d against a United Kingdom strategic
clear deterrent contribution to NATO
the longer term or on the characteris-
s of a future system for this purpose, it
were to be decided that we should
quire one. I thought you would wish
have written evidence from the
partment which you could, with some
ervations, be free to publish. How-
r, I am following the precedent of
2 in preparing a memorandum classi-
"secret", which I can let you have
the next few days, if you wish, in
ch I can amplify some aspects of the
es in more detail than I can do either
ral or written evidence for the record.
nk you.

Thank you, Secretary of State. I
ld like to ask you whether you have
n satisfied with the performance of
Polaris fleet after the number of
s we have had it in operation?——
answer to that is an unequivocal
s". Happily, of course, it has not
to be used but I believe it has
ed out to be one of the best arrange-
ts that we have made and we are, of
se, greatly indebted to the United
s administration for making it avail-
and for continuing the support
ngements.

Mr *Roper*

We have had evidence submitted
s that there was of course con-
ible argument as to whether it
d be a fleet of four boats or five
Some evidence we have had from
who have had experience in this
would suggest that there were very
lerable military arguments for
g five boats, rather than four. After
ve had now some experience for
years of the four boats would you
give a judgment on that?——It
decision taken, of course, a very
ime ago and the major considera-
ould have been one of cost. How-
of course the argument for five
is that it is then much easier to
in a permanent patrol of two
whereas with a force of four boats
ime to time—we always have at
one boat permanently on patrol
course with the need for re-fits
e rest—it is impossible always to
in a patrol of two boats. Of
at a time of tension it would be
icy to get all the boats that were
available at sea as quickly as

possible, so that at that time we would expect to have two, perhaps three, or even in very favourable circumstances all four.

Sir *Frederic Bennett*

5. Could I follow this up on the same point? Mr Roper asked about the decision to have four boats and you say it was reached, basically on cost, a long while ago. The methods of following and keeping track with the two, or perhaps three that might be at sea—or one—were much less advanced than they are now and the last time that we investigated this we were given evidence that in fact the potential enemy's capacity to track down these boats was much greater than it had been. There have been advances in all fields. In your reply you said that it was obviously better to have five boats because you could keep two always at sea, whereas at the moment, I believe, there are periods of the year when there can only be one—I am excluding periods of tension——* * *.

6. * * *.

7. * * *.

8. * * *.

Mr *Conlan*

9. What steps have you taken to prevent a re-occurrence of the events at Faslane?——We have no means, if you are thinking of the industrial dispute, of preventing civilian employees from time to time being in dispute. Similarly we have had no disputes which have caused us the anxieties they caused us in the summer but we resolved that by employing Naval personnel to do the job of getting the next boat out to sea in time to relieve the boat which was due to come back for a re-fit.

10. Have you made a conscious, deliberate policy decision to increase the proportion of service personnel servicing these four boats than obtained in the summer of last year?——No, we have not. We have not been able to make completely military arrangements, but we are finding in most situations the existing military personnel can cope. I personally believe that in times of difficulty we shall have complete loyalty from the civilian employees at Faslane and other nuclear bases. We would have difficulty recruiting help which balanced the highly specialist personnel.

11. During that difficult period was the intention to keep one boat on patrol maintained?——I will not go into great detail but there was a period when one boat was due back in port to be relieved by another boat and we had to use military personnel in order to make it possible for the outgoing boat to leave in time to meet that commitment.

Mr *Kershaw*

12. In your opening statement, Secretary of State, you said that you were satisfied that the Polaris could remain on into the 1990s. Originally the 1980s was the target. Is that due to operational experience or something different—a better reactor—or what?——It is an assumption. One of the restricting factors, of course, is the hull life of the boats themselves, and secondly, the Americans, who, of course, have more experience of Polaris than we because they have many more Polaris boats, they have found it possible to prolong the life of their boats. But, it is a mattter which is under review and as each year goes on we form a view.

13. If the hull life was satisfactory are you completely satisfied that the missiles will remain in good order if the United States is not continuing to manufacture them for their own purposes?——We have no reason to doubt the United States' undertaking to support the programme for as long as necessary.

Mr *Sandelson*

14. When will a decision be taken with regard to necessary replacements?——The first question is whether there should be a replacement of the present force. The time scale would depend on whether a decision were to be taken to replace it and if so on what it was to be replaced with. It is quite impossible to give an arbitrary time. One factor, and I would not say that this necessarily would follow in the next generation, if there was to be one, is that it was six years from the Polaris agreement to the first boat going into service.

Mr *Roper*

15. But the Secretary of State will have heard the Prime Minister at question time say that he thought the decision should be taken within the next 2 years?——I think that would be a reasonable assumption, if one were to take all the

APPENDIX 1

OPTIONS FOR THE UK's FUTURE NUCLEAR WEAPONS POLICY

Memorandum by Mr Farouq Hussein, Research Associate, International Institute for Strategic Studies

OPERATIONAL LIFE OF UK SSBN FLEET

Estimated Life of Submarine Hulls

The hull life of the UK Polaris submarines was originally estimated at twenty years. However, such estimates are always cautious approximations and more recent evaluations suggest that all four submarines should comfortably exceed this figure by twenty-five to fifty per cent (5–10 years). The operational life cycle of the UK Polaris fleet (figure 1) involves year-long refits once every four years. From this it can be seen that the first of the Polaris submarines to become operational (HMS) *Resolution*) will reach a period when hull fatigue problems may present themselves around 1997–2000. The last SSBN to be deployed (HMS *Revenge*) is unlikely to present any hull fatigue problems prior to the period 1999–2005. Based on the estimated hull life of the submarines alone, it can reasonably be assumed that the UK SSBN fleet can be maintained throughout this century.

