9 The UK's key legal obligations in relation to nuclear weapons are set out under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and the Comprehensive Nuclear Test Ban Treaty (CTBT), although the latter has not yet entered into force. Throughout this review, only options that would continue to meet these obligations were considered.

4.10 The UK's position remains that pursuit of a renewal of Trident or adoption of a new system or posture does not breach the NPT. Article VI of the Treaty contains no specific steps and no timetable; the obligation is to negotiate towards multilateral nuclear disarmament, not to disarm unilaterally, and renewal or replacement is not prohibited by the NPT in view of the fact that there is no treaty on general disarmament.

4.11 Any collaborative work with allies to deliver an alternative system would need to be done in full compliance with our mutual obligations under the NPT. Collaboration with another state on a nuclear-capable delivery vehicle (eg a cruise missile) would not be constrained by any UK legal obligations (the NPT does not preclude such cooperation because a missile is not a nuclear weapon) but could be covered by that state's obligations under the Missile Technology Control Regime (MTCR). Much would depend on the view of any partner about what level of collaboration would be consistent with their legal obligations.

4.12 Operating a cruise missile-based system is likely to require the UK to deploy nuclear capable systems in different geographical regions than it does today. There are no legal constraints in relation to international airspace and international waters although forward basing would not be permissible if the proposed location were to be within a Nuclear Weapon Free Zone.

Part Two

Part One discussed concepts for alternative systems and postures, alongside the associated high-level policy and legal implications.

Part Two analyses and costs the major technical, industrial and programmatic issues associated with designing, developing, delivering and sustaining each of the representative systems and supporting infrastructure and personnel.

Chapter Five: Technical, Industrial and Operational/Programmatic Analysis

5.1 It is important to note three caveats about the technical analysis conducted for this review. First, the system options considered are representatives of what might be deliverable in the timeframes, based on assumptions about the potential characteristics of various capabilities. In reality systems would be designed from first principles (or heavily modified off-the-shelf) to meet a specific requirement and could differ considerably from what this review has assumed in technical and cost terms. A more detailed system-design approach, akin to a ‘concept phase’ in equipment procurement terms, was far beyond the resources and time available for this review. Second, Industry was not engaged due to the classification and sensitivity of this review. Instead, subject matter experts benchmarked their advice against known industrial capabilities and against comparative conventional and nuclear projects. Third, given the timeframes considered, the novelty of some of these options, and the complexity of a nuclear capability and its supporting systems, it was difficult to assess the uncertainties, particularly when compared with the Successor submarine programme that has undergone years of detailed analysis. Nevertheless, a broad comparison has been conducted across a very wide range of factors, including systems, personnel, logistics and infrastructure, and techniques were used to capture and present the potential variance in cost and risk.

5.2 **Summary:** The UK’s current nuclear weapon enterprise is finely tuned to provide the specified minimum number of nuclear warheads for the Trident D5 missile on a 4-boat SSBN fleet operating a continuous-at-sea-deterrence posture through life under UK operational command and control. Procurement of non-nuclear components and management structures are dependent on the US and the UK also benefits substantially from collaboration with the US on nuclear propulsion. The development of an alternative nuclear weapon system would be a substantial undertaking, requiring major integrated programmes to develop a new warhead, missile, platform and nuclear infrastructure in a very tightly controlled regulatory environment. Design and development of the warhead and its integration into a cruise missile or bomb with suitable safety, security, command, control and communications measures would be the critical challenge.

5.3 The design and manufacture of a safe warhead for a cruise missile would be a major component of the overall system costs through-life, which could be reduced only if it were possible to link to a technically and temporally aligned US programme. Currently, there is no such programme. Crucially, therefore, the time required to deliver a new warhead is judged by experts to be longer than the Vanguard-class SSBN submarines can safely be operated. Estimates suggest that, starting promptly in 2016, an initial warhead capability integrated into a cruise missile might be delivered (with some risk) by about 2040. A high-risk accelerated programme might deliver a few years earlier but with compromises to the design features requiring subsequent work and cost. However the last two Vanguard-class submarines are planned to leave service well before 2040, after considerable planned life extensions and expert judgment is that their lives could not be stretched further without extremely high-risk and high-cost re-construction of the submarines.

5.4 The operational, technical and programmatic risks associated with attempting to progress an accelerated warhead programme in parallel with sustaining and extending an ageing fleet of two remaining Vanguard-class submarines were judged to be extremely high. Subsequent analysis therefore focused on delivering a warhead programme in 2040 and bridging the capability gap by ceasing Continuous At-Sea Deterrence in 2016 and subsequently transitioning from the Vanguard fleet to a two boat Successor SSBN fleet until the alternative system enters service, albeit this course of action would reduce the level of deterrence the UK could deliver to materially below the current level for a number of years, whatever the credibility and deterrent effect of the chosen long-term option. This had the effect of reducing further the number of options: only those that could meet the 2040 in service date were taken forward for the final iteration of costing – the SSN(Horizontal Launch) was excluded as the warhead was judged not to be available until around 2050.

5.5 **Detail:** The main technical and cost challenges associated with delivering the full list of options are set out below, along with detailed exploration of the timelines and costs associated with warhead delivery and the challenges for any transition period.

5.6 **Delivery Vehicle:** The development and manufacture of a free fall bomb, in itself, would not pose a significant technical challenge for UK industry; integration with the warhead and the development of suitable launch mechanisms from the aircraft to meet the necessary nuclear assurance requirements would be the more challenging aspect. A cruise missile solution could draw heavily upon current development of stealth technology and missile concepts for the UK's conventional weapon programme. UK industry could deliver a stealthy subsonic cruise missile by 2035, although it would benefit greatly from collaboration. The costs therefore assume a UK-only programme but with access to collaborative technologies. However, UK industry has less experience of designing and manufacturing high speed missiles, whose propulsion and aero-thermal characteristics pose significant technical challenges. The cost estimates for the supersonic missiles reflect considerable technical risk and uncertainty. Technology transfer could reduce the risks if countries were willing to collaborate.

5.7 Some areas of missile design would require more detailed examination fully to understand the technical risks involved in making them nuclear-capable; the costings attempt to reflect this uncertainty but we cannot be confident that they have done so accurately. The key challenges include: mitigating long-term exposure to ionising radiation from the warhead; developing navigation systems that could operate completely independent of satellite navigation systems (in case an adversary were to disrupt the satellite capabilities); designing fail-safe fusing systems; and ensuring the survivability of the missile in the vicinity of other nuclear detonations.

5.8 **Warhead and Integration with Delivery Vehicle:** Aside from the development of cruise missile technology, conversion into an integrated nuclear-capable system is the over-riding risk and cost factor for all of the alternative system options. The UK has no recent experience of designing an integrated nuclear warhead and missile capability on its own; it would be essential to establish a UK nuclear systems integration organisation in order tightly to manage the collaboration between AWE and the missile industry.

5.9 The design of a warhead and its delivery vehicle has to be developed as a single "system" because the interaction between the warhead and the delivery vehicle is critical to its performance. There may also be implications for the materials used and the manufacturing capability required if, for example, low radiation-dose warheads are required due to the proximity of the warheads to personnel on the platform and/or the lack of shielding measures.

5.10 The warhead costs take account of the design variations and different safety, security and arming features (the 'non-nuclear components') that would be needed for the various missile and platform combinations. On a sliding scale, costs would be at their minimum for a new Trident warhead, increase through the update to the previous UK freefall bomb design and the cruise missile warhead and peak for the low radiation cruise missile warhead.

5.11 The cost of producing non-nuclear components would be particularly sensitive to the extent to which we might be able to cooperate with another nation, such as the US, in accordance with our mutual legal obligations.

5.12 **Warhead development timescales**: Analysis of the timescales likely to be associated with delivering a new warhead was conducted, using as a baseline studies that supported the 2010 Strategic Defence and Security Review and ongoing studies for a possible new Trident warhead (should one be required). The design and development of a new nuclear warhead for the current, Trident-based system is judged by experts to take approximately 17 years from the initiation of work to the first production unit. Without access to live nuclear testing the programme relies heavily on computer-based modelling and extensive hydrodynamic trials to underwrite the safety and performance of the design. A complex series of tests is then conducted to certify safety and performance in all stages of its life (storage, transportation, deployment, maintenance etc). Manufacture and assembly of the final design then follows, with subsequent timelines dictated by manufacturing capacity to deliver the required number of warheads.

