University of Southampton

Lifeboats

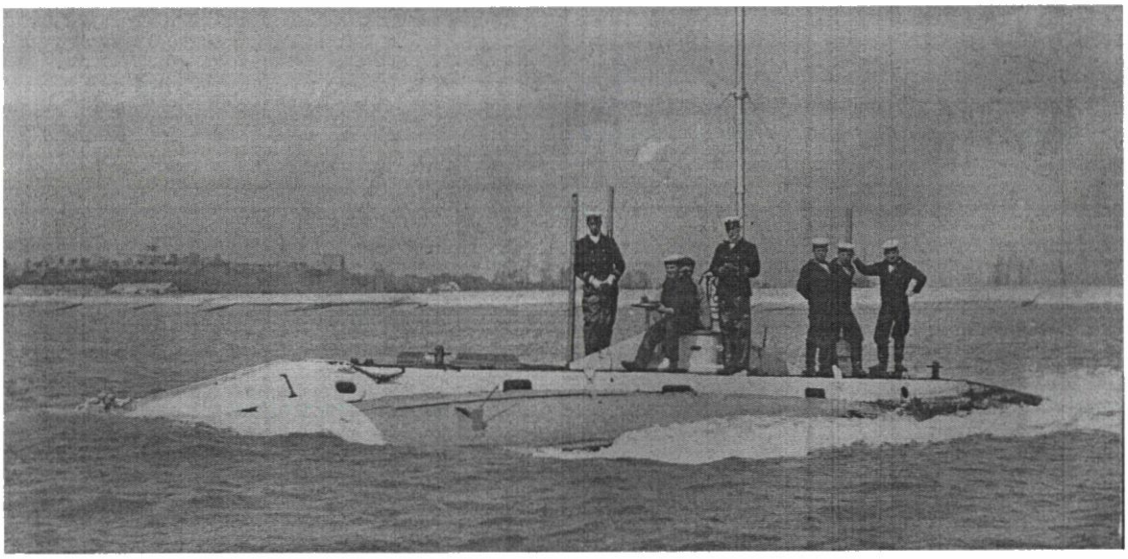
School of Engineering Sciences

Ship Science

Buying Boats – Comparing Lifeboats and Nuclear Submarines

University of Southampton RNLI lecture - 2 December 2003

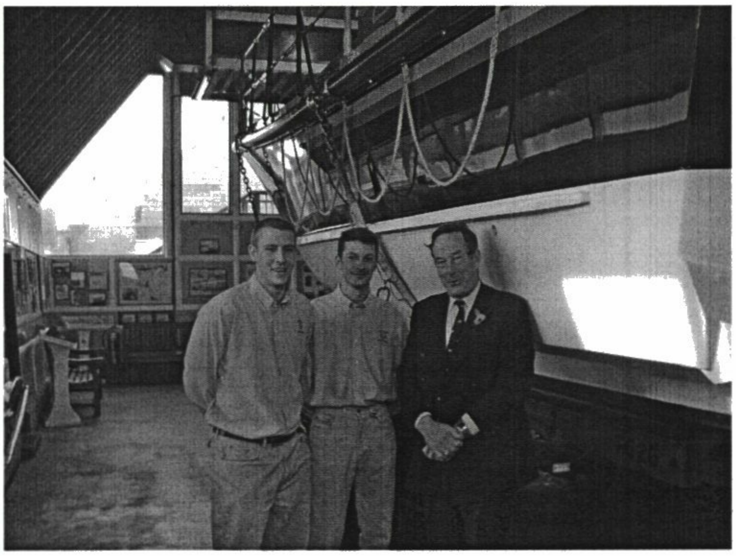
The intended theme of these talks is safety and engineering in the maritime environment. I am very conscious that the two preceding speakers at this event, which in its third occurrence surely qualifies as a traditional annual lecture, were exceptionally well endowed with personal experience in particular areas of these subjects. It will therefore come as no surprise that I have chosen a topic which suits my own background. However unlikely, the subject of my talk is therefore a comparison between buying two sorts of boats: lifeboats for the RNLI and nuclear submarines for the Royal Navy. The unifying theme which brings relevance to this comparison is the need to deliver a service with people using a vessel; a vessel which doesn't exist at the time the first contract is placed and which for operational and safety reasons must embody unquestionable standards of excellence.



For the Royal Navy this is more or less how it all started. The submarine pictured here, with its distinctly jaunty looking crew, was one of five Holland class, named after their Irish designer John Holland who had gone to work in the United States in the 19th century. After a number of US prototypes seemed to bring the prospect of a working submarine close to reality, the Admiralty became seriously interested and ordered the 5 Royal Navy Hollands to be built at the Vickers yard in Barrow-in-Furness between 1901 and 1903. It is these boats which were the justification for our submarine service celebrating its centenary a couple of years ago. Powered by an American petrol engine, they displaced just over a hundred tons, had a dived endurance of 3 hours at five knots and were armed with a single torpedo tube. In effect they had little fighting value. But they did ensure that crucial submarine disciplines were learned: controlling the watertight integrity boundary; managing lead acid batteries with their tendency to produce potentially explosive hydrogen; and coping with the awkward combination of a petrol engine - which means unbreathable fumes - with a Direct Current motor - which means sparks. In the round, taking on just a handful of these 100 ton craft required the establishment of a new set of naval competences.

And it all had to be done at the double. By 1906, the United States had 12 submarines, the Russians had 27 in service or planned, the French had 45 and the Royal Navy had 35. Sensitive naval security issues derived from the need to develop and learn new technologies and from the strategic significance of the promised capability. Partly for these reasons and partly because of the imperative of speedy construction, the Admiralty designated the shipyard at Barrow as the sole supplier of submarines until 1912. But despite the Hollands costing only £35,000 each compared to the £1,000,000 for a contemporary battleship, then as now it will not have been easy to agree a price and specification for a new vessel, particularly in the absence of competition. The dominant naval personality of the day was Admiral Fisher and he was extremely concerned to enhance the Royal Navy's submarine fleet. Never a man to take kindly to delays, he will have been extremely irritated by the then Principal Director of Navy Contracts' explanation of the difficulty of agreeing a submarine contract with the Vickers Shipyard. In a resounding admonition, Admiral Jackie Fisher thundered: **"I want submarines, not contracts. And if I do not get submarines, I will turn your wife into a widow, and your home into a dunghill."** I have had quite a few experiences of an uncomfortably similar nature and the rest of this talk may be not wholly inaccurately characterised as my response to such criticisms.