Part of the difficulty in predicting precisely the SSBN fleet hull life expectancy is because the methods by which these could be assessed were insufficiently developed at the time of the fleet's construction. The submarine hull is designed to remain stable up to a specified collapse pressure very much larger than the pressure experienced by the submarine at operational depth. In addition the pressure hull is subject to cyclic loads due to changes in depth experienced by a submarine during normal operation. The stresses from cyclic loading must be sustained without substantial fatigue damage during the submarines operational life. Determining the hydrostatic loads in terms of the specified collapse pressure in straightforward. But cyclic loading presents considerable problems. During a twenty year operational life an SSBN may be subject to around ten million cyclic loading stresses of varying degrees of severity. In order to predict the effect of such stresses it is necessary to maintain an accurate depth change profile for each operational period of a submarine. After a minimum of eight years operational experience with each SSBN it should be assumed that this data now exists in sufficient and representative quantity for each of the SSBN in the UK Fleet. The proper use of this data will permit a much greater degree of attention to hull fatigue problems as and when they might occur with each SSBN. At present it is recognised that all four SSBN will exceed their hull life expectancy by a minimum of five years. But at the end of that five years period it is quite possible that the hull life expectancy could again be extended for a further five years. These extensions depend on the number and frequency of the hull fatigue problems that might arise, and, of course, their severity. Of equal importance is the relative effectiveness of any remedial measures that might be taken.

Because submarine design criteria maintain wide margins of safety in engineering standards—particularly when sufficiently accurate data on fatigue problems is not available—it would be reasonable to assume that the original estimates of fatigue problems from cyclic loading were very conservative and that small modifications in operational procedure can greatly alleviate these problems. In addition to low cyclic stress fatigue problems there are high cyclic fatigue stresses due to the vibration from the submarine propeller and engine and machinery. Low and high cycle stresses in combination may also have an effect in advancing hull fatigue but providing due care and attention is given to these possibilities there is no reason to suggest that the UK SSBN fleet cannot remain operational throughout the 1990's.

In addition to the hull fatigue problems associated with low and high cycle stresses there are some other considerations worth noting. The submarine hull is constructed of high yield steel with a yield strength of 80,000 psi (HY 80).

But the welding of the hull constitutes a potential source of weakness. No submarine can be built without some imperfect welding and about ten per cent of the total welding of a new submarine may show minor fractures. However, with adequate maintenance and surveillance routines the conditions of the pressure hull welding can be carefully monitored and treated. General stress/fatigue problems resulting from hydrogen embrittlement, and stress corrosion cracking (SSC) can be expected to occur. While it may be possible to monitor all major areas of the submarine's hull for fatigue-related damage it is unlikely to be practical to attempt to determine this for the whole submarine. The submarine propeller is itself subject to cavitation corrosion but since this item is easily replaced it poses no serious problems.

Irradiation of the submarine hull in the reactor section could be a possible source of material damage. But it appears that this problem was anticipated because the reactor shielding for UK SSN/SSBN is thicker than that for equivalent American types. In most other respects the reactor design is identical with that of the Westinghouse S5W type which is the most prevalent type throughout the US and UK nuclear submarine fleets. A number of modifications have been made to the basic S5W design mainly to extend the core life which is currently estimated at around four years, and to quieten the noise made by the reactor during operation of the steam turbines (figure 2). Further information on the limited extent of this type of damage can be expected to become available in 1982 when the submarine hull and reactor section of HMS *Vulcan* are dismantled after 18 years of operation. At present it is possible to make 100 per cent inspections of the reactor pressure vessel using ultrasonic techniques and equally through assessments of the submarine hull section. So far there have been no signs that any significant radiation damage has been caused, and certainly no evidence to suggest that such damage could significantly reduce the anticipated operational life of the submarines.

In general, hull fatigue problems for the UK/SSN/SSBN fleet are being studied. This research effort should provide an adequate base for determining the latest point at which the SSBN fleet should be withdrawn from service without compromising any of the rigorous safety standards necessary for submarine operations. This period can at present be anticipated to be around the turn of the century.