5.13 The analysis found that delivering a warhead for an alternative system would take longer, primarily due to the lack of recent experience in working with non-Trident systems. The starting point would be less mature, even if building upon a previous design (as assumed for this review). The AWE facilities, processes, modelling techniques and expertise would need to be adapted away from their current focus on a ballistic missile-based system. Non-nuclear components different from those we procure today would need to be developed And having to develop the delivery vehicle in parallel with early design work on the warhead may risk extending the programme, in contrast with a programme for Trident in which the missile and its environmental data is well-known. Consequently experts assess that, starting promptly in 2016, an initial warhead capability integrated into a cruise missile might be delivered (with some risk) by about 2040, a timescale of 24 years. To deliver the low-radiation warhead design for the SSN(Horizontal Launch) would take an additional 10 years due to the need to build a new facility at AWE. This assumes that as much work as possible can be progressed in parallel with construction of a facility. Given these long timescales, the warhead is the primary time driver for all non-Trident based options.

5.14 This estimate was heavily scrutinised and work was conducted to consider ways in which the programme might be accelerated. Potential programmatic short-cuts were investigated, such as: limiting the design work and accepting a short initial service life; designing the missile around the warhead; and delivering UK non-nuclear components as early as possible. This concluded that, in theory, an accelerated warhead programme might be possible but: it would come at high risk; the initial stockpile produced would probably need to be modified perhaps within 5-10 years; and the programme would need to be driven as a UK national imperative. Above all, to deliver an initial capability by about 2035 non-nuclear components would need to be available by 2017 (an extremely challenging task). The more likely timescale of 24 years – commencing work in 2016 and delivering an initial warhead capability in 2040 – was judged to be the more realistic approach upon which to base the final costing work.

5.15 **Transition period: Vanguard life-extension:** The time required to deliver a new warhead is longer than experts judge that the Vanguard-class submarines can safely be operated, posing a major challenge for transitioning from the current system to any alternative. The Vanguard Class submarines were originally built with a design life of 25 years: in 2006, they were extended and in 2010 the Trident Value for Money study further extended each submarine’s life up to 37 years, with out of service dates occurring well before 2040. The service lives of these submarines is driven by the condition of a small number of critical components and systems (e.g. the reactor pressure vessel (that holds the nuclear fuel core), steam generators, condensers and gearbox) and the opportunities that exist to refurbish or replace them. The factors that cause them to need replacement are complex and not necessarily helped by cessation of continuous patrolling. The only opportunity to refurbish or replace the major components is during each boat's remaining Long Overhaul Period (LOP). However, the manufacturing lead time for these systems is such that an order would need to be placed well ahead (years) of the LOP in order for the system to be available in time. To operate to 37 years already assumes these key components would be refurbished. Any further extension would require replacement through an extremely expensive and high-risk re-construction of the submarines, which was judged not to be a viable option.

5.16 Analysis therefore focused on the costs and risks of delivering a warhead programme in 2040 and bridging the 'gap' by transitioning from the Vanguard fleet to a 2 boat Successor fleet operating at a reduced posture. The final stages of the review's analysis therefore only focused on costing those options that could meet this date and which were judged most credible: Large Aircraft with stealthy cruise missile; JSF with supersonic cruise missile; SSN(Vertical Launch) with stealthy cruise missile; and SSBNs with ballistic missiles.

5.17 **Platforms:** Existing platform designs would need modifications to their communications and to their safety and security arrangements. The most important modifications would be the integration of appropriate missile storage and launch systems which would need to meet different safety requirements than for conventional missiles.

5.18 The large aircraft costs are based on a generic military aircraft. The JSF costs are based on the F35-B (Short Take-Off Vertical Landing) variant that the UK is procuring for conventional requirements with the flexibility to deploy on the UK's aircraft carrier or to forward land bases. In both cases, the costs represent the through-life costs of acquiring and sustaining the aircraft.

5.19 The SSN(Vertical Launch) option has been costed as a new design submarine with a PWR3 reactor (because the safety authorisation for a further submarine using the current PWR2 reactor is unlikely to be granted), which would be larger than the Astute-class but smaller than Successor, and vertical launch tubes for cruise missiles. It assumes that the design work draws heavily on Successor concept studies and assessment phase.

5.20 Finally, the costs for the SSBN option are based on estimates of the Successor programme and, as such, there is more confidence in the cost estimates than for those of the alternative systems.

5.21 **Nuclear Infrastructure and Basing:** One of the key programmatic challenges for building nuclear infrastructure in the UK would be ensuring that sufficient time is planned into the delivery schedule to secure the appropriate regulatory planning consents and licences and to overcome any legal challenges. Using only existing MOD-owned land would shorten the timeline because Compulsory Purchase Orders would not be required to acquire the necessary sites. For the submarine and surface ship options, much of the existing infrastructure and bases in the UK could be used, with some modifications to berthing or to weapon storage and handling facilities. In addition, costs have been estimated for a forward operating base with appropriate berthing, operations and accommodation facilities but not with facilities for weapon storage which is a function assumed, for security reasons, to be conducted in the UK only. In the absence of a detailed infrastructure assessment of a specific location there is a risk that the forward operating base costs may underestimate the actual extent of work that could be required.

5.22 The air options would require investment in new or refurbished nuclear infrastructure at their main operating bases, including highly secure and environmentally-controlled facilities for the handling, integration and maintenance of the warheads and missiles behind multiple layers of security. The cost estimates include the construction and maintenance of these facilities to nuclear regulatory standards of safety, security and radiation hardness.

5.23 **Nuclear Command, Control & Communications**: The ability to communicate securely with a deterrent platform at all times, including after a nuclear attack on the UK, and despite any attempts by an adversary to disrupt or spoof transmissions, is a critical enabling capability that underpins the credibility of the system and, ultimately, the ability of the Prime Minister to issue a launch order. Alternative systems would require coverage of very different operating areas than at present. Developing an assured global sovereign capability would require very significant investment. The concept that has been included in the costs for alternatives systems is based on the re-use and extension of existing systems, but it should be recognised that this could provide a materially lower level of assured communication than today, and this is an essential element of an effective deterrent.

5.24 **Supporting forces:** Cost estimates for supporting forces (ie for logistics support or protection) have been included wherever the options would demand additional conventional assets above what is expected to be in the UK's future conventional force. Judgements have been made about the level of tasking that conventional assets could be expected to sustain if required to support an alternative system during periods of high readiness. For instance, no additional supporting force costs have been included for Successor on the assumption that assets would be made available when required or would have been procured to meet other conventional requirements. Similarly fast jets, or other air capabilities, are assumed to be available to escort the large aircraft as a key strategic asset but additional tanker support has been costed to allow for potential concurrent demands on tanking support before or during a conflict. The availability of alliance assets has not been assumed but in many scenarios might also be available.

5.25 **Industrial Issues - the Submarine Enterprise:** The UK nuclear submarine industry comprises submarine design and construction, nuclear propulsion design and construction, and submarine support services. It was optimised during the Strategic Defence & Security Review 2010 through a planned build programme of 7 Astute Class SSNs, followed by 4 Successor SSBNs, followed by a future submarine known as "Maritime Underwater Future Capability" (MUFC). The deterrent requirement is to deliver Continuous At Sea Deterrence (CASD) from a fleet of 4 SSBNs while maintaining the minimum credible and sustainable industrial entity. The build programme was modified to delay the introduction of Successor SSBN to the latest date possible, commensurate with sustaining CASD. As a result, the programme has a limited capacity to accommodate change in the short to medium term if the critical skills required to design and manufacture submarines and nuclear reactors are to be maintained.

Chapter Six: Costs

6.1 The review examined indicative whole-life costs for the various alternative options, which are presented in constant 2012 economic conditions (excluding VAT). **The costs presented are for comparison purposes only. They are not suitable for budget setting or investment decisions**. **Nor do they represent a comparison of equivalent constant capability because the performance levels, vulnerability and postures differ between the options.** The cost data does not allow a direct comparison with costs produced outside the Alternatives review, not least because these costs may exclude common costs that did not vary between the options.

6.2 As with the technical analysis, the levels of confidence in the estimates vary considerably, given the timescale (out to the late 2050s and beyond) against which the costs have been forecast and the conceptual nature of many of the options. The costs are not based on detailed bottom-up estimates: some are calculations based on valid data typical for projects of this maturity; some are based on two or more top down estimates; and some are parametric estimates. Wherever possible, cost data for recent or planned equipment projects have been used as comparators.

6.3 Costs presented here focus on options judged to be the most technically credible of the alternatives and able to meet the more realistic 2040 in-service date, set against the costs for a 4 and 3 boat SSBN fleet delivered by 2035 (the current in-service date).