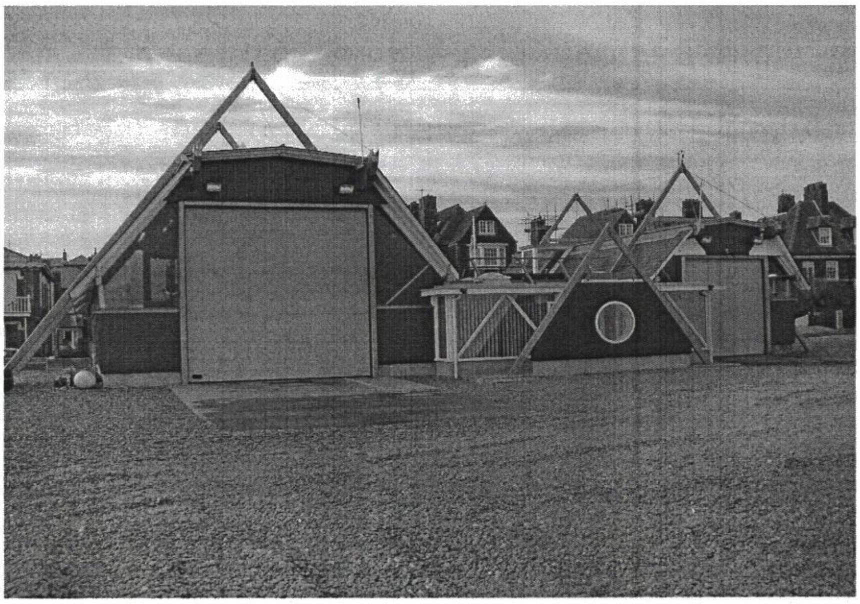
By way of further explanation of the talk's title, I should comment on the longstanding naval custom of referring to submarines as 'boats'. Always difficult to get to the root of such usage, but the Oxford English Dictionary gives a clue when it explains that the term 'boat' is basically applied to a small open craft and that this is often extended to larger vessels which are in some way different from a ship. Well the first submarines didn't have names, just numbers, and were for purposes of pay and administration classed as tenders to a larger vessel; they could, I suppose, be seen as ship's boats in that sense. They also fail the technical test, sometimes used for defining a ship, of having a continuous upper deck, a criterion which nicely contrasts with the OED's 'open craft'. Whatever the reason, the tradition of referring to submarines as boats is deeply embedded, although I've never felt that it should be written usage and have a residual unease that it is an inappropriate description of a 15,000 tonne ballistic missile submarine. Nor is all submariner's language so difficult to explain: 'Baby's Head' just is an accurate description of a tinned steak and kidney pudding; and the absolute prohibition on the use of the word 'close' in preference to 'shut' just reflects the imperative of clear orders in relation to maintaining watertight integrity.



Here is another jaunty crew, namely the Coxswain, Mechanic and Secretary of the Aldeburgh lifeboat pictured alongside their Mersey class vessel safely in its dry stowage position. I think it is right to start with the people because it is they who turn material potential into capability, and in this respect one cannot but be struck by the new attention to training being given by the RNLI. The move to Competence-based Training, with economical arrangements for taking it to where the crews are, is a major and expensive undertaking but is also an important part of the commitment to safety. To my mind this strongly echoes the disciplines of the submarine service, where on arriving in one's first boat, one is designated as a 'Part 3', which is a shorthand recognition of the need to complete a third component of one's training after basic naval training and then classroom work on submarine subjects. For every Part 3 submariner, a formal notebook is completed after about three months sea service in his first submarine. By this time a trainee will be expected to be able to demonstrate a good overall knowledge of the submarine, including the position and function of the valves and hatches controlling watertight boundaries.

The acquisition of such knowledge is greatly helped by the use of pocket sized training aid books. These are well produced, both in their physical robustness and in the quality of their text and illustrations. They contain detailed and accurate diagrams of every system on board, together with an explanation of its purpose and how it works. Despite being expensive to produce, they are a lot cheaper than the alternatives of either system ignorance or incorrect knowledge. I am told that the idea of training aid books was uncovered by the Americans after World War II as having been adopted by the German Navy in order to train U-boat crews in the fastest and most reliable way. The scheme was then adapted by the US Navy to support the expansion of their nuclear fleet and migrated from there to the

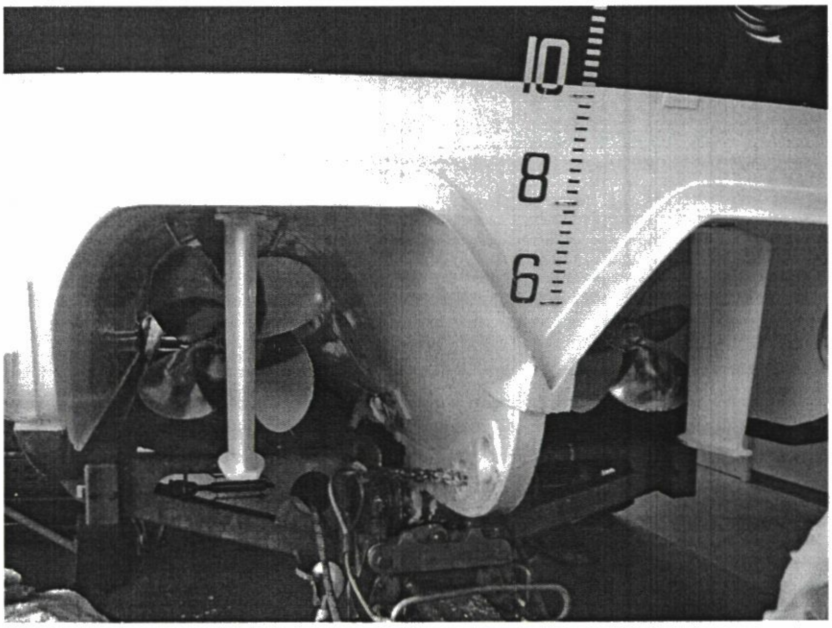
Royal Navy as part of the arrangements for our first nuclear submarine. Whatever the details for delivering training, they do need to be given the greatest attention, including putting really good people in charge – trainers who can both deliver effective instruction and easily command the respect of the trainees. In consequence of this emphasis on being qualified to do the job, the term 'Part 3' has long passed into submarine folklore as a kindly if somewhat dismissive description of anybody who doesn't seem to know what they're doing in any walk of life. But it doesn't go down well in a domestic kitchen.