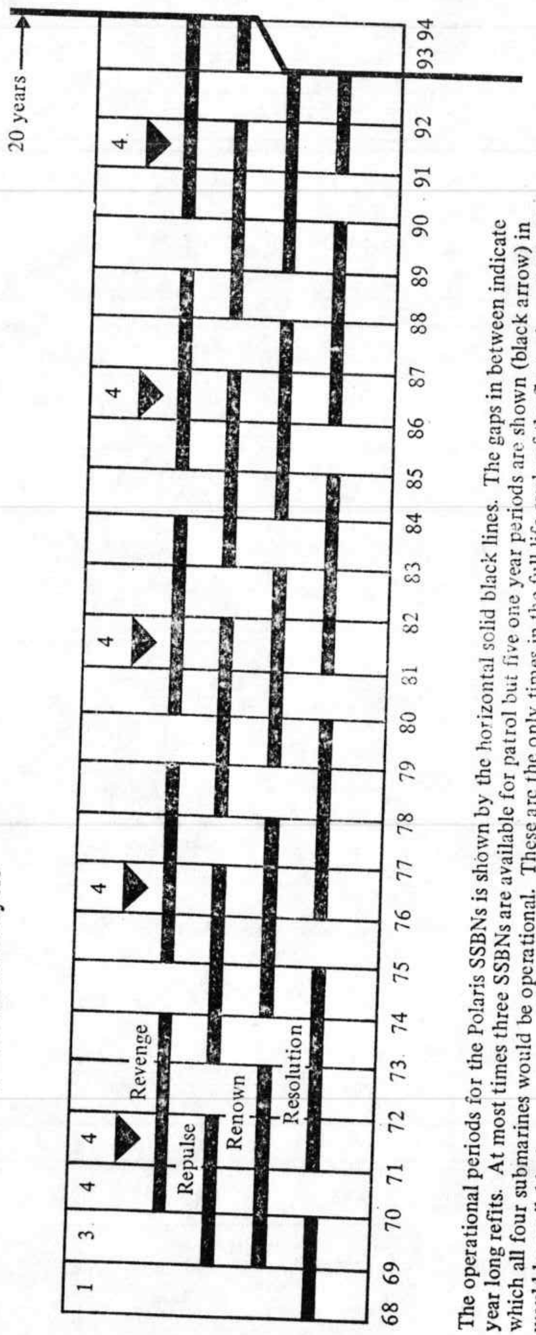
Vulnerability to ASW

The vulnerability of the UK Polaris fleet to Soviet ASW is perhaps one of the more exaggerated threats to its survivability. The argument rests on two main points: firstly, the small size of the SSBN fleet (one which under usual operational circumstances has only two submarines on patrol at any time). Secondly, the vulnerability of SSBN's to trailing by Soviet hunter/killer submarines. The significance of the first point diminishes when considering the UK Polaris fleet as being deployed as an integrated part of the NATO Theatre Nuclear Forces, and not as an independent one. At the time of some future crisis or impending war there is little reason to suppose that any significant military advantage would be forthcoming to the Soviet Union from an attempt to eliminate such a fractional part of the NATO TNF's in isolation. The second point is very much less important when considering the deployment areas for the UK Polaris fleet, and the extent to which NATO ASW can afford protection within them. In addition, any evaluation of the threat of Soviet ASW to US/UK and French SSBN's needs to take into account the substantial technological lead presently held by NATO.

For maximum effectiveness ASW operations combine the use of aircraft, ships, submarines, and elaborate data gathering and processing facilities incorporating the use of shore based computer facilities, and satellite communications. The effectiveness of Soviet ASW is usually calculated on the basis of the combined capabilities of these component forces. Even so these capabilities are thought to be at present only ten per cent effective. That is, if the Soviet ASW forces undertake hunt and kill operations against NATO submarines at sea only ten per cent of the fleet is expected to be destroyed. A comparable estimate for the effectiveness of the US/NATO ASW forces against Soviet submarines is about 30 per cent.

Because such combined ASW operations are easily observed and not particularly effective, they are not the most serious threat to SSBN's. This is posed by the

Fig 1
Polaris SSBN Fleet Operational Life Cycle



The operational periods for the Polaris SSBNs is shown by the horizontal solid black lines. The gaps in between indicate year long refits. At most times three SSBNs are available for patrol but five one year periods are shown (black arrow) in which all four submarines would be operational. These are the only times in the full life cycle of the fleet when all SSBNs would be available for patrol. At most other times three SSBNs are available for patrol. The period of hull life at twenty years is shown to occur around 1983–94. In practice all SSBNs can be expected to comfortably exceed the twenty year hull life expectancy. This diagram is an approximation based on data from open sources.

Nuclear Submarine Reactors (US and UK)

RDT & E	Reactor	Date of commission in submarine	Description	Submarine type	Submarine class name	Number of submarines in class
Westinghouse, Bettis Atomic Power Laboratory, Argonne National Laboratory	S1W	dismantled	PWR Land based (Thermal)	Prototype	Arco, Idaho	—
	S2W	1954	PWR Thermal	Attack	Decommissioned Nautilus*	1
	S2W–A	1959	PWR Thermal	Attack	Seawolf*	1
	S3W	1957/60	PWR Fleet	Hunter/K	(Skate) Halibut*	1
	S4W	1957	PWR Fleet	Hunter/K	Skate	4
	S5W	1959	PWR High Speed	Hunter/K SSBNs	Permit (18) Skipjack(s) SSBN4s	56
	S5W–A	1974	PWR High Speed, Silenced	Research/Attack	Lipscomb	1

* Research.

Technology Transfer (1958 and 1963)

Rolls Royce Associates, Admiralty Reactor Test Facility: HMS Vulcan	S5W	1963	PWR High Speed	Hunter/K	Dreadnought	1
	NSSS 1	1967	Extended Core Life	SSBNs	Resolution	4
		1966	S5W modification	Hunter/K	Valiant	2
	NSSS 2	1970	S5W mod. extended core life low noise.	Hunter/K	Churchill	3
	NSSS 3	1973	S5W mod. extended core life low noise.	Hunter/K	Swiftsure	5
	NSSS 4	Due mid-1980's	High Speed, Silenced. Original design.	Hunter/K SSBN	—	—

General Electric, Knolls Atomic Power Laboratory	S1G	dismantled	Intermediate sodium.	Land based	West Milton, N.Y.	—
		—	Liquid metal cooled.			
	S2G	dismantled	LMC Intermediate Sodium	Attack/res.	Seawolf	1
	S3G	—	PWR Advanced	Prototype Land based.	West Milton	—
	S4G	1959	2 PWR Advanced in 1 sub.	Radar Picket	Triton	1
	S5G	1969	PWR Natural Circulation	Land based and res./att.	Arco, Idaho, Narwhal	1
	D2G	1974	PWR Surface Ship reactor	Res./attack	Los Angeles	23

Combustion Engineering	S1C	1957	PWR compact, low noise	Land based	Windsor, Conn.	—
	S2C	1960	PWR compact low noise**	Hunter/K	Tullibee	1

** Linked to Turbo-electric drive.

possibility of a SSBN being continually trailed while on patrol by a Soviet hunter killer submarine which could on command proceed to destroy the SSBN before it could launch its missiles. But such a pre-emptive attack would require a minimum of two submarines devoted to trailing each SSBN in order to have a reasonable degree of confidence in the trail being maintained. Also required is a command and control network that could assure that more than 90 per cent of the SSBN fleet would be rapidly destroyed in such an attack. Factors that determine the likelihood of this type of threat depend on the size of the Soviet attack submarine fleet, its ability to operate against NATO ASW, and the technical requirements to achieve the ability to continuously trail SSBN.