6.4 **Scope:** The indicative whole-life costs presented include estimates of: the design, development, manufacture and in-service support for new platforms, missiles, training equipment and any additional supporting forces; the design, development and any additional support costs for new warheads; the design, construction and maintenance of new infrastructure; and manpower costs for operating the platforms and for supporting the wider capability (if greater than that which is in place today). All costs are assumed to fall to the UK, except where there are existing collaborative arrangements for the Joint Strike Fighter, the Successor SSBN and the Trident D5 missile or where collaboration on non-nuclear components for a new warhead might be possible. It was also assumed that the UK submarine industry would be sustained for any of the options.

6.5 The whole-life costs do not include: common costs that do not vary between options (such as current AWE operating costs and maintenance of existing common infrastructure); the cost of disposing of the systems or the residual value from selling them at the end of their service life; and de-commissioning or MOD redundancy costs that might result from transitioning to a non-submarine-based option (because the balance between upfront costs, natural wastage and longer-term savings was too complex to calculate but was assumed to have minimal impact on the overall cost picture). In line with comparisons of this type, the costs do not include escalation or VAT. Consequently, the total costs quoted in this report are different from the 'absolute' through-life cost of every option (including the SSBN).

6.6 The cost comparison of options is not a comparison of equivalent capability or of operational posture. Performance, vulnerability and posture of each option varies: the cruise missile-based systems include indicative costs for a forward operating base that is assumed to be available if required for any distant scenarios; the 3 boat SSBN fleet could sustain back-to-back patrols for a period but could not sustain CASD for its service life without planned (and, probably, unplanned) breaks; the 4 boat SSBN fleet could sustain a CASD or non-CASD posture; and the silo could sustain continuous operation with 24/7 manning but with greater vulnerability than a submarine-based deterrent.

6.7 All non-SSBN options include the manufacture of 2 x Successor SSBNs to bridge the capability gap by operating a 2 boat fleet after the Vanguard submarines leave service; and the in-service support of the 2 x SSBNs until an alternative cruise missile-based system enters service. The construction of the SSBNs is judged sufficient to sustain the submarine industry until the start of a future SSN programme, with some additional cost to sustain the workforce. All options other than the 4 x SSBN option assume that CASD would be broken in 2016.

6.8 **Presentation of the data**: The whole-life cost estimates for each option are presented as a range to account for uncertainty about things that could happen to affect the costs. The range was generated by a statistical simulation (Monte Carlo).

6.9 The costs have been discounted, using the standard HM Treasury discount rate of 3.5 %, in order to compare their Net Present Value (NPV). The process of discounting gives more weight to costs which arise earlier and reduces the contribution of costs incurred later. This is a standard cost comparison tool.

6.10 **Costs:** The costs presented below focus on the 2040 options, all of which include the procurement of 2 x SSBNs to fill the capability gap until 2040. For most options, the two additional SSBNs are assumed to be retired once the new deterrent system is in service. In addition, costs are presented for a ‘mixed-fleet’ option of procuring 3, rather than 5, SSN(Vertical launch) and converting the 2 x SSBNs to ‘SSGNs’ capable of firing cruise missiles mid-way through their service lives once they are no longer required to perform ballistic missile-based deterrence. They are set against the cost estimates for a 3- and 4-boat SSBN fleet delivering to their envisaged dates.

6.11 The relative whole-life costs are shown in Chart 1, with each bar highlighting the range of cost due to uncertainty and potential risk.

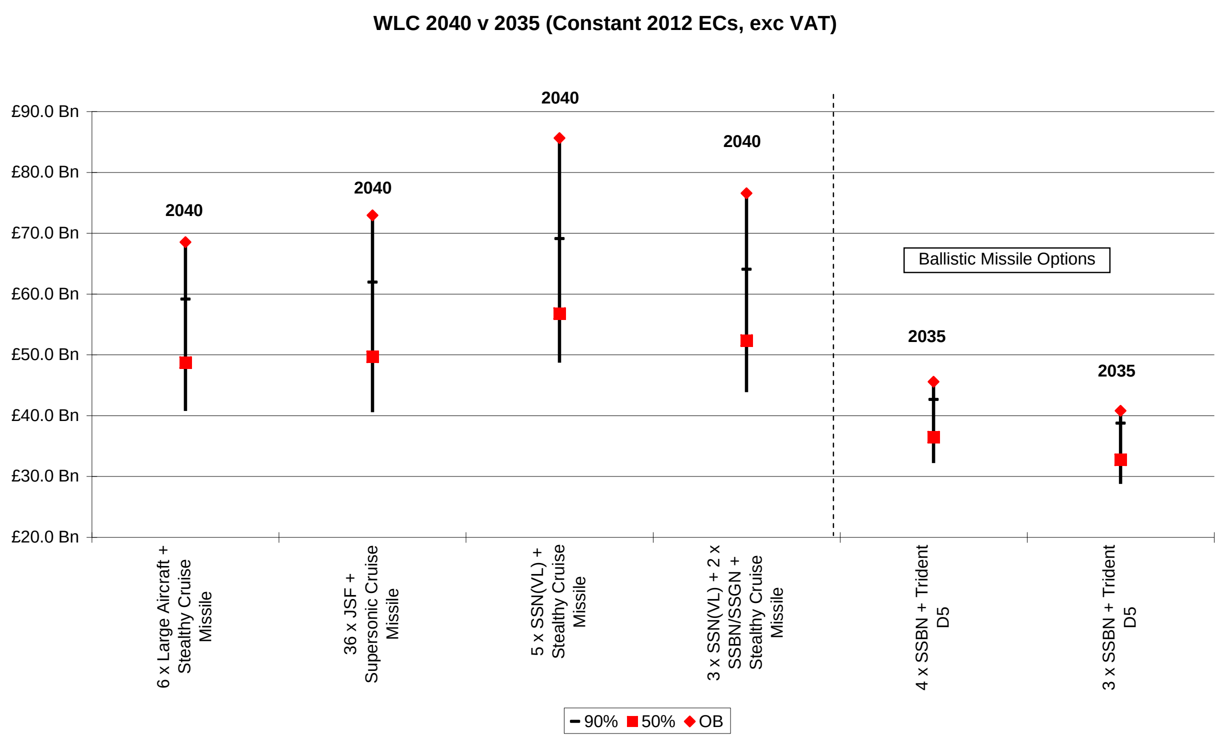

Chart 1 – Whole-life cost comparison

6.12 Chart 2 illustrates the breakdown of the whole-life costs in Net Present Value terms. The red element represents the ‘policy change’ cost impact of not proceeding with a 4-boat Successor programme and the orange represents the costs of procuring and supporting 2 x SSBN until the alternative system enters service.

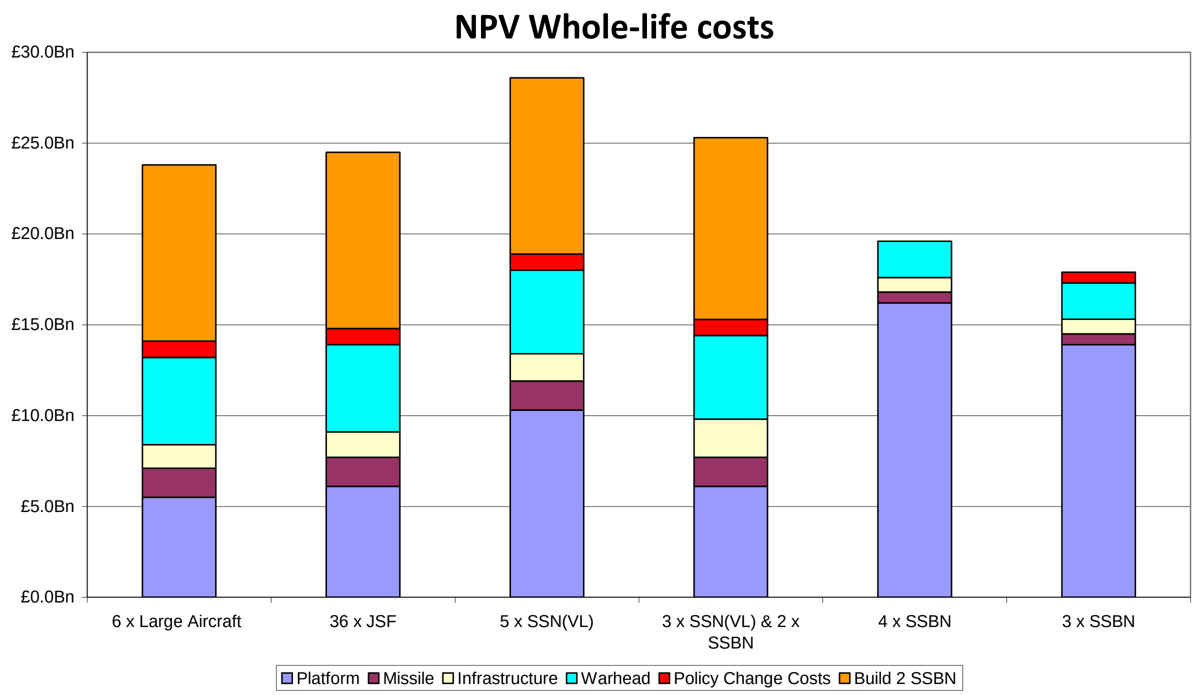

Chart 2 – Net Present Value comparison and breakdown (50% confidence)

6.13 Chart 3 shows the indicative spend profiles for each option, as a guide to its likely affordability. They suggest that when compared with the 4-boat SSBN profile, the cruise missile options require additional spend in the periods 2016-2022 and from 2027 onwards, with less spend in the period 2022-2027. The majority of the savings for a 3-boat SSBN option fall in the period 2025-2035.