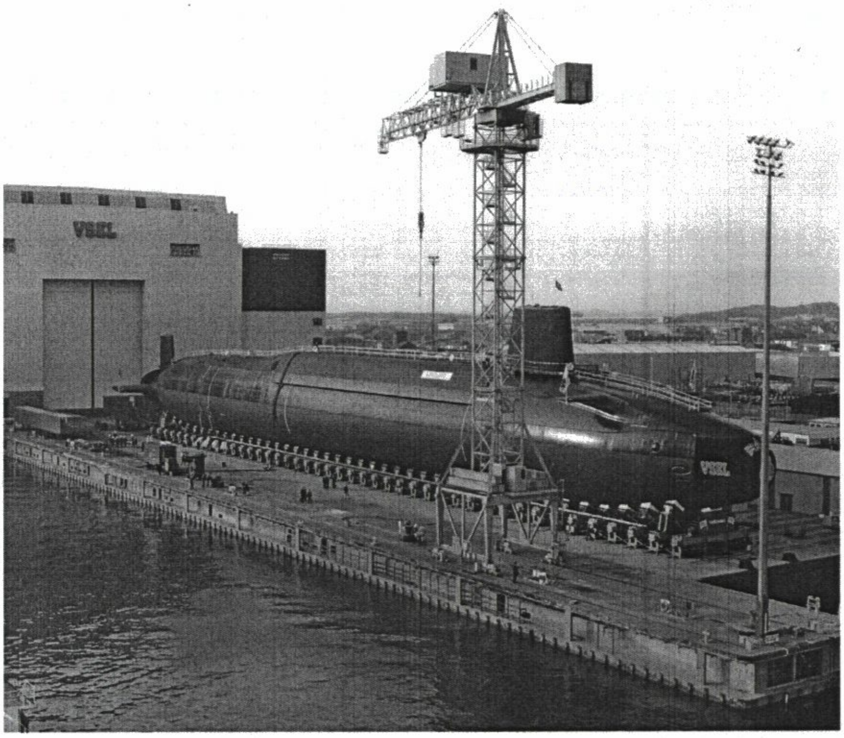
The assured availability of a lifeboat includes the arrangements for getting it into the water, or for looking after it if it is kept afloat. This rather futuristic new lifeboat station on the Suffolk coast faces the sea across some 50 metres of typical shingle. The lifeboat's waterproof tractor is kept under cover at the station and pulls the lifeboat, strapped down onto its launching carriage, first out of the shed at the left hand side of this picture, before manoeuvring so that the tractor can push the carriage and lifeboat bow first into the sea.

Crucial decisions have to be made by those on board about releasing the lifeboat, with its engines running, from the carriage strap down arrangements at just the right moment, and immediately afterwards the tractor crew must launch the lifeboat off its carriage by an ingenious catapult arrangement.

It’s a dynamic process even if the sea is calm, but in the rough weather which can easily be associated with a call-out, or ‘shout’, it requires good co-ordination and execution. This picture is approaching the moment critique for a rough weather launch at Aldeburgh. It didn’t go as well as expected and the lifeboat was soon rolling beam on against the shelving shingle beach, with the Coxswain applying all the stern power he could muster to pull her off.



And it most certainly isn't luck, that even on those occasions when the carriage launch isn't smoothly executed the lifeboat hull is strong enough and the propellers well enough shielded in troughs, properly known as tunnels by boat designers, for the lifeboat to get underway and fulfil its mission. The usual amateur videos of such unseamanlike occurrences then go on to provide years of good humoured entertainment for those who were and were not involved alike, with the former being notably less easy to find. But it is impossible to ignore the overall impression of fitness for purpose of the hull and propulsion combination in the context of a lifeboat's mission and launching arrangements.



Here is a submarine about to undergo a launch that is designed to be anything but dynamic. At the extreme left hand end of the vessel you can see the upper rudder sticking up proudly and, just to the left of that, the horizontal starboard after stabiliser. Between these two massive pieces of structure is a smudge, which is about as clear a view as anyone here will ever get of the single propulsor used in a nuclear submarine. The propulsor must work absolutely silently even at high speed and it certainly turns much more slowly than a lifeboat's propellers, despite being able to give a significantly higher speed to this 15000 tonne vessel. The design, manufacture, operation and maintenance of a submarine's propulsion train is a critical determinant of acoustic signature or stealth, and therefore of the submarine's performance. In the underwater world, detecting others long before they detect you is nearly as important as watertight integrity, because ultimately they can be the same thing. Comparing the lifeboat propellers with the submarine arrangements is another gold standard instance of a principle first enunciated by a famous zoologist, Sir D'arcy Thompson, in 1917: **structure is an expression of function**. Engineers and boat designers ignore this principle at their and others' peril.

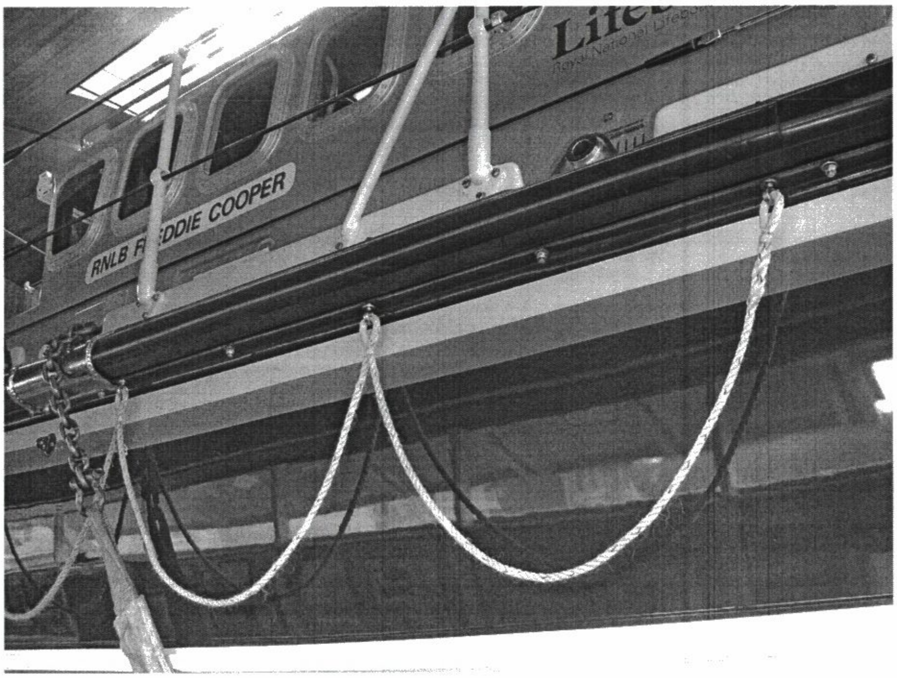
Returning to the picture, the submarine, which is virtually complete in all respects and is coming towards the end of a six year build period, has been transported on bogeys so that it is sitting on a large flat platform, known as a shiplift, which can be very slowly lowered into the water so that the submarine can then be floated off. In the background are the closed doors of a much bigger shed than the Aldeburgh lifeboat station. The proper name of the Barrow shed is the Devonshire Dock Hall or DDH and, when this picture was taken just over 10 years ago, it was part of Vickers Shipbuilding and Engineering Limited. It is within this DDH that the submarine was built and in which 3 or more other vessels would generally be at different stages of construction. It is always difficult to get an idea of the scale of really large buildings from photographs, but some sort of a yardstick is that the internal area available for shipbuilding is about twice the size of Manchester United's Old Trafford ground.