Trailing SSBN

The Soviet fleet has 36 nuclear powered attack submarines compared with 76 available to NATO. This Soviet fleet is too small to trail, even one for one, the US/UK and French SSBN fleet comprising a total of fifty ballistic missile submarines. Even assuming a Soviet attempt to trail the SSBN in the NATO Theatre Nuclear Forces alone, some twelve to fourteen SSBN would require the efforts of the majority of the Soviet nuclear attack SSN fleet. Because of maintenance and operational patrol cycles (including transit times to and from base), at least two submarines need to be assigned to each SSBN in order to ensure a single submarine on trail. The attack submarines need to intercept the SSBN at the time they leave their bases and then maintain their trail throughout the SSBN patrol. This sort of operational procedure ensures assembly points around the SSBN bases all of which can be more than adequately protected by NATO ASW. The Soviet attack submarines can in turn be trailed by combined air, surface, and submarine forces, and since the SSBN deployment areas are within NATO coverage the relative effectiveness of a Soviet SSN trail is very unlikely to endanger more than a small fraction of the NATO SSBN fleet.

Some arguments have suggested that the Soviet diesel attack submarines could be used to trail SSBN. In particular, the 56 Foxtrot class submarines are considered by some US and NATO officials as very good for anti-submarine roles in the prime UK SSBN deployment area of the Norwegian Sea. However, these submarines cannot be considered effective for the continuous trailing of SSBN. Even when cruising at low speeds diesel submarines must recharge their batteries every 48 hours. During the period of recharge the diesel motor noise masks the submarine's sonar. In addition to being able to break the trail at these times an SSBN could probably outrun any diesel powered submarine with or without the assistance of countermeasures against its sonar.

The trailing of one submarine by another is achieved by acoustic detection. The propagation of sound undersea is considerably affected by the physical properties of the sea, such as the water temperature and salinity which may vary according to depth, geography and season. As the result of a very considerable research effort, systems and methods have been developed which make possible the prediction of sound propagation paths undersea for particular conditions and locations. However, some areas of ocean have natural conditions which make the use of sonar particularly difficult. A submarine attempting to trail another has to cope with a wide variety of acoustic anomalies created by changes in the physical state of the ocean.

The sonar system of the submarine can be active (that is, transmitting sound signals which are reflected back from objects underwater), or passive (that is, simply listening to sounds made underwater and determining the location, range and source). The advantage of the passive systems is that they have considerably greater range and do not reveal themselves to the submarine being trailed, which can listen for submarines and active sonar signals searching for it. For this reason attack submarines trailing an SSBN would tend to rely on passive sonar systems. It has been suggested previously that the UK Polaris fleet might be vulnerable to trailing by Soviet attack submarines using high frequency active sonar. Apart from the already mentioned disadvantage of active sonar for trailing, high frequencies are more rapidly attenuated underwater than low frequencies and so have much shorter range. In addition the propagation of higher frequencies underwater is subject to more complicated anomalies due to changes in sea state. Consequently, it is most unlikely that the Soviet attack submarines could maintain an effective trail of an SSBN by this method alone. But it is possible that some high frequency active sonar system could be of value to determine accurate locations just prior to an attack against an SSBN.

Sonar systems are being improved by the use of computer processing of ASW data, and though advances in materials technology which have made possible acoustic detection techniques several orders of magnitude more sensitive than those previously used. These are now capable of distinguishing submarines hundreds of kilometres away. But these advances are closely matched by efforts to silence submarines, and to develop a wide range of electronic and other countermeasures to reduce the likelihood of a submarine being detected, or, if momentarily located, to prevent trailing over long periods.

Silencing SSBN

All submarines create characteristic noise patterns which serve as " fingerprints " to identify them. The purpose of quietening a submarine is to reduce substantially or eliminate those noise levels and frequencies which are most characteristic of the submarine as distinct from other background noises in the ocean, particularly those frequencies which can be detected above background at long ranges. All measures to quieten submarines are attempts effectively to reduce the range at which the submarine may be detected. Some nuclear powered attack submarines have been specifically designed for low noise operation, others as research vessels to test possible improvements to existing SSN/SSBN's in which silencing was not a main design consideration.

The sources of poise when a submarine is moving underwater are generated in a large part by its propulsion machinery. In nuclear submarines the main sources can be identified as:

The reactor coolant pumps;

Steam turbines;

Propulsion gearing and drive shaft.

The last of these is most difficult to quieten. In some nuclear attack submarines attempts to reduce noise have involved replacement of the steam turbines with turbo-electric drive motors. In addition to the major sources of noise the movement of a submarine churns up the surrounding water and creates a characteristic and detectable sound. Submarine hull forms are designed to reduce this drag-induced noise to a minimum—the ideal hull forms being tear-drop or cigar shaped. Submarine propellor blade induced cavitation is an additional source of noise which is difficult to deal with and the design of the propellor attempts to maximise efficiency of operation and quietness.

In attempting to reduce the vulnerability of the UK Polaris fleet to Soviet ASW two approaches should be taken. The first is to quieten the operation of the submarines to the maximum level that is technically feasible and cost-effective. Secondly, to provide the SSBN with a range of countermeasures to make detection and particularly continuous trailing extremely difficult. Attempts to reduce noise levels generated by the UK SSBN have concentrated on quieter reactor operation, and on a variety of methods of damping the noise generated by the steam turbines and propulsion gearing. The use of certain metals with high specific damping capacity, (the ability to absorb sound frequencies and dissipate them in the form of heat), has been made for the external casings of gearing and motors. These metals do not have high tensile strengths and are not suitable for the construction of gearing or the drive shaft. Composite materials are also used in damping noise generated by propulsion machinery.

All these measures are incremental and costly to introduce into the existing SSBN fleet. The relative value of reducing noise levels has to be weighed against the cost of implementation over the protracted refit cycle of the UK SSBN fleet. A single major modification takes a minimum of four years before it can be fitted into all four submarines. However, substantial noise reductions have been possible with the SSBN fleet though it is likely that a threshold will shortly be reached where to improve the overall standard of operation. Similar changes (of systems and components) have been made to the software and missile computer memory for its storage and retieval of targetting information which it receives from the submarine's main computer. Such incremental improvements in the quality of the missile can be said to maintain the effectiveness of the Polaris A-3.

Improvements to the performance of the Polaris A-3 missile can be best implemented through changes to the guidance system. Although substantial advances have been made in propellants it is difficult to introduce these without extensive static testing and full flight tests of the complete missile. However, improved guidance systems can be retro-fitted to existing Polaris missiles having been flight tested on other launch vehicles.