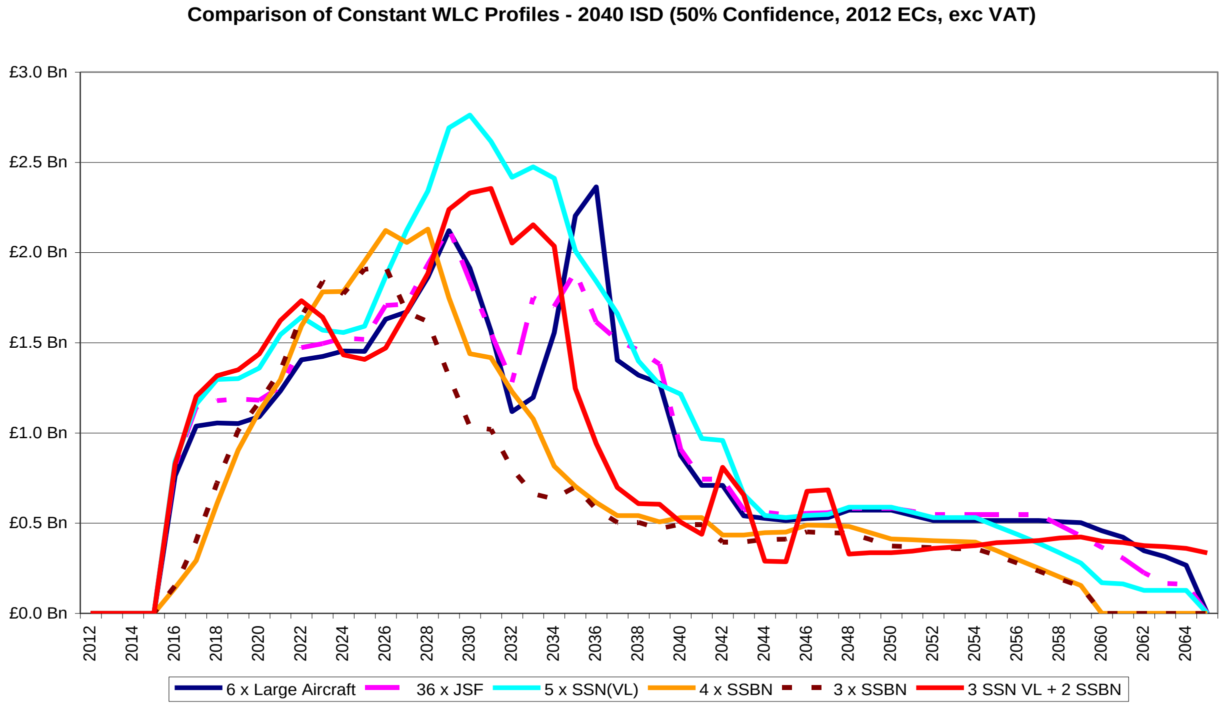

Chart 3 – Whole-life spend profile comparison (50% confidence)

6.14 **Cost Driver Analysis:** The top three cost drivers for each option are set out in Table 4. The major cost drivers for the SSBN options are the acquisition and support costs for the submarines, with most of the rest of the capability (infrastructure and missiles) already being in place. The main cost drivers for the air options are the warhead costs and the aircraft in-service costs (the acquisition costs are relatively small), alongside the acquisition costs for the 2 x SSBNs. The main drivers for the SSN(Vertical launch) options are the warhead costs and the submarine acquisition costs, alongside the acquisition (and any re-role) costs for the SSBNs.

Option	Cost Element	
Large Aircraft + Stealthy Cruise Missile + Warhead	1	BUILD & SUPPORT 2 SUCCESSORS
	2	WARHEAD
	3	PLATFORM PEOPLE
JSF + Supersonic Cruise Missile + Warhead	1	BUILD & SUPPORT 2 SUCCESSORS
	2	WARHEAD
	3	PLATFORM IN SERVICE
SSN(VL) + Stealthy Cruise Missile + Warhead	1	BUILD & SUPPORT 2 SUCCESSORS
	2	PLATFORM ACQUISITION
	3	WARHEAD
Mixed Fleet SSN(VL) + SSBN + Stealthy Cruise Missile + Warhead	1	BUILD & SUPPORT 2 SUCCESSORS
	2	WARHEAD
	3	PLATFORM ACQUISITION
4 x SSBN + Trident D5 + Warhead	1	PLATFORM ACQUISITION
	2	PLATFORM IN SERVICE
	3	WARHEAD
3 x SSBN + Trident D5 + Warhead	1	PLATFORM ACQUISITION
	2	PLATFORM IN SERVICE
	3	WARHEAD

Table 4 – Top three cost drivers for each option

6.15 **Warhead costs:** One of the main cost drivers for delivering any alternative system is the cost of developing a warhead. Estimated warhead costs were developed by considering the technical complexities and risks likely to be associated with: design, development and qualification activities, including safe integration with the missile/bomb and with the platform; production of the nuclear physics package; production of the non-nuclear components (which would differ depending upon the combination of missile/bomb and platform); and building or adapting any necessary supporting infrastructure, principally at AWE. The review also estimated the costs of developing a new warhead for Trident. Current AWE operating costs were excluded from all options.

6.16 We collaborate with the US on the non-nuclear components of our current warhead (in compliance with our mutual legal obligations). Collaboration with the US on the non-nuclear components of an alternative warhead would depend upon US willingness to do so, while in parallel continuing to support our current arrangements, and on the availability of a US programme with which to align. For costing purposes various assumptions were made about circumstances in which it might be possible to share certain costs of the non-nuclear components with the US, subject to appropriate political, legal and technical arrangements being established.

6.17 The most likely cost estimates are presented graphically below. Overall, the resulting difference in cost between delivering a warhead for a cruise missile or bomb and that for Trident is primarily due to AWE being highly-tuned towards a ballistic missile-based warhead and there potentially being less opportunity to benefit from US collaboration than we do now.