The principal motivation for investing in the DDH was to improve shipyard productivity by bringing submarine construction out of the weather and onto a level surface. I should explain that submarine pressure hulls have to be perfectly circular in order to withstand diving stresses and that the construction process generally consists of a number, say 4 or 5, of massive hoop shaped sections that are first filled from both ends with as much equipment as possible, and are then butt welded together on the building berth. The absence of the need to launch down an inclined slipway avoids one of the most traumatic events in any ship's life and is to be welcomed in itself. In the case of a submarine, as with many other ships, the launch event also generally imposes a carefully calculated all-up weight limitation. Whatever has had to be left out of the hull to meet this launch weight limit by way of equipment, pipes, cabling etc has to be put in later.

Rules of thumb are both useful and dangerous generalisations, but chancing my arm, I would say there is a 10 to 1 factor between the cost of doing something afloat, where access has to be via hatches and along, up and down what seem extremely narrow internal passages and ladders, and the cost of doing it in a construction hall when there is full access across both ends of the 10 metre or so hull diameter. And doing stuff afloat always carries the nightmare possibility of seriously compromising watertight integrity. After all, it was on 15 May 1969 that the USS GUITARRO, while being fitted out at the San Francisco Bay Naval Shipyard, sank in 35ft of water for reasons which the subsequent Congressional investigation deemed to be wholly avoidable. So while submarines traditionally were dry-docked immediately after launch to avoid the watertight integrity worry for as much of the submarine's build period as possible, as well as to allow temporary access holes to be cut low down in the pressure hull for people and equipment, the basic difficulty and inefficiency of a prolonged post-launch construction period remained.

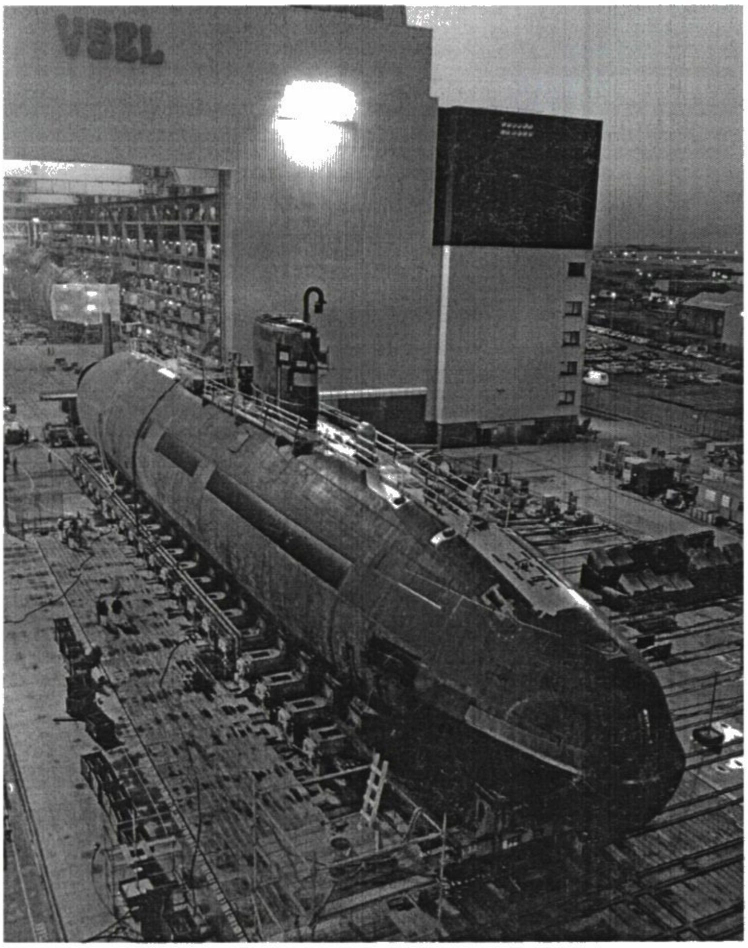
The shiplift on which this submarine is sitting is an intriguing piece of equipment with a very demanding safety case to justify the safe raising and lowering of a completed nuclear powered vessel. The Barrow shiplift consists of a platform some 500ft long supported by 54 winched cables down each side, with a theoretical lifting capacity of about 24,000 tonnes. The arrangement used for the 100 tonne Hollands, incidentally, was simply to pick them up using the battleship gun turret crane and lower them into the water. Back to the more complicated shiplift, and difficult to see in this picture, the submarine sits comfortably in a cradle which maintains the ship upright, and the cradle in turn sits on bogies which allow the submarine to be slowly, very slowly, moved out of the Devonshire Dock Hall and onto the shiplift platform. The moment when the submarine starts to cross the boundary between firm dry land and the shiplift platform is still quite a tense event, despite being justified by a great many calculations, not least to ensure that the load imposed by the submarine's weight is reasonably evenly transmitted to the shiplift structure. Critical to such calculations is knowledge of both the design and the 'as built' standards for the flatness of rails, for the bogey suspension systems and for the load acceptance of the cradle blocks, where it is the accuracy of their positioning and curvature which allows the bottom of the submarine hull to nestle comfortably. And not just the as built standards, but also the maintenance schemes at the shipyard designed to retain those standards on each and every occasion of use of the shiplift. A stiff intellectual challenge must be mounted on such issues as the currency and appropriateness of the maintainers' training standards and whether a repeated error by a single individual could lead to a significant failure.

Furthermore, because this is a nuclear powered vessel, everything associated with its support ashore and during its time on the shiplift has to be engineered to withstand the possibility of a seismic event. And guess what, it was Barrow which experienced one of Britain's biggest ever earthquakes, albeit more than a hundred years ago, with many houses destroyed.

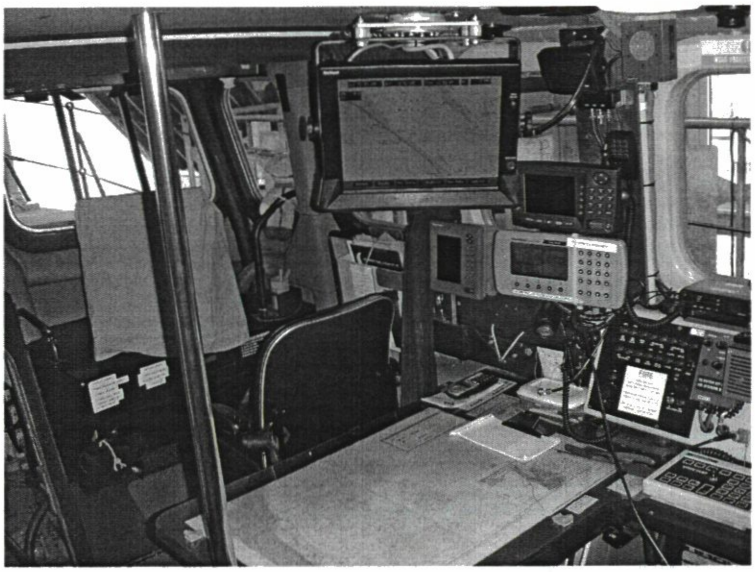


I said at the beginning of this talk that excellence was a unifying theme between the RNLI and the submarine service. This picture shows the standard of finish of a lifeboat which has seen many years service and is in all respects ready for launch. The gleaming appearance isn't just cosmetic; it ensures that any fault, whether it be incipient rust or a crack, is readily visible. And in some ways most important, you just know that somebody cares about such a vessel. That is why a familiar naval saying has stood the test of time: a ship is known by its boats.