The effect of changing the guidance system could substantially improve the accuracy of the Polaris missile. A similar change of guidance system for the US Titan ICBM has resulted in a considerable improvement of the estimated circular error probable (CEP) for the missile. Under the original guidance system the Polaris A-3 had an estimated CEP of 0·5 nautical mile, but with the fitting of advanced inertial guidance systems this CEP could be improved to 0·3 nautical mile.

Missile Costs

The UK Polaris missiles were bought very cheaply for a total of £53 million—42 per cent less than the estimated purchased cost. Any replacement missile would cost considerably larger amounts of money whether purchased from the United States or especially if developed independently. However in order to replace Polaris missiles fired in tests and to store spares in sufficient quantity the costs involved are likely to be around £50 millions at current prices—based on final production costs of the missile. It should be noted that such costs do not reflect the full cost involved in maintaining the Polaris missile. The additional costs incurred are related to various aspects of the Polaris improvement programme and intended improvements and modifications to the missile sub-systems. However, all costs associated with maintaining Polaris are likely to be considerably less than any replacement system. Although no formal approaches were made to the United States regarding the possible purchase of the Poseidon a figure quoted to the Defense sub-committee of the US Senate in 1971-72 estimated the cost of converting 31 Polaris submarines at being roughly 154·4 million dollars per boat (£62 million). The Poseidon programme ran into considerable development difficulties and the actual cost of conversion is substantially larger than this figure. In addition the conversion cost did not include the development of the MIRVed warhead for the missile. The costing for MIRVed warheads for the Polaris was given in 1973 to the Parliamentary Expenditure Committee as being in tens of millions rather than hundreds of million pounds. However, it seems likely that both the cost of Poseidon and the MIRV development for either missile were low estimates which have escalated following the difficulties encountered during the flight testing of Poseidon.

An additional factor is that conversion to Poseidon would have increased the MTE of the UK fleet from around thirty to sixty megaton equivalents, and provided considerably greater flexibility in targetting. It would also have considerably increased the total number of warheads available. The principal difficulty of an option based on replacing the Polaris with a fourth or fifth generation US SLBM (either Poseidon or Trident) lies in persuading any future or present President of its necessity. The exclusion of sale or transfer of such technology to third countries is under consideration in US-Soviet arms control negotiations and an arrangement which substantially increases the nuclear capability of the present British force would weigh heavily on the consequent issues relating to strategic balance estimates for SALT. But a replacement strategic weapon system which leaves the overall balance in much the same state might find acceptance. At present it is not clear how the Soviet Union would respond to the US making a decision to supply technology or assistance for a follow on strategic weapon system to Polaris but with roughly equivalent strategic lethality. There is considerable room for irreconcilable dispute over this issue which, in any case, may not become transparent until the treaty drafting stages or even later.

The option of a solely British-developed missile presents considerable problems. The cost of such a programme is likely to be prohibitive, and the estimates that could be made are unlikely to be reliable because the range of developmental problems cannot be anticipated. The industrial base for the development of a British ballistic missile was largely lost following the cancellation of the Blue Streak and could not now be easily resurrected. The British aerospace industries do not provide sufficient diversity in the key technical areas to allow for any kind of competitive tender for parts of a ballistic missile project. Any difficulties that arise during development would have to be treated as a method by which manufacturers were "learning the techniques as they went along".

There is bound to be a high degree of inaccuracy in predicting development and production costs for any advanced technology system particularly where the industrial base must be specially expanded to accommodate the project. In this respect it is worth reflecting on the experiences with Blue Streak and with British experiences within the European Launcher Development Organisation (ELDO). More recently projects such as Concorde and the Panavia Tornado have also shown the difficulties of keeping development costs within those originally estimated. On the basis of the required expansion of the British Aerospace industry, labour costs, and the technical problems involved it seems reasonable to anticipate the costs for RDT & E for an independent ballistic missile project to be around £2,000–£2,500 million at current prices. This figure is roughly three times larger than that given by Ian Smart ("The Future of the British Nuclear Deterrent", The Royal Institute for International Affairs, 1977). The cost for the production of 200 or so missiles is based on the final production costs of the Polaris A-3 and Poseidon C-3 SLBM and would perhaps be in the region of £500–£1,000 millions. (For operating costs see figures 3, 4).

Figure 3

Polaris SSBN Life Cycle Costs.

30 *January* 1964 *estimate :*

£140·3 million for 4 submarines.
£92·2 million for 16x4 Polaris A3 missiles.

Actual cost

£162 million for 4 submarines (6 per cent increase).
£53 million for missiles (42 per cent decrease).
Overall decrease in purchase cost for SSBN fleet and missiles was 42 per cent.

Operational costs

1963–64	na
1964–65	na
1965–66	£128 million (includes bomber force)
1966–67	£60 million (total £105 million, £45 million for bomber force)
1967–68	£65 million (total £104 million, £39 million for bomber force)
1968–-69	£70 million (total £95 million, £25 million for bomber force)
1969–70	£55 million (total £60 million, £5 million for bomber force)
1970–71	£32 million
1971–72	£34 million
1972–73	£38 million
1973–74	£39 million
1974–75	no defence estimates published.
1975–76	£58 million
1976–77	£78 million
1977–78	£96 million
1978–79	£93 million

Nuclear R&D estimate for Polaris Improvement Programme begun 1974–75 is given as £450–500 millions.

The possibility of an Anglo-French developed SLBM successor to Polaris is frequently presented as a prospect where British participation would be in the area of warhead technology and the French participation in terms of the missile propulsion. The greatest single obstacle to this scheme is that it is unlikely that Britain can offer sufficient expertise to the French to make co-operative participation worthwhile (see next section). Also such co-operation would require US approval because of the information exchange and commonality of nuclear weapons design specifications between the United States and Britain.