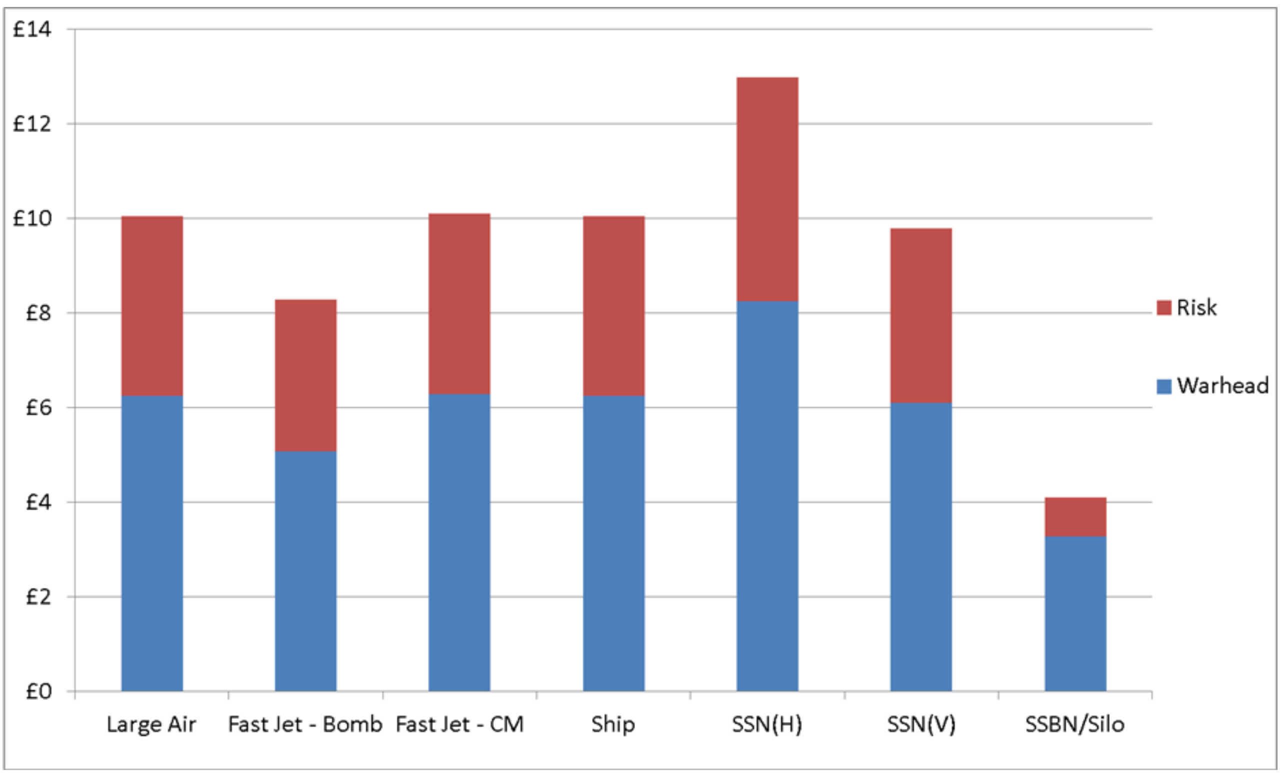

Chart 4 - Most Likely Warhead Costs (£Bn, 2012 constant prices)

6.18 **Dual-capable SSN fleet:** As described in Chapter 3, a small study was conducted to estimate the fleet size for a dual-capable SSN fleet. This showed that a fleet of between 10 and

18 SSNs might be required, depending on how much risk it was judged acceptable to take against concurrent conventional and deterrent tasks. This compares to the current position where the MOD would have a total of 4 x SSBN and 7 x SSN to conduct the different duties. A high-level costing analysis was conducted to compare the costs of procuring and supporting two different submarine fleets versus one dual-capable fleet. For costing purposes two options were analysed: a dual-capable fleet of 12 x SSN(V) with 2 x SSBN to cover the capability gap; and alternatively 10 x SSN(V) + 2 x Successor converted to launch cruise missiles.

6.19 Chart 5 compares (out to 2065) the costs of the dual-capable fleets with the costs of procuring and supporting 3 or 4 SSBNs and 7 future conventional-role SSNs. Comparing the dual-capable fleets, the costs of converting the 2xSSBNs to SSGNs, and of maintaining the associated infrastructure, cancels out the saving from building fewer SSNs (which is heavily discounted because it falls in the late 2050s).

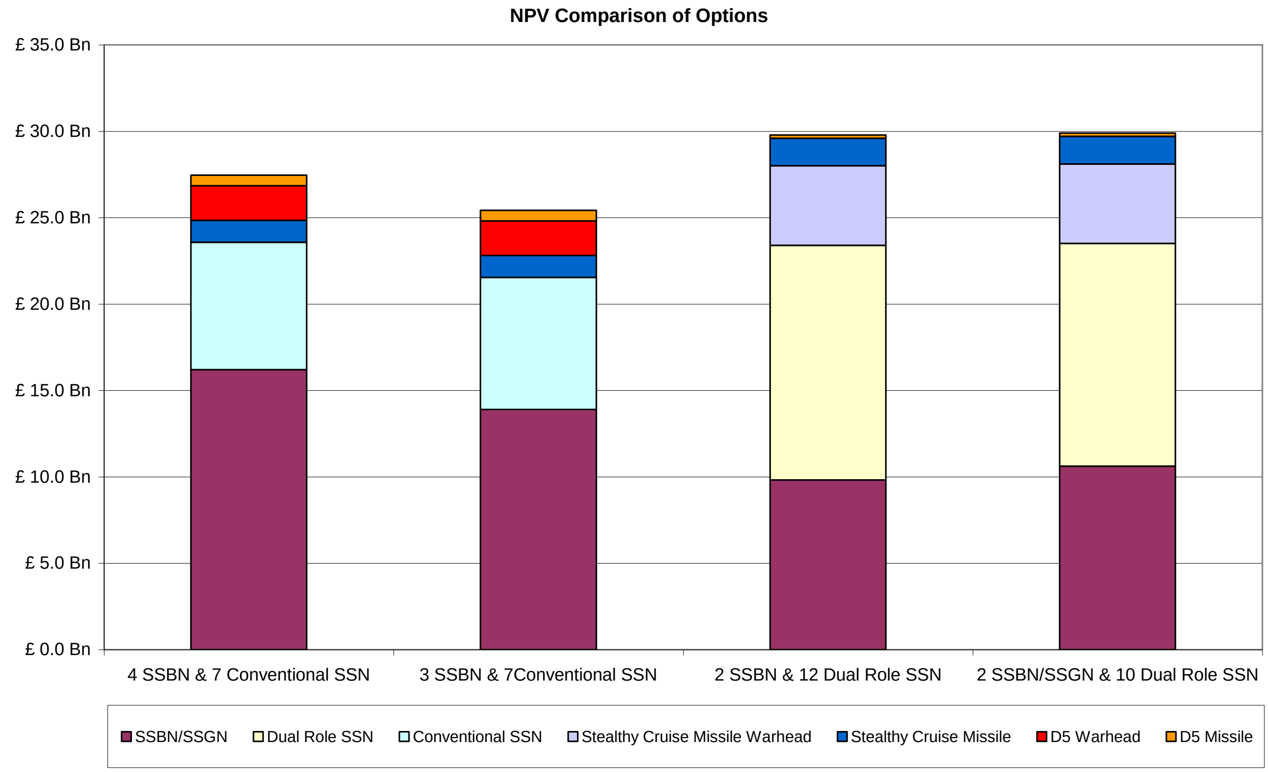

Chart 5 – NPV comparison of dual-capable SSN fleet vs separate SSBN and SSN fleets (50%)

6.20 **Conclusions**. Recognising that, compared with the SSBN system, the cruise missile options offer a much reduced level of destructive and second-strike capability and an increased level of operational complexity, the analysis indicates that:

a. on their own, the cruise missile based platforms are cheaper to procure than the SSBN platform, but considerable additional investment would be needed to develop the cruise missile, warhead and new infrastructure, assuming that the technical challenges could be overcome, compared with that required to sustain a BM capability.

b. the air options would be cheaper through-life than the 3 or 4 boat SSBN fleet, were it not for the need to include the cost of building 2 x Successor SSBNs due to the time it would take to bring a new cruise missile warhead into service;

c. a 5 boat SSN(Vertical launch) fleet would be more expensive than a 3 boat SSBN fleet, even without the cost of the 2 x Successor SSBNs, primarily due to the warhead costs. This remains the case, even if creating a mixed fleet of 3 x SSN(Vertical launch) and converting the 2 x SSBNs to carry cruise missiles or transitioning to a dual-capable 12-boat SSN fleet;

d. overall, because of the complexity and risks associated with developing a cruise missile-based option, given where we are in 2013, the analysis shows that transitioning now to any of the realistic alternative systems would be more expensive than procuring a 3 or 4-boat Successor SSBN fleet.

ANNEX A

Overview of Postures for Air Options

Note: The concepts discussed below explicitly **do not** reflect policies or readiness levels for nuclear-armed air assets of the UK's allies. The possibility of forward deploying UK air assets has not been explored with possible host nations, whose explicit consent would be required.

A1. **Operating concept**. The operating concept for the air platforms seeks to enhance survivability from a pre-emptive attack by dispersing the aircraft across several locations and by using a range of overt and covert measures to create uncertainty about the location of the system components at any given time. Maintaining the option to base the aircraft overseas (including with NATO allies) would enhance the deterrent effect by providing additional flexibility to disperse the system, to posture overtly or ambiguously in line with the overall deterrence messaging. Reach would rely on a combination of: the range of the aircraft and of the missile system; the flexibility of basing options; and the availability of air-to-air refuelling. At-base survivability would rely upon hardening and dispersal. In-flight survivability would rely upon organic self-protection and/or stealth capabilities or upon additional escort aircraft.