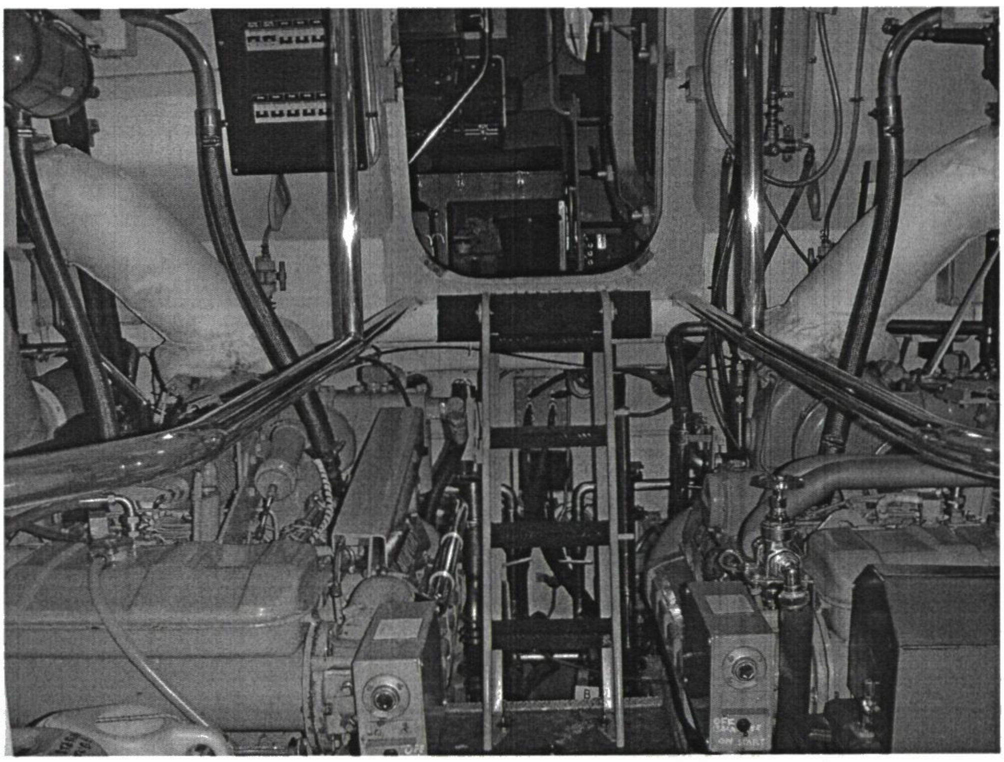
Here is the 15,000 tonne HMS VANGUARD on the day of her launch, having emerged from the Devonshire Dock Hall and while waiting to go on the shiplift. I think you can see that the standard of finish would not disgrace the RNLI. For a submarine, the hull coating is the first line of defence against the persistent, gnawing corrosion of sea water but a gleaming hull also allows the visual inspection of 'fairness of form' to be far more effective. And just to make it clear that real, hard engineering work has to go on to bring submarines – or lifeboats for that matter – to this standard of presentation, here is a picture of HMS TRIUMPH at night in more or less the same position.



Perhaps now it's time to take a look inside these two types of vessel just to get a glimpse of the complexity of what the RNLI, on the one hand, and the Royal Navy on the other, is involved in buying. The photograph at the top of the next page is the chart space in the starboard after corner of the Freddie Cooper and I'm sure you will be struck by both the compactness and the density of electronic equipment.



Here is the engine room of the same craft, again looking aft.



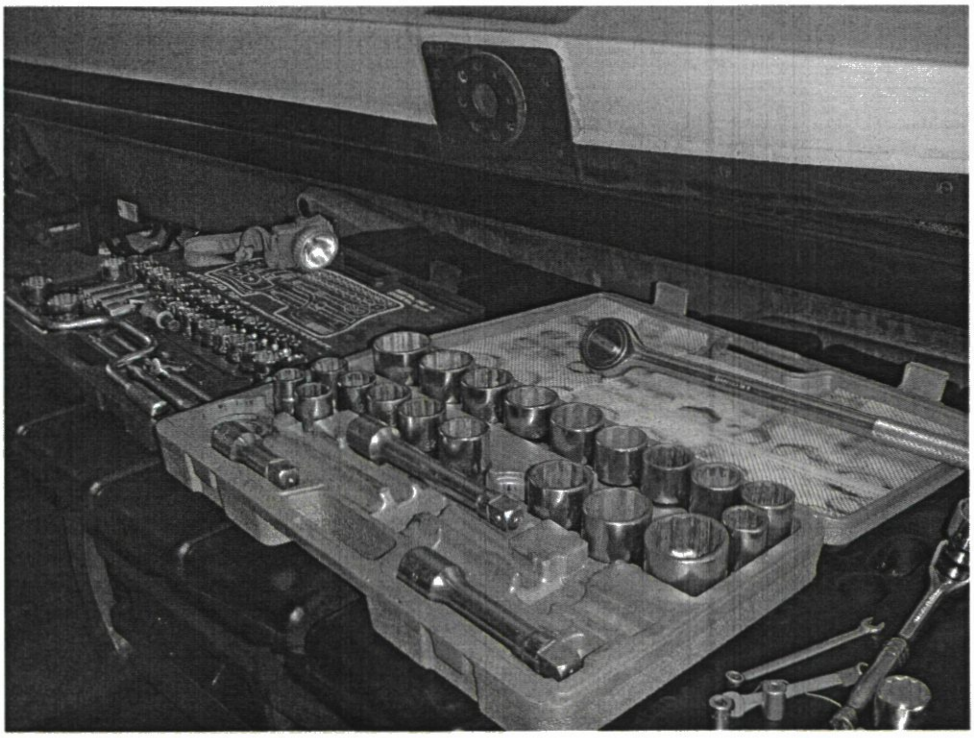
However inexpert the photograph, I would ask you to note the ladder in the centreline and the essentially similar yellow engine blocks either side. Duplicate engines, duplicate propulsion trains. In short, redundancy; this gives a resilient design which can still provide safe propulsion even if there is a failure of one side. The position of the handrail over the inboard edges of the engines demonstrates that there isn't much spare space. So what does all this look like on a bigger scale?