WARHEAD TECHNOLOGY

Changes in the warhead configuration for the UK Polaris missiles have been considered in order to improve their ability to penetrate Soviet ABM defences, and to provide greater flexibility in targetting. The Polaris improvement programme which included some warhead modifications was begun in 1973 and was one of three separate warhead development projects which had been under way at the Atomic Weapons Research Establishment (AWRE), Aldermaston. The other two projects were to develop a low yield air-delivered nuclear weapon and an artillery-fired atomic projectile AFAP. The latter has since been cancelled. Recent reports suggest that the Polaris warhead improvement programme has run into difficulties and that it too has been cancelled in favour of purchasing an American-designed warhead and re-entry vehicle to replace the present triplet warhead on Polaris.

Since the initiation of the Polaris improvement programme the United Kingdom has conducted three underground nuclear tests at the Nevada test site, (figure 5). Data derived from seismological detection indicated that the estimated yields of these three tests were in the 20-150 kiloton range. Although the Minister of Defence has claimed that some of these tests were connected with the maintenance of the existing warheads this explanation seems unlikely. Between 1963-74 the United Kingdom conducted only five underground nuclear weapons tests. If only two weapons tests were required for evaluating the design and efficiency of operation of the British Polaris warhead, the renewed rate of testing seems to suggest changes in the warhead design rather than tests of reliability, of which very few are ever required. It is worth comparing the number of French nuclear tests over the same period (66 tests since 1963), to gauge whether British expertise in nuclear weapons design can any longer be considered significantly ahead of the French. It is unlikely that, given the very large effort placed on nuclear weapons development by the French, they would be in sufficient difficulty to warrant any degree of enthusiasm for Anglo-French nuclear collaboration.

Fig. 5

British Nuclear Weapons Tests since 1963

Date	*Time*	*Site and Type*	*Yield estimated*	*Name*
17 July 1964	171830	NTS—U	Low	Cormorant
10 September 1965 ...	171200	NTS—U	15Kt	Charcoal
23 May 1974	—	NTS—U	L—I	Fallon
26 August 1976 ...	143000	NTS—U	L—I	—
May 1977	—	NTS—U	—	Antelope*
April 1978	—	NTS—U	20–150Kt	—

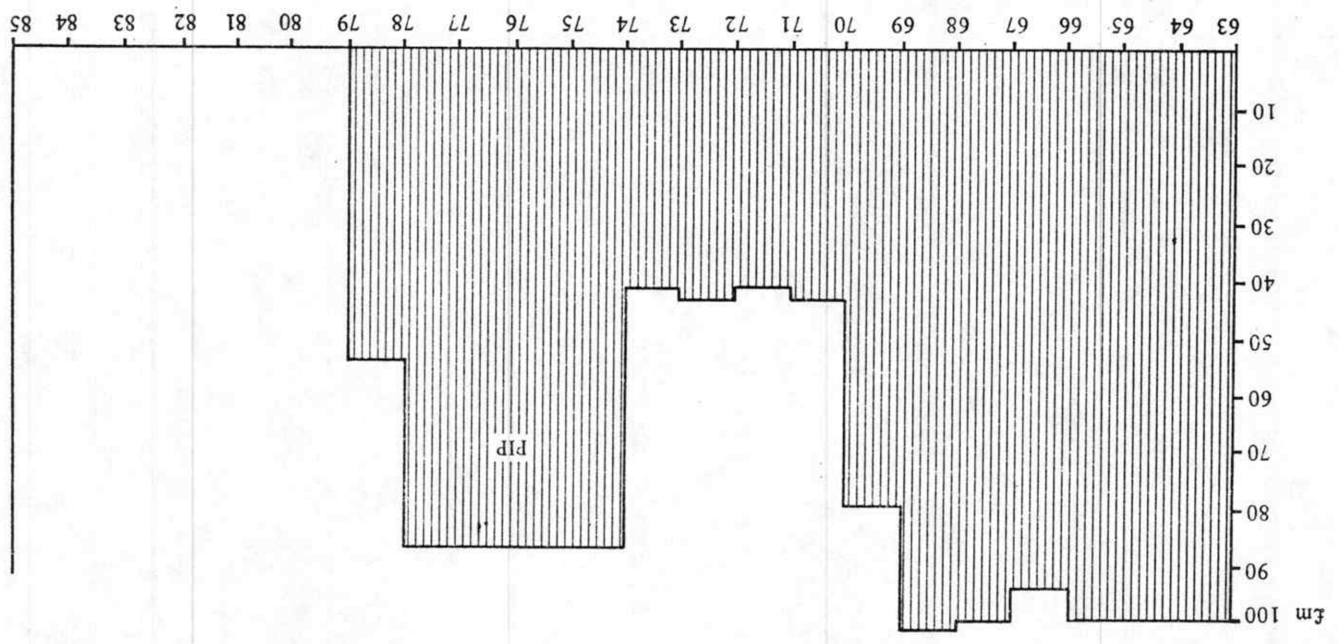
NTS: Nevada Test Site.
U: Underground.
L—I: Low to Intermediate.

* Two weapons tests were scheduled but were postponed.

Note: The Threshold Test Ban Treaty limiting nuclear weapons tests to yields not exceeding 150Kt was signed 3 July 1974.

The estimated yields of the UK nuclear weapons tests are an indicator of the warhead development undertaken in the Polaris improvement programme. The throw-weight of the Polaris missile—that is the weight of the warhead, re-entry vehicle and penetration aids that it can carry to target—is around 454 kilograms. Within this weight limitation a Polaris missile can be armed with up to six warheads of around 40 kiloton yield. The overall weight of the warheads and re-entry vehicles

Fig 4



at 1974 prices

R & D and operating costs for the U.K. Polaris Fleet is shown above (@ constant prices for 1974) PIP represents the Polaris improvement programme. Running costs from 1970–79 are shown as being between £40–£50 millions per year (@ 1974 prices).

reduced estimates of the missile's range. Because of favourable deployment areas the United Kingdom Polaris missiles can afford some range deduction and still be able to reach all required targets in the western Soviet Union.