A2. Every air option has the ability to be dual-roled for deterrent and conventional duties, thereby maximising their potential use. Costs associated with different firing mechanisms and communications systems and crew training would factor in the decision to fit none, some or all of the fleet for both roles, as would the impact on service life of the platforms. From the deterrence perspective there would be advantages in having all the aircraft known to be dual-capable: an irregular and ambiguous deployment pattern, sometimes with and sometimes without nuclear weapons would complicate an adversary's calculations on whether to attempt a pre-emptive attack. The impact on the wider security context and on the availability of host nation support for the aircraft when performing each role would need to be assessed. However, when engaged in conventional military operations a clear distinction between their roles would need to be made in order to avoid inadvertent escalation and, therefore, we have assumed that aircraft would not perform conventional and nuclear roles concurrently.

A3. **Continuous:** As part of a continuous posture, the aircraft would be based in such a way as to minimise possible transit times to an adversary for the life of the system.

A4. **High Readiness:** At high readiness the aircraft would need to be able to launch from their airbases within minutes of receiving the order to do so. A focused deterrence posture would involve some of the assets either being dispersed to forward bases within reach of a potential adversary, or all held in the UK at short notice to take-off with air-to-air refuelling support.

A5. **Medium Readiness:** At medium readiness the system would be protected from attack through dispersal, hardening and other security measures. Aircraft would demonstrate an ability to deploy with nuclear weapons at shortened alert states if required.

A6. **Low Readiness:** At low readiness the platforms undergo deep maintenance or conduct conventional duties and the nuclear weapons are held securely as part of a preserved posture. A minimum capability could be maintained at medium readiness to improve resilience to a surprise attack or to form an initial capability if the posture needed to change upwards.

A7. **Policy and messaging:** In policy terms, it would be possible to maintain a variety of declaratory postures and deterrence messages, ranging from overtly not deployed and not targeted through to ambiguously dispersed (with a neither confirm nor deny policy) up to overtly deployed to enhance deterrence.

A8. **Maritime deployment**: Carrier-basing of the fast jet options provides additional flexibility for forward deployment but this would be an option only when adopting the highest readiness against a specific threat, given the considerable constraints on deployment of the carrier that would result from embarking nuclear-armed aircraft as part of a medium readiness profile.

AIR PLATFORMS

	High Readiness	**Medium readiness**	**Low Readiness**
Context	*Heightened tension or conflict exists.*	*No active hostility. Must be able to attain High readiness within months (not years).*	*No hostile backdrop. Must be able to attain High readiness within years (not months).*
Policy and messaging	• Actively deterring conflict or escalation. • Assets at readiness to respond at very short notice. • Targets held at risk from operating bases. • Could include a launch-on-warning posture to deter a first strike against the deterrent system. • Able to reach targets despite defences.	• Maintaining stable deterrence but no immediate threat. • If the threat changes, the UK will change its posture. • The system is protected from attack and has an inherent ability to respond quickly if necessary. • A surprise attack would fail to remove all of the UK's capability and would provoke a proportionately grave response.	• There is no perceived threat but we retain ability to be agile if there is a change.
System and deployment	• Continuous: The aircraft are dispersed to minimise transit times and are maintained in this pattern for the life of the system. • Focused: The aircraft are dispersed across a number of bases in the UK. • Depending upon situation, host nation agreement and UK's messaging some could be deployed to forward operating base(s). • Warheads are mated with cruise missiles. • Cruise missiles ready to be loaded or are loaded onto the aircraft. • Platforms and crews are on standby times commensurate with the adopted alert state.	• Sustained and Responsive: A minimum number of aircraft are dedicated to deterrence at bases in UK and overseas. • Remainder undergoing deeper maintenance or limited conventional duties. • Warheads are stored securely at the bases. Some may be mated with the missiles. • A number of nuclear-capable airbases are maintained within the UK. • Appropriate forward operating base(s) may be maintained to receive and support aircraft, missiles and warheads with months' (not years) notice.	• Preserved: Warheads stored in UK; limited-life components not integrated. • Enough cruise missiles are procured such that full operational requirement could be procured within a few years (not months). • All aircraft have been procured. A number are assigned as reserve deterrent platforms if required but are able to conduct conventional duties and deterrent training. • Bases are maintained with appropriate infrastructure to support deterrent.
Responsiveness	• Time to launch: the lead-time will be determined by the ability to hold concurrently multiple aircraft at the adopted alert state and the time it would take to launch if ordered. • Any required supporting assets are assigned and dedicated to the deterrent, commensurate with adopted alert state.	• Attaining High: the lead-time is time it takes to retrieve reserve platforms and supporting assets from conventional duties. • Response to surprise attack: the lead-time is the time it takes to conduct final preparation of weapon (on base), and prepare mission plans. • Minimum number of supporting assets is available to deterrent if required with months' (not years) notice.	• Changing readiness: the lead-time is the procurement of additional missiles and, if required, conversion of the aircraft. • Response to surprise attack: A small capability is held at medium readiness to deter a surprise attack, either in the UK or possibly overseas with a close ally • No supporting assets are dedicated to deterrent but assets are designated to be available with years (not months)notice

ANNEX B

Overview of Postures for Above Water Vessel

B1. **Operating concept**: It is impractical to have a fleet of nuclear-armed surface vessels sustained across multiple operating areas close to potential adversaries. At the other extreme, holding all the nuclear-armed ships in the UK at very short notice to sail (as is possible for the aircraft options) is also not appropriate, given the ships' significantly longer transit times. Instead, ambiguous or irregular deployment of platforms with nuclear missiles would seek to prevent a potential adversary from predicting where the UK's nuclear capability was at any one time. However, this deployment pattern is likely to impact upon the ability of the wider fleet of ships to enter overseas ports unless they declared that they were not nuclear-armed, thereby limiting the ambiguity that was sought. Maintaining a number of strategic ports overseas that allowed for the safe and secure berthing of the UK's nuclear-armed ships and/or dock-side storage of the UK's nuclear missiles would improve responsiveness to specific threats and allow greater flexibility for ships to switch from conventional to nuclear carriage after deployment from the UK. Reach would rely on a combination of: the ability to sustain a protected patrol in international waters close to an adversary; the availability of tanker support; and the UK's access to strategic ports such that the system did not rely solely on replenishment in the UK. At-sea survivability would need to be demonstrated through self-protection capabilities and additional protection assets that would need to be assigned to the nuclear-armed ships.

B2. **Continuous**: As part of a continuous posture, back-to-back overt patrols would be sustained close to the relevant missile launch area for the life of the system.

B3. **High Readiness**: At high readiness levels the nuclear-armed ships would need to be able to launch within minutes of receiving the order to do so by sustaining a patrol within, or very close to, the appropriate launch area as part of a focused deterrence posture.

B4. **Medium Readiness**: At medium readiness sustained or responsive postures could be adopted. As part of a sustained posture there would always be one or more ships deployed with nuclear missiles. As part of a responsive posture an irregular deployment pattern would be adopted, with periods of time when there are no ships deployed at sea with nuclear weapons. For either, it might be possible to create a limited amount of ambiguity about the location of the nuclear-armed ships by exploiting their lack of distinction from the other platforms conducting conventional duties and by regularly changing their operating areas. The responsiveness to a surprise attack is dependent upon the time it takes to sail from wherever nuclear-armed ships happened to be to within range of a specific adversary.

B5. **Low Readiness**: At low readiness the platforms undergo deep maintenance or conduct conventional duties and the nuclear weapons are held securely as part of a preserved posture. A minimum capability could be maintained at medium readiness to be able to respond to a surprise attack or to form the initial capability if the posture needed to change upwards.

B6. **Policy and messaging**: In policy terms, it would be possible to maintain a variety of declaratory postures and deterrence messages, ranging from overtly not deployed and not targeted through to ambiguously dispersed (with a neither confirm nor deny policy) up to overtly deployed to enhance deterrence. As with dual-capable aircraft, there is a risk that operating with dual-capable surface craft might be constrained.

B7. **Alternative concepts**: An alternative to the above concept would be for the ships to form part of a wider multi-platform deterrent capability with, for example, air platforms that are also able to carry the same nuclear missiles if required.

B8. The readiness levels are compared in the table below.