[SM engine room without engines]

Hard to believe, but this is a submarine engine room, during the construction phase but without the engines. The curious pale coloured segment is a security measure imposed on the slide, but I think you can see the essentially symmetrical layout, with one very important exception. Right in the central background is a single, circular yellow coloured shape. That is where the main shaft driving the propulsor will be inserted to be connected, via a reduction gearbox, to port and starboard steam turbines. Thus redundancy is achieved for much of the propulsion train, while preserving the submarine imperative of a large and therefore slow turning propulsor. As with the lifeboat, the structure of the propulsion scheme is well adapted to its function.

[SM engine room with engines]

Here is the same submarine with the main engines fitted and essentially occupying the top half of the pressure hull. The two vertical white shapes underneath the engines, looking rather like white prawn shells, are the pipes carrying cooling water to the main condensers which enable the used steam to be recirculated as feedwater to the boilers. The buff coloured shapes are plywood protection panels for instrument clusters and the like. Apart from the sheer density of equipment, note the essentially symmetrical layout and the ability to slide in the main engines via the open end of this pressure hull block. Crucially, before installation, the engines have already been run at power in a Machinery Test Installation that is located in the shipyard. It is possible to fix main engine or gear box problems once the hull has been closed up, but it just takes much longer and costs far more – besides the task becoming a huge disruption to the schedule for completion of the build.



Time to get down to nuts and bolts and what can be done to tighten them. I said that this talk was to about the buying activity and I hope that at least most here will have been persuaded that both vessels in my comparison have extremely demanding standards to meet. Who should design such vessels? Who should build them? Who sets the performance specification? Should all identical vessels be built in the same yard or should there be a 'build to print competition' against a proven design? In that case, who carries the performance responsibility? And, above all, how should a fair price be agreed in the contract?

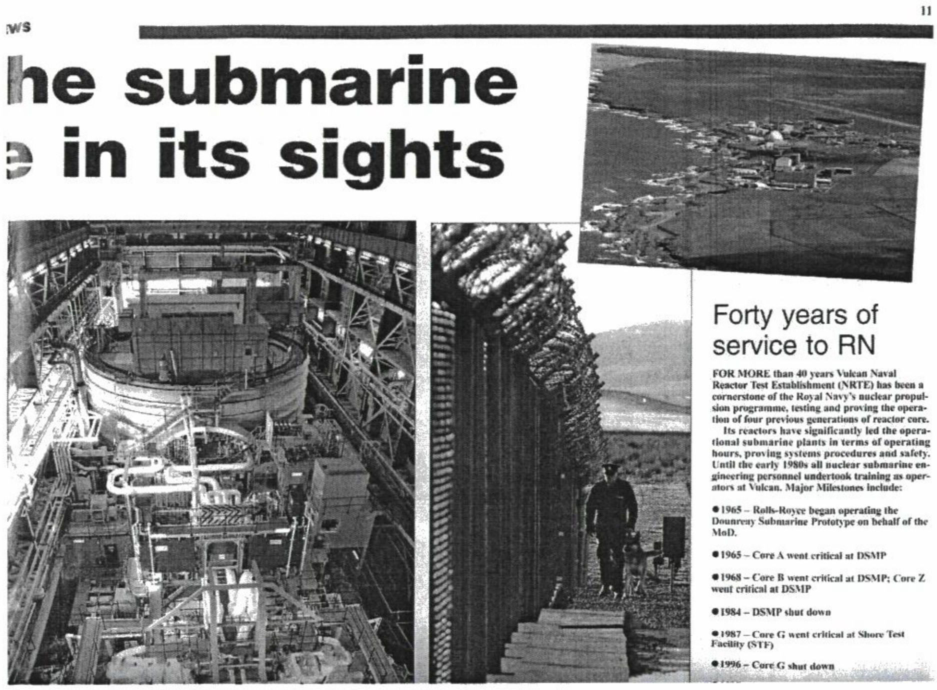
The RNLI has some pleasantly enduring traditions, not least being that a class of lifeboat is named after the river on which it was first developed. Thus the new design vessel now under testing as a prototype is called 'Tamar' to reflect its Devonport heritage. A name which pleasantly reinforces the submarine connexion implicit in this talk, since it is at Devonport that HMS VANGUARD is currently being refuelled after her first eight year's service. The contract for the Tamars recognises one or two enduring truths about the maritime industry. First, that it is for the Owner-Operator to specify what he wants the vessel to do.

At its simplest, the Operator says he wants to know the time, and it is for the ship designer to ensure that this simple requirement is adequately teased out so that it expresses the required accuracy of timekeeping and how and where knowledge of the time is to be available. Once that is done, the ship designer will be able to suggest whether this is achieved with an analogue or digital clock, where it should be positioned and how satisfaction of the requirement should be demonstrated. For it is an often ignored truism that if you don't know how you will demonstrate the satisfaction of a requirement, then you haven't really got a requirement. The immense bureaucracy implicit in such processes can, however, be substantially overcome with a prototype, whose suitability can be assessed by the operator.

A second point is that no shipyard or boatyard wants to employ its designers on producing detailed designs which they will not then have the opportunity to build. To do so would simply ensure that the shipyard was starved of designs which it could build - and building vessels is the yard's raison d'etre. Furthermore, the pricing arrangements for such design work are usually based on an agreed man-hour rate for white collar staff multiplied by an estimate, subject to later verification, of the total hours required. There is no way a genuinely profitable business can be built on such a basis.

The contracts for the Tamar prototype and its predecessor, the so called Experimental Boat - a shiver went down my spine as I recalled that the Eurofighter had been based on an Experimental Aeroplane – both rather cleverly placed an obligation on the contractor to provide target costs for the later Pre-production and 4 follow on Production boats. There are escape clauses in the overall contract which allow these subsequent phases to be competed should the relevant agreed target costs be exceeded. In my view this is an excellent arrangement which places a tight discipline on the contractor selected for the initial phase not to increase his prices at the point when the later phases get contracted. It also has the great advantage that the selected contractor is pretty much in control of his own destiny – he gets the work if he meets the agreed target costs. All in all, a contract with sound motivations towards good behaviour, although in the submarine world we would also be concerned about how we bound the shipyard into achieving economic through life maintenance costs.

With the image of that lifeboat clock still ticking in my mind, I reluctantly draw your attention to this article which appeared in the Sunday Times on 23 November. The 'monster' is the first submarine of the new Astute class and, I regret to say, it is not going to reach the Royal Navy on its planned date of 2005. Since I have lived with, and in one way or another been responsible for, the genesis of this ship since 1993, it is reasonable to question how we wanted it to go and why it failed to achieve the planned schedule. First, at a round numbers production cost of £500 million there can be no question of having a prototype, and there is certainly nothing new in that so far as warships are concerned. Secondly, as with any machine, there needs to be pre-contract confidence that the primary power plant will do its stuff.



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he submarine
e in its sights

Forty years of service to RN

FOR MORE than 40 years Vulcan Naval Reactor Test Establishment (NRTE) has been a cornerstone of the Royal Navy's nuclear propulsion programme, testing and proving the operation of four previous generations of reactor core.