It is important to recognise that changes in the Polaris warhead are not required strictly to maintain penetration capability of the missiles against Soviet ABM defences. The Polaris missile with its original 3x200 Kt triplet warhead is essentially a counter-city weapon. All three warheads have a maximum separation of half a mile providing an explosive force of one megaton equivalent over an area target. The contribution of the UK Polaris fleet to the NATO TNF's is limited by confining the targeting of the missiles to large area targets. By improving the accuracy of the Polaris missiles and replacing the existing warheads with lower yield and larger separation of warheads the targeting flexibility and strategic lethality of the force is improved.

The strategic lethality of a given missile force against point targets depends on the relative accuracy of the missile and the warhead yield. A rough approximation of strategic lethality can be calculated using the formula:

$$K = \frac{y^{\frac{2}{3}}}{(CEP)^2}$$

where K is the index of lethality. y=yield of warhead (megatons), CEP is the circular area probable of the missile.

K increases much more rapidly with improvements in accuracy than with increases in yield. If a missile carries n warheads, each of lethality K, then Kn is the cumulative destructive power of that missile against point targets. The total number of missiles in the force gives Knm=KN which is an approximation of the lethality of that force against a given number of point targets (one target per warhead in the case of independent re-entry vehicle, one target per three warheads in the case of Polaris with 3x200Kt warhead configuration).

The strategic lethality of the UK Polaris fleet can be estimated for improvements in missile accuracy and/or changes in the warhead configuration and these are shown:

Missile	Yield (MT)	CEP (nm)	K	Number of re-entry vehicles	M	KN
(*a*) Polaris A-3 ...	0·20	0·5	1·4	3	64	269
(*b*) Polaris A-3 ...	0·20	0·4	2·2	3	64	422
(*c*) Polaris A-3 ...	0·20	0·3	3·8	3	64	746
(*d*) Polaris A-3 ...	0·04	0·5	0·48	6	64	184
(*e*) Polaris A-3 ...	0·04	0·4	0·75	6	64	288
(*f*) Polaris A-3 ...	0·04	0·3	1·3	6	64	499

While the KN for (*b*) and (*c*) are substantial improvements on that for the present force configurated as (*a*), all three examples are limited to one target per missile. For cases (*d*), (*e*) and (*f*), up to six smaller targets per missile would be available. Even if only two independently targetable warheads were to be fitted the number of target options would be doubled.

For comparison the MTE for the UK Polaris fleet after a conversion to 6x40Kt warheads per mission would be:

32 x 6 x 0.11696 = 22.5 for two submarines
48 x 6 x 0.11696 = 33.7 for three submarines
64 x 6 x 0.11696 = 44.9 for four submarines

(Where $y^{\frac{2}{3}} = 0.11696$, $y = 0.04$ Mt.)

fleet in its original configuration. But even for a fleet of four Poseidon missile submarines with sixteen missiles each and armed with ten MIRVs per missile this would increase to 105 MTE. These are relatively small increases in MTE compared with the cost of implementation. However, with the Poseidon option as with cases (*d*), (*e*) and (*f*) the KN and number of targeting options are considerably increased.

Both the KN and MTE approximations are relatively crude methods by which to determine the credibility of a strategic deterrent force. But it is possible to see that changes in warhead configuration and improvements in missile accuracy are by far the most important factors in technically improving the capability of any given strategic force. Also, both changes are much cheaper to implement than complete changes to new missiles.

Vulnerability to ABM

In order to increase the penetration capability of the warhead re-entry vehicles against ABM defences a number of penetration aids are carried by the missile. The additional weight is a limiting factor on the throw-weight available for the warheads themselves. It is possible therefore to conceive of a Polaris warhead modification which has only two independently targetable warheads but which are supported by both endo-atmospheric and exo-atmospheric penetration aids. These usually consist of chaff to " blind " radar, decoy warheads, and various electronic countermeasures to deceive the tracking radar and IR of ABM.

Both US and Soviet ABM systems are restricted by treaty but research and development of new systems is permitted. Since the early 1970's the Soviet Union has demonstrated a number of qualitative improvements it is capable of making to its ABM force. These relate specially to the operation of its ICBM tracking radars but also to the development and testing of new ABM. The testing of certain air defence radars (SAM-5) in phased array against re-entry vehicles simulating an ICBM/SLBM attack was halted in 1975 only after protest that some violation of SALT had occurred and even then only after sixty tests had been completed.

These tests might suggest that the Soviet Union was preparing to use SAM-5 launchers for terminal ABM defence in the event of a nuclear attack. There are 1,100 SAM-5 launchers deployed around the Soviet Union and the SAM-5 missile, though originally designed as an high altitude air defence weapon, is thought to be capable of being used as an ABM after some modification. There are reports of a Soviet ABM similar in external configuration (necessary for hypersonic flight) to the US Sprint ABM. In most respects the possibilities for substantial qualitative improvement of existing ABM systems is large and does not depend on the application of exotic technologies such as high energy lasers and charged particle beams.

If the SAM-5 launchers were able to be used in an ABM defence, for example, this would provide the Soviet Union with an ABM warhead to attacking ballistic missile ratio of roughly 2:1 against the US intercontinental and submarine launched ballistic missiles. But against the independent operation of a British Polaris fleet the ABM warhead to ballistic missile ratio is around 20:1. These ratios do not take into account the reload capabilities of Galosh and SAM-5s and which are estimated at around six missiles per launcher (for SAM-5s).

The prospect of maintaining penetration capabilities of strategic missiles against the suspected improvement of Soviet ABM defences is reasonable for the United States because of the total number of missiles and warheads in her strategic arsenal. With the assistance of advanced penetration aids and manoeuvrable warheads that can evade attacking ABMs a significantly large fraction of the US missile force can be expected to reach their targets. But for a small missile force such as the British and French the chances of maintaining credible defences (on the basis of the criteria described in the appendix) against the Soviet ABM defence is diminishing—if such a force is considered as one that must maintain distinct independence from the United States.

