# THE SAFE OPERATION OF NUCLEAR SUBMARINES

BY

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*This article which was first published in the* Journal of Naval Science, *Volume* 5, *No.* 2, *April* 1979 *sets out the role of the submarine fleet, outlines the duties of nuclear propulsion plant operators, the manner in which those duties are executed and the training carried out to meet the high standards of operation called for by considerations of both nuclear and submarine safety. It then looks at operating experience to date and concludes with some thoughts on the interplay between nuclear safety and operational factors. It endeavours to leave the reader with an appreciation of the many activities which together can be described as the safe operation of nuclear submarines, from the point of view of nuclear safety.*

*A nuclear-powered warship demands these high standards of operation for two reasons. Firstly because of its complexity and the interaction between the systems that ensure its ability to float, move and fight and secondly because the consequences of a nuclear mishap can be so far-reaching that an exceptionally high level of assurance is demanded.*

*Safe operation of a nuclear submarine demands the highest standards of everyone on board and nowhere more so than in the operation of the nuclear propulsion plant.*

## The Role of the Submarine Fleet

### *Nuclear Submarine Contribution to Fleet Strategy and Tactics*

The nuclear-powered submarine fulfils two major roles in the Royal Navy. First, it is the platform for the United Kingdom strategic deterrent and, secondly, it acts in the tactical role as a major anti-ship and anti-submarine weapon system.

With its ability to circumnavigate the globe unseen and without the need for refuelling or logistic support the nuclear submarine armed with the Polaris missile and backed up by modern technology is the ideal means for deploying a nuclear deterrent force. This Missile force of four submarines has kept at least one vessel, armed with sixteen missiles, continuously at sea on patrol for ten years; a notable achievement which highlights the reliability of the submarine and its operators. Nothing more may be said about the role and operation of these vessels.

The Royal Navy's ten other nuclear-powered submarines are designated Fleet Submarines. They are armed with torpedoes and will shortly be fitted with 'Sub-Harpoon', a U.S. anti-ship missile capable of submerged launch. The fleet submarine will soon be the capital ship of the fleet deploying the major strike weapon and replacing the aircraft carrier just as it replaced the battleship. Unlike these predecessors however, this nuclear-powered vessel can be deployed unsupported anywhere in the world without a potential enemy having knowledge of her whereabouts before she chooses to act. Thus, her very existence presents an undefined threat to a potential enemy. Whilst the fleet submarine is pre-eminently a potent anti-ship and anti-submarine weapon system in time of war, her peace-time roles as a deterrent are equally important.

The current order of battle for our nuclear submarines is given in Table I.

TABLE I—*Submarine Order of Battle*

| *Name* | *Desig.* | *Year Entered Service* |
|---|---|---|
| *Dreadnought* | SSN01 | 1963 |
| *Valiant* | SSN02 | 1966 |
| *Warspite* | SSN03 | 1967 |
| *Churchill* | SSN04 | 1970 |
| *Conqueror* | SSN05 | 1971 |
| *Courageous* | SSN06 | 1971 |
| *Swiftsure* | SSN07 | 1973 |
| *Sovereign* | SSN08 | 1974 |
| *Superb* | SSN09 | 1976 |
| *Sceptre* | SSN10 | 1978 |
| *Spartan* | SSN11 | 1979 |
| *Splendid* | SSN12 | 1981 |
| *Trafalgar* | SSN13 | |
| *Resolution* | SSBN01 | 1967 |
| *Renown* | SSBN02 | 1968 |
| *Repulse* | SSBN03 | 1968 |
| *Revenge* | SSBN04 | 1969 |

### *The Current Employment of Nuclear Fleet Submarines and their War Role*

In the early 1970s, the Flag Officer Submarines developed the following concept of operations:

> '. . . to be not only prepared for war but also operationally committed to today's confrontation'.

Within the context of this seemingly simple concept, peacetime submarine operations nevertheless cover a wide spectrum of activities. TABLE II shows a break-down of these activities.

In a period of tension, the nuclear submarine will continue to fill a deterrent role but at increasing threat levels, culminating in offensive action should war break out. The potential and actual disposition of nuclear submarines must be such as to provide maximum protection for NATO convoys to Europe by presenting a potent disincentive to aggressive submarine and surface forces. There is thus likely to be a requirement for submarines to get on station in the approaches to enemy ports and remain there in the traditional Nelsonian blockade. This will require long patrol durations with the ability to change patrol areas quickly and prosecute targets without counter detection. Time spent on passage must be as short as the operational situation will allow if maximum time on station is to be obtained with the modest numbers available.

In the more open oceans of the approaches to Europe the need is to police as large an area of the ocean as closely as possible with the force levels available to NATO. Here, maximum sonar operating speed and detection range advantage are crucial, not forgetting weapon system performance.

With the advent of more modern weapon systems the Fleet submarines will be equipped to engage surface targets at long range and so deny the enemy deployment of these forces except at prohibitive cost.

For the propulsion plant these roles present clear requirements: reliability, quietness, and a wide speed range. The plant operators are crucial to these aims and any unreliability on their part, whether in normal or emergency circumstances, will put the whole submarine at hazard apart from prejudicing the main aim. Nuclear safety rests on reliable operators and there is already a tangible link between the wartime role and the dictates of peacetime nuclear safety.

Table II—*SSN Availability and Usage 1978–9*

| | *Submarine Weeks* | *Per cent.* |
|---|---|---|
| *Total availability* | *386* | *100* |
| *Non-available time (1)* | | |
| Maintenance periods | 139 | 36 |
| Leave outside Maintenance | 16 | 4·1 |
| Training | 16 | 4·1 |
| Safety work-up | 20 | 5·2 |
| Total | 191 | 49·4 |
| *Available Time* | | |
| Fixed Tasks: | | |
| Operational Patrol (2) | 62 | 16 |
| Group Deployment (3) | 28 | 7·2 |
| Others | 7 | 1·9 |
| Total | 97 | 25·1 |
| National and NATO tasks: | | |
| Trials | 27 | 7 |
| Weapon training | 7 | 1·8 |
| Exercises | 40 | 10·4 |
| Visits | 15 | 3·9 |
| Public relations | 1 | 0·3 |
| Unallocated | 8 | 2·1 |
| Total | 98 | 25·5 |
| Grand Total | 386 | 100 |

Notes:
(1) Roughly half a submarine's availability is spent in maintenance, giving leave and self-training.
(2) Operational Patrol covers activities fundamental to the submarine concept of operations:
  (*a*) Operations in support of the Polaris