Its reactors have significantly led the operational submarine plants in terms of operating hours, proving systems procedures and safety. Until the early 1980s all nuclear submarine engineering personnel undertook training as operators at Vulcan. Major Milestones include:

- 1965 – Rolls-Royce began operating the Dounreay Submarine Prototype on behalf of the MoD.
- 1965 – Core A went critical at DSMP
- 1968 – Core B went critical at DSMP; Core Z went critical at DSMP
- 1984 – DSMP shut down
- 1987 – Core G went critical at Shore Test Facility (STF)
- 1996 – Core G shut down

Nowhere must this dictum be taken more seriously than with nuclear propulsion. The Naval Reactor Test Establishment at Dounreay on the north coast of Scotland, with its familiar and long defunct fast reactor golf ball in the background, has been providing a naval reactor prototype test facility since 1965. The reactors under test, with successively more advanced fuel and safety features, have all been of the Pressurised Water type. Each of these prototypes has been designed and built by Rolls

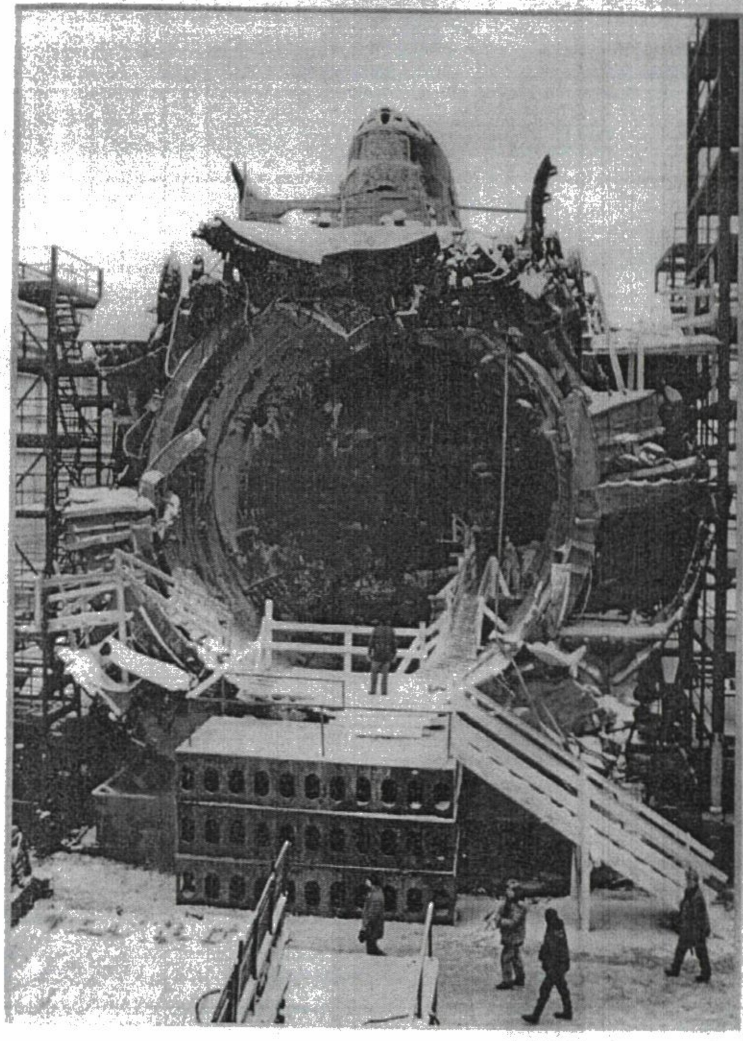
Royce with appropriate help from the submarine builders at Barrow. The latest in a long sequence of cores first achieved criticality – exactly in accordance with design predictions – during 2002 and will be able to provide all the power needed by Astute throughout its 25 year life. The same core is compatible with the Vanguard class reactor plant and, after her current refuel at Devonport, the new core will be able to power her for the rest of the submarine's life.

Astute will also have new generation sensors, principally sonar, and these started development during the 1990s. Since then, the major sensor equipments and the combat management system have been installed as an upgrade in a Trafalgar class submarine, and first went to sea last year. Many other equipments, such as those required to turn sea water first into reactor quality fresh water and then into breathable quality oxygen while safely and quietly disposing of the waste hydrogen, will be incremental developments of tried and tested Vanguard class installations.

The weapons for Astute, torpedoes and cruise missiles, already exist and will be subject to the normal upgrade programmes to ensure they remain at Premier League effectiveness standards. Finally, the hull and submarine control systems will generally be linear developments of the Trafalgar Class, with considerable focus on improving their cost of ownership. I feel fairly comfortable, therefore, that - quite unusually - each strand of the inherently technical aspects of this new class of submarine has a sound de-risking programme.

But the commercial aspect is crucial too. When it came to placing the contract for Astute it was decided to order the first three vessels as a batch, since experience tells us that a three ship order saves about 10% by comparison with ordering them separately. Against a round number unit production price of £500 million, that represents a very worthwhile saving, but we had never done it before with nuclear submarines, principally because of the immense commitment three such ships implies, and perhaps latterly just because it was easier to go on doing things in the same way. The design costs, which are about the same as a single ship production cost, were bundled up with the three submarine order to give a broad overall cost of £2 billion. The contract also required the provision of support for the maintenance of the submarines during their early years and was structured around a large number of performance requirements – from submarine speed to torpedo tube reload times. Finally the contacting arrangement, known as 'Target Cost Incentive Fee', was designed to incentivise innovation. In such a contract, the contractor and his customer share under-runs and over-runs against a carefully agreed target cost, the result being that the less it costs the contractor to build the three boats, the more profit he would make and the cheaper would be their cost to the Ministry of Defence. It was an asymmetric arrangement in one important respect, in that if the outturn cost exceeded the target cost, the increasing price to the Ministry of Defence was protected by a maximum price for the whole package. Finally, since the cost and time to license any shipyard other than Barrow to construct nuclear submarines would be prohibitive, this was a non-competitive contract. The whole package had its target cost established by breaking down the work content according to an agreed structure, feeding this with agreed labour charging rates, productivity improvements, material and sub-contract costs, and formulae for working out the overall shipyard overhead rates as the 10 year submarine design and build contract unfolded. A hugely complex process and one that carried more than a whiff of Admiral Fisher and his 1901 admonition to the Principal Director of Contracts.