In November 1977 it was reported from sources in Washington that the UK had cancelled plans to complete the development of a new warhead for the Polaris missile in favour of purchasing an American designed warhead and re-entry vehicle. The reason for the cancellation (if the report is accurate) is likely to be based on the political directives being made towards a comprehensive test ban treaty. If such a treaty were to be signed within the next couple of years it is unlikely that the present warhead development programme would have been completed. But even if a purchase agreement for an American designed and tested warhead for the British Polaris missile is to be made this is unlikely to reduce much the present level of activity in British nuclear weapons research.

American and British nuclear weapons research and development have been closely interconnected by exchange agreements. As a result British and American nuclear weapons designs have substantial commonality of component parts, materials, and testing and evaluation methods. The original warheads and re-entry vehicles for the British Polaris missiles were virtually the same design as those for the American Polaris except that the British warheads were manufactured and assembled at facilities in Britain and tested under British direction at the Nevada Test Site with the co-operation of the United States. In addition British nuclear weapons research contributes in small measure to that of the United States though the full extent of the collaborative research with American nuclear weapons laboratories is unknown. It is also reported that a significant amount of collaborative research is financially supported by grants from the US nuclear weapons laboratories. One consequence of this extensive co-operation is that the British ability to build and develop new nuclear weapon types without American assistance is much reduced.

Because British nuclear weapons make use of special nuclear material produced in the United States and purchased by Britain, an attempt to build nuclear weapons wholly independently would require expensive expansions of the nuclear industry in the UK. Occasionally, the cost of nuclear weapons production can and has been reduced by obtaining as much of these special nuclear materials as possible from indigenous sources. A case in point is the manufacture of tritium for which Britain had formerly maintained a purchase agreement with the United States since 1958. This agreement was renewed in 1974 but was cancelled in 1976 two years before it was due for renewal. The cancellation was brought about because it had become possible to produce tritium in sufficient quantities in Britain and to do so would save money. The cancellation should not be interpreted as being a shift towards independent development of nuclear weapons since other special nuclear materials that are purchased from the United States would be extremely expensive to produce within the UK.

It would appear that within the period that the Polaris fleet is expected to operate the most suitable form of modification to the warhead is to provide independently targetable re-entry vehicles even though this would slightly reduce the yield available per warhead. But even two independently targetable warheads per missile would increase the targetting options currently available and would improve penetration capability against improved Soviet ABM defences. The extent to which these changes are required depends very much on how the missiles are targeted. While the British Polaris fleet is targeted as an integral part of SIOP the effective penetration capability of the missiles would always be substantially greater than if it were considered as an independent force. Apart from the Polaris warhead the extent to which the development of a new low yield warhead for delivery by tactical aircraft is needed depends on whether a political decision has been made to maintain "wholly" British nuclear weapons within the present American stockpile at the disposal of NATO. At present the majority of the British weapons are air-delivered bombs and a much smaller number of nuclear depth charges, and these weapons are placed at the disposal of NATO in a similar manner to the Polaris fleet. But the British nuclear weapons are being phased out as they reach obsolescence and are replaced by US systems. The British stockpile had originated from early research, development and production prior to the acquisition of the Polaris system. In the future it may become increasingly difficult to justify maintaining the expense of independently developed nuclear weapons for the NATO TNFs particularly when US nuclear warheads are already required for the British operated Lance missile and for nuclear-capable artillery.

If a comprehensive test ban treaty is signed within the next two years and the UK intends to sign, then it will be necessary to abandon any nuclear weapon programme which still requires testing. It would appear that such programmes that relate to Polaris or to lower yield weapons for tactical or theatre use in Europe can be cancelled in favour of reliance on American types currently available.

SUMMARY

The decision regarding a follow on strategic weapon system after the Polaris fleet reaches obsolescence is considered to rest on a ten year lead time for the development and deployment of any new strategic weapon system. The factors affecting the operational life of the present Polaris force based on the hull life of the submarines, vulnerability of the submarines to Soviet ASW, and the effective life of the Polaris missiles suggests that the period when a decison must be taken will not be reached until 1987-89.

Submarine Hull Life: Based on known problems relating to structural fatigue of submarines the hull life of the UK SSBN is likely to exceed the original estimates by five to ten years. This means that the SSBN fleet is unlikely to have to be withdrawn from operation until around the turn of the century. Providing reasonable attention is given to hull fatigue criteria no compromises need be made in the standards of safety and operation required for the SSBN fleet.

Vulnerability to ASW: Soviet ASW does not pose any significant threat to the UK Polaris fleet while it is deployed as a constituent part of the NATO Theatre Nuclear Forces, and while the SSBN fleet is afforded the protection of NATO ASW cover. Specific measures can be taken to further reduce this vulnerability by carrying out measures to silence the submarines, and to provide electronic countermeasures against attempts to trail them by Soviet hunter/killer submarines.

Operational Life of the Polaris A-3 SLBM: The Polaris missile can be maintained effectively throughout the period of the SSBN hull life expectancy. The shelf-life of the solid propellent motors can be extended by refrigerated storage and sufficient numbers of replacement motors and other spares are available from the United States. The accuracy of the missile and other factors relating to its qualitative performance can be upgraded within standard operational maintenance and overhaul routines. A comparatively limited number of replacement missiles and related spares would be required to maintain Polaris. The costs of an independently developed ballistic missile are considered to be prohibitive, and the prospects for Anglo-French collaboration are considered unrealistic.

Warhead Technology: If a Comprehensive Test Ban Treaty is to be signed within the next few years it is considered that the UK will not be able to develop a new warhead either for Polaris or for any follow-on ballistic missile. While the UK is capable of independently developing nuclear weapons the result of extensive American co-operation and use of US nuclear test facilities has resulted in an erosion of the capacity to develop nuclear weapons independent of American assistance. Consequently any follow-on system or decision to modify the Polaris warhead is likely to require the use of an American design. This will definitely be the case if a Comprehensive Test Ban Treaty is signed.

January **1978**