SHIP			
Context	**High Readiness**	**Medium readiness**	**Low Readiness**
	Heightened tension or conflict exists.	*No active hostility. Must be able to attain High readiness within months not years.*	*No hostile backdrop Must be able to attain High readiness within years (not months).*
Policy and messaging	• Actively deterring conflict or escalation. • Assets are held at readiness level that is able to respond at very short notice. • Targets held at risk from the patrol area. • Could include a launch-on-warning posture to deter a first strike against the deterrent system. • Able to reach targets in spite of defences.	• Maintaining stable deterrence but no immediate threat. • If the threat changes the UK will change its posture. • The system is protected from attack. • A surprise attack would fail to remove all of the UK's capability and would provoke a proportionately grave response.	• There is no perceived threat but we retain ability to be agile if there is a change.
System and deployment	• <u>Continuous</u>: The required number of ships is sustained within the commit area for the life of the system at minutes' notice to fire. • <u>Focused</u>: The required number of ships is sustained within the commit area for a defined period of time, followed by recuperation periods. • Warheads are mated with cruise missiles. • Cruise missiles are loaded into the silos on the patrolling ships.	• <u>Sustained</u>: At any time a number of ships are at sea with nuclear weapons. • <u>Responsive</u>: There are periods when there is no platform at sea with nuclear weapons. • Warheads and missiles are stored securely at the naval base when not deployed. Warheads and missiles do not need to be mated. • When not deployed remainder of the fleet is undergoing maintenance or conventional duties. • A number of nuclear-capable naval bases are maintained in the UK. • If appropriate, forward operating base(s) are maintained to receive a nuclear-armed ship with months' (not years) notice.	• <u>Preserved</u>: Warheads are stored in UK; limited-life components not integrated. • Enough cruise missiles are procured such that full operational requirement could be procured within a few years (not months). • All ships have been procured. . A number are assigned as reserve deterrent platforms if required but are able to conduct conventional duties and deterrent training. • Bases are maintained with appropriate infrastructure to support deterrent.
Responsiveness	• Time to launch: the lead-time will be determined by the ability to sustain ships within the patrolling area and the time it would take to launch if ordered. • Protection assets and any support tankers sustain the ships in the patrol area	• Attaining High: the lead-time is time it takes to deploy the required number of ships to the appropriate patrol area. • Response to surprise attack: the lead-time is the time it takes to sail to a launch point from wherever nuclear-armed ships happen to be. • Minimum number of supporting assets available if required with months' (not years) notice	• Changing readiness: the lead-time is the procurement of additional missiles and, if required, conversion of the ships. • Response to surprise attack: a small capability is held at medium readiness and is stored securely at a naval base. • Supporting assets are designated to be available with years (not months) notice.

ANNEX C

Overview of Postures for Submarines with Cruise Missiles

C1. **Operating concept**: The operating concept for the SSN relies upon maintaining an indistinguishable fleet of dual-capable platforms that allows a truly ambiguous posture to be maintained. Being able to change the number of platforms deployed with nuclear weapons would mean that an adversary could never know with absolute confidence the locations or number of deployed deterrent SSNs. This posture could impact upon the ability of the wider fleet of submarines to enter overseas ports or transit maritime choke points unless they declared that they were not nuclear-armed, thereby limiting the ambiguity that was sought. However, maintaining a number of strategic ports that allowed for the safe and secure berthing of the nuclear-armed submarines would improve responsiveness to specific threats and allow greater flexibility for submarines to switch from conventional to nuclear carriage after deployment from the UK, thereby improving the reach and sustainability of each deployed platform.

C2. It is not possible to consider a fully ambiguous posture if operating a mixed fleet of submarines, in which the nuclear-armed boats are distinguishable from the conventionally-armed platforms. However, in theory, some uncertainty could be created by regularly switching the patrolling areas of the nuclear-armed boats to frustrate a potential adversary's ability to predict where they might be at a given time. Planned deployments would seek to manage where the boats might be needed if the context changed.

C3. **Continuous**: As part of a continuous posture, back-to-back covert patrols would be sustained within the missile launch area for the life of the system.

C4. **High Readiness**: At high readiness levels the nuclear-armed submarines would need to be able to launch missiles within minutes of receiving the order to do so by sustaining a covert patrol within, or very close to, the appropriate missile launch area.

C5. **Medium Readiness**: At medium readiness sustained or responsive postures could be adopted. As part of a sustained posture there would always be one or more submarines deployed at sea with nuclear missiles. This continuous deployment would not require a submarine to be within a defined patrolling area at any one time but would require back-to-back deployments. As part of a responsive posture an irregular deployment pattern would be adopted, with periods of time when there are no submarines deployed at sea with nuclear weapons. If operating a mixed submarine fleet, a potential adversary would be able to identify when all of the deterrent platforms were in the UK.

C6. **Low Readiness**: At low readiness the platforms undergo deep maintenance or conduct conventional duties and the nuclear weapons are held securely as part of a preserved posture. At-sea deterrent training could be conducted without the nuclear missiles in order to maintain crew readiness in case the context changed.

C7. The readiness levels are compared in the table below.

SUBMARINES WITH CRUISE MISSILES			
Context	**High Readiness**	**Medium readiness**	**Low Readiness**
	Heightened tension or conflict exists.	*No active hostility. Must be able to attain High readiness within months (not years).*	*No hostile backdrop. Must be able to attain High readiness within years (not months).*
Policy and messaging	• Actively deterring conflict or escalation. • Assets are held at readiness level that is able to respond at very short notice. • Targets held at risk from the patrol area. • Could include a launch-on-warning posture to deter a first strike against the deterrent system. • Able to reach targets in spite of defences.	• Maintaining stable deterrence but there is no immediate threat. • If the threat changes the UK will change its posture. • The system is protected from attack. • A surprise attack would fail to remove all of the UK's capability and would provoke a proportionately grave response.	• There is no perceived threat but we retain ability to be agile if there is a change.
System and deployment	• Continuous: The required number of boats is being sustained within the commit area for the life of the system at minutes' notice to fire. • Focused: The required number of boats with missiles is being sustained within the commit area for a defined period of time, followed by recuperation periods.	• Sustained: At any one time a number of boats are at sea with nuclear weapons. • Responsive: There are periods when there is no boat at sea with nuclear weapons. • Warheads and missiles are stored securely at the naval base when not deployed. Warheads and missiles do not need to be mated. • When not deployed on deterrent duties the rest of the fleet is undergoing deep maintenance or conventional duties. • A number of nuclear-capable naval bases are maintained in the UK. If appropriate, forward operating base(s) are maintained at a level where they could receive a nuclear-armed submarine with months' (not years) notice.	• Preserved: Warheads are stored in UK; limited-life components not integrated. • Enough cruise missiles are procured such that full operational requirement could be procured within a few years (not months). • All boats have been procured. A number are assigned as reserve deterrent platforms if required but are able to conduct conventional duties and deterrent training. • Bases are maintained with appropriate infrastructure to support deterrent.
Responsiveness	• Time to launch: the lead-time will be determined by the ability to sustain boats within the patrolling area and the time it would take to launch if ordered.	• Attaining High: the lead-time is time it takes to deploy the required number of boats to the appropriate patrol area and ready others for back-to-back patrolling. • Response to surprise attack: the lead-time is the time it takes to sail to an appropriate launch point from wherever nuclear-armed boats happen to be. • Conventional assets required to support covert deployment of the boats are available	• Changing readiness: the lead-time is the procurement of additional missiles and conversion of the platforms. • Response to surprise attack: a small capability is held at medium readiness and stored securely at the naval base. • Assets are nominally designated to be available to support covert deployments with notice

ANNEX D

Overview of Alternative Postures for Submarines with Ballistic Missiles

D1. **Operating concept**: The operating concept for the SSBN relies upon the ability of the platforms to sustain covert deployments. They are able to hold at risk all potential adversaries from a single operating area. For the purposes of this review a number of non-continuous postures were developed. These are explicitly different from the UK's current policy of Continuous At-Sea Deterrence (CASD) and are mutually exclusive. Either a CASD posture can be maintained, in which back-to-back patrols are sustained for the life of the system (as has been done since 1969), or a non-continuous posture could be adopted, in which back-to-back patrols are sustained for a period of time deemed necessary and at other times patrols are conducted at a frequency deemed necessary to sustain the capability and to keep the crew fully-trained.

D2. For these non-continuous postures the range of the missiles provides additional risk mitigation for periods when a submarine is returning or has returned to the UK, which is a mitigation that is unavailable to the cruise missile-based submarines.

D3. **High Readiness**: By definition the highest readiness level should a non-CASD posture be adopted would be back-to-back covert patrolling for as long as it is required.

D4. **Medium Readiness**: At medium readiness sustained or responsive postures could be adopted. As part of a sustained posture there would always be one submarine on deterrent duty. The on-duty SSBN would be permitted to return to base at some point(s) during its patrol period for a short stay without being replaced by another submarine on covert patrol. As part of a responsive posture an irregular deployment pattern would be adopted, with periods of time when there are no submarines deployed at sea or on deterrent duty in port as for the previous posture. A potential adversary would be able to identify when all of the deterrent platforms were in the UK, although the irregular deployment would complicate predictions about when they might next deploy.

D5. **Low Readiness**: At low readiness platforms either undergo deep maintenance, conduct conventional duties as part of a 'Preserved posture' or conduct at-sea deterrent training in order to maintain crew readiness in case the threat changes and a responsive or sustained posture is required. The nuclear weapons could be on board the submarine or held and maintained securely on shore.

D6. **Policy and messaging**: It would be possible to maintain a variety of declaratory postures and deterrence messages aimed at deterring a surprise attack against the submarine bases.

SUBMARINES WITH BALLISTIC MISSILES			
	High Readiness	**Medium readiness**	**Low Readiness**
Context	*Heightened tension or conflict exists.*	*No active hostility. Must be able to attain High readiness within months (not years).*	*No hostile backdrop. Must be able to attain High readiness within years (not months).*
Policy and messaging	• Actively deterring conflict or escalation. • Assets are held at readiness level that is able to respond at very short notice. • Targets are held at risk from patrol area. • Could include a launch-on-warning posture to deter a first strike against the deterrent system. • Able to reach targets in spite of defences.	• Maintaining stable deterrence but there is no immediate threat. • If the threat changes the UK will change its posture. • The system is protected from attack. • A surprise attack would fail to remove all of the UK's capability and would provoke a proportionately grave response.	• There is no perceived threat but we retain ability to be agile if there is a change.
System and deployment	**Either** • CASD: Continuous back-to-back covert patrols for the life of the system. **or** • Focused: Back-to-back covert patrols for a defined period of time, followed by recuperation periods.	**Either** • CASD: Continuous back-to-back covert patrols for the life of the system. **or** • Sustained: At any one time a boat is on deterrent duty with short returns to UK permitted. • Responsive: There are periods when there is no boat at sea or alongside on deterrent duty. • Warheads and missiles do not need to be mated. • When not deployed on deterrent duties the rest of the fleet is undergoing maintenance.	**Either** • CASD: Continuous back-to-back covert patrols for the life of the system. **or** • Preserved: Warheads could be on board the submarine or stored in UK. Missiles could be on board the submarine or maintained at base. • All boats have been procured and are maintained at sufficient levels to sustain crew training and to be able to raise readiness if required. • Bases are maintained with appropriate infrastructure to support deterrent.
Responsiveness	• Time to launch: the lead-time will be determined by the ability to sustain boats within the patrolling area and the time it would take to launch if ordered. • Conventional assets required to support covert deployment of the boats are available.	• Attaining High: the lead-time is time it takes to deploy boats and ready others for back-to-back patrolling. • Response to surprise attack: the lead time is time it takes to load and submerge a submarine to launch-depth. • Assets are nominally designated to be available to support covert deployments with notice.	• Changing readiness: the lead-time is the loading of missiles and warheads and training sufficient crew on the deterrent role. • Response to surprise attack: A small capability is held at medium readiness to deter a surprise attack and is stored securely at the naval base. • Assets are nominally designated to be available to support covert deployments with notice

ANNEX E

Overview of Postures for Land-Based Silo

E1. Operating concept: The review considered a concept for which two silo bases were located within the UK. Each silo base was based upon twelve missile tubes and using Trident D5 missiles. In principle a silo system would be able to maintain a continuous operating pattern, through a continuously manned command and control facility, and therefore has an in-built ability to maintain a continuous posture for the life of the system. The range of the D5 missile would provide very good reach. Survivability would rely upon a combination of limited hardening against conventional and asymmetric threats, upon geographic dispersal of the sites across the UK and upon physical security measures. Recognising its vulnerability to a nuclear strike, during very high tension where such a strike was a real possibility a combination of messaging, possibly a launch-on-warning policy and the effect of collective deterrence might deter successfully such an attack.

E2. **High Readiness**: At highest readiness levels the silos are able to launch at very short notice. In extremis a 'launch-on-warning' policy could be adopted in order to deter a first strike by an adversary.

E3. **Medium Readiness**: At medium readiness the silos are loaded with missiles and are able to launch the required number, even when one silo and its missiles are undergoing maintenance procedures. Measures could also be adopted to keep this maintenance process covert if necessary.

E4. **Low Readiness**: At low readiness political steps could be taken to reduce overtly the numbers of missiles that are kept operationally ready. However, if deemed necessary the system could continue to maintain a contingency number of operational missiles able to respond in the unlikely event of a strategic surprise.

E5. **Policy and messaging**: In policy terms, it would be possible to maintain a variety of declaratory postures and deterrence messages. Key to all would be the message that any threat aimed at rendering the silos inoperable would be deemed to be an existential threat to the UK and would provoke a suitably severe response.

E6. The readiness levels are compared in the table below.

LAND-BASED SILO			
Context	**High Readiness**	**Medium readiness**	**Low Readiness**
	Heightened tension or conflict exists.	*No active hostility. Must be able to attain High readiness within months (not years).*	*No hostile backdrop. Must be able to attain High readiness within years (not months).*
Policy and messaging	• Actively deterring conflict or escalation. • Assets are held at readiness level that is able to respond at very short notice. • Targets are held at risk from UK. • At highest levels, readiness could include a launch-on-warning posture to deter a first strike against the deterrent system. • Able to reach targets in spite of defences.	• Maintaining continuous deterrence but there is no immediate threat. • If the strategic context changes the UK will change its posture (covertly if required). • The system is protected from attack and has an inherent agility that allows it to respond very quickly if necessary. • A surprise attack would fail to remove all of the UK's capability and would provoke a proportionately grave response.	• There is no perceived threat but we retain ability to be agile if there is a change.
System	• All warheads and missiles are mated and loaded into silos. • All silo bases are operational and at short notice to fire; each site is able to launch the minimum required number of missiles.	• Minimum required number of missiles (distributed across sites if/as necessary) can be launched. • Some maintenance can be conducted on the remaining missiles/warheads at this readiness level. • One or both silo bases are operational (depending upon maintenance schedules).	• Warheads are de-mated from the missiles and stored securely. • There is flexibility to either retain the unmated missiles in the silos or to return them to the US. • If retaining a minimum capability for contingencies, a minimum number of warheads and missiles could be mated and loaded into silos.
Responsiveness	• Receipt of order: short notice to launch • Main dependency would be early warning capability to identify in-bound threats.	• Attaining High: the lead-time is time taken to make all silo bases fully operational. • Response to surprise attack: a number of missiles could respond if an attack failed to destroy completely both silo bases. Lead time would be issuing of the order.	• Changing readiness: the lead-time is the delivery and loading of additional missiles and raising operational level of the bases. • Response to surprise attack: a small capability is held at medium readiness to deter a surprise attack.

ANNEX F

Postures, Strategic Threat and Risk Mitigation

POSTURE		CRUISE MISSILE SYSTEMS: SSN	CRUISE MISSILE SYSTEMS: SHIP	CRUISE MISSILE SYSTEMS: AIRCRAFT	BALLISTIC MISSILE SYSTEMS: SSBN	BALLISTIC MISSILE SYSTEMS: SILO
HIGH READINESS	CONTINUOUS	Continuous covert patrols for life of system	Continuous overt patrols for life of system	Dispersed at bases for life; short notice to take-off	Continuous covert patrols for a period	Continuous operation; each site is capable of launching minimum required number of missiles.
HIGH READINESS	FOCUSED	Continuous covert patrols for a period	Continuous overt patrols for a period	Dispersed for a period, with some transit time flex; at short notice to take-off		
MEDIUM READINESS	SUSTAINED	Sustained covert patrols with alternating operating areas	Sustained ambiguous patrols with alternating operating areas	Dispersed with ambiguous or irregular basing and with a range of lower response times	Sustained covert patrols with short on-duty periods in port	Continuous operation; all sites needed to launch minimum required number of missiles.
MEDIUM READINESS	RESPONSIVE	Covert patrols with irregular gaps (SSN(H) can create added ambiguity between patrols)	Overt patrols with irregular gaps		Covert patrols with irregular gaps	Some periods when non-operational
LOW READINESS	PRESERVED	No armed patrols; training or conventional duties only	No armed patrols; training and conventional duties only	Weapons secure; training or conventional duties only	No armed patrols; training or conventional duties only	No mated missiles in launch tubes

STRATEGIC THREAT

CONTINUOUS AT SEA DETERRENCE

LEVEL OF RISK MITIGATION