So where does all the delay, and hence this article, come from? Throughout the previous section I have been using the term 'contractor' but I did not explain that this was the first time that the Ministry of Defence had passed to industry the total responsibility for achieving delivered nuclear submarine performance. While industry always wants to take on such a prime contracting role, there were some skill gaps that took longer than expected, first to realise and then to remedy. But the crucial difficulty came with using a new design tool based around a large number of workstations. These remarkable new modern aids, however good they are on aircraft and cars, do struggle a bit with artefacts as large as a submarine. Every time one part is repositioned, it affects another one and may even disturb systems or fittings in other compartments throughout the submarine. Training designers to use such systems efficiently takes longer than anyone realised and so the design has taken much longer than predicted to mature. Wisely, the shipyard, with Ministry of Defence support, resisted the temptation to crack on with the build process while the design was still settling down. We now understand both that other shipyards have had similar problems and, much more constructively, that the accuracy of design emerging from such tools does show the way towards achieving the improved productivity standards we had assumed in the original pricing. While it isn't for me to comment on whether the programme is out of the woods, I am confident that the result will be both a fine submarine and a world class submarine building process.



The Kursk
- in dock after recovery from the seabed -
November 2001

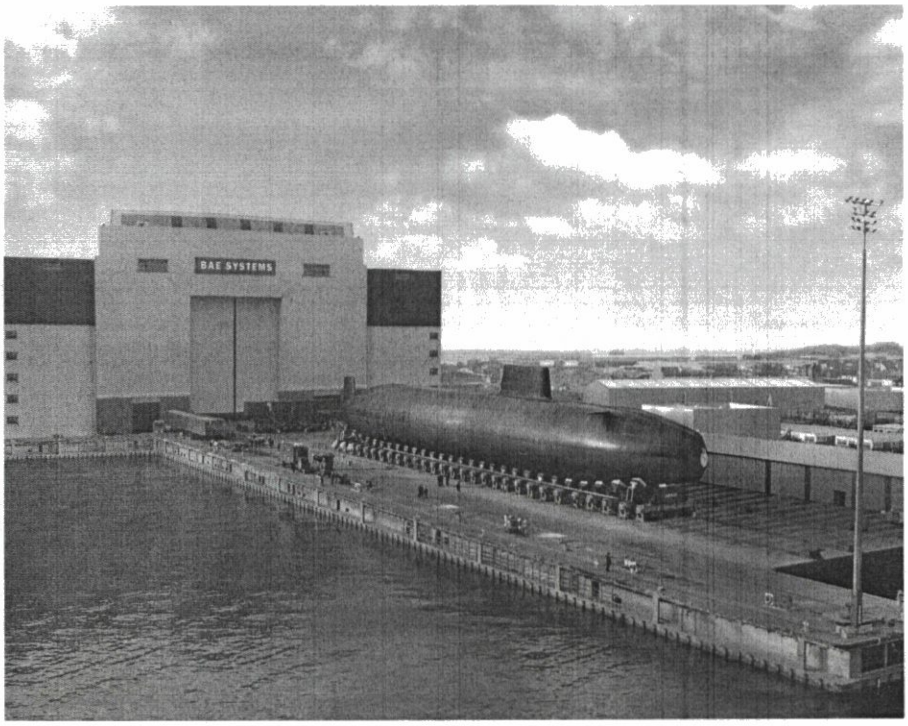
Somehow, I seem to have got quite a long way through this talk without giving safety the major emphasis it deserves. But the above slide, which shows the open forward end of a nuclear submarine, is indeed my personal vision of hell. Difficult to see, confident that the result will be both a fine submarine and a world class submarine building process.

Somehow, I seem to have got quite a long way through this talk without giving safety the major emphasis it deserves. But this slide, which shows the open forward end of a nuclear submarine, is indeed my personal vision of hell. Difficult to see, but all the fixtures and fittings have simply disappeared and just a few open ended pipes and ruptured cables hang limply inside what must have been, for a few truly terrible moments, an inferno of fire and brimstone. It is, of course, the Kursk, once the pride of its crew and a key unit of the Russian Northern Fleet.

The story is far from clear, but it is incontrovertible that the Kursk sank in waters of a depth comparable to its own length during a fleet exercise off Russia's north coast in August 2000. According to a Norwegian seismic observatory, this sinking was associated with two closely timed explosions, the second much larger than the first. While a great deal of the subsequent reporting has been about how the rescue was initiated and mounted, and then how the submarine was recovered from the seabed some 14 months later, I have seen little official by way of an explanation of the catastrophe itself. But the loss of this huge vessel does seem likely to have been associated with the detonation of its internal weapon load. If much of the circumstantial reporting is to be believed, this detonation may have been initiated by the premature start of a torpedo engine while it was being loaded into a torpedo tube. Beyond emphasising the extreme power density of a torpedo engine, and mentioning that the Royal Navy had a torpedo fuel explosion on board a submarine alongside its depot ship in Portland in 1955 which resulted in 13 dead, I would rather not speculate further on the cause of the Kursk accident. But this picture should be burnt into the mind of everyone with submarine safety responsibilities.

The assessment of the safety of any vessel depends on an understanding of its likely operational environments as well as its material condition, all underpinned by careful definition of the concept of operations and the required crew competences. Checking that the design has been faithfully implemented during the build process, followed by scrupulous system and equipment testing, before operating first in harbour and then at sea, will substantiate achievement of the design intent. At the global level, some of the key aspects of safety, such as the crush depth of a submarine, are impossible to demonstrate and have to be justified by calculation reinforced by extrapolation of strain gauge measurements taken during operation within the planned stress limits. But physical demonstration can have an important psychological, confidence boosting effect. For instance, it is well known that each new lifeboat goes through a self-righting demonstration in front of its crew. Such spectacular occasions do matter, but safety is also a matter of attention to detail. For example, what may be less well known is that the lifeboat's launching tractor is subject to all the usual road vehicle tests.

Hence this licence disc and the delightful idea of demonstrating an emergency stop from the tractor's maximum speed of 4 mph. Before I close, and on anything but a point of detail, I want to thank the RNLI staff at Poole and Aldeburgh who helped me with information and photographs, the Royal Naval Submarine Museum at Gosport who provided the Holland photograph, the Defence Procurement Agency for their picture of Dounreay and Murray Easton, Managing Director Submarines at BAE SYSTEMS, who allowed me to use some of the Yard's wonderful pictures. My thanks also go to Professor Shenoi of the University's School of Engineering Sciences who - with the not inconsiderable help of his computer literate students – arranged for all these pictures to reach the screen.



But my final slide brings me to an artist's impression of Astute on the Barrow shiplift. By the time this happy situation has been reached, the prime contractor - working with the Ministry of Defence - will have demonstrated the entire submarine safety case comprising ship stability, manoeuvrability and structural strength; comprising nuclear safety, radiological safety and atmosphere management; comprising battery ventilation, fire fighting, weapon stowage and embarkation; and comprising how all these and other factors interact. Each is a major technology in its own right. Taken in the aggregate, their safe combination is an awesome responsibility and demands organisational clarity as well as countless individual competences. It is clear to me that such disciplines have been developed independently but along essentially parallel paths by the Submarine Service, by the RNLI and by the industries which support them. I wish all engaged in these vital activities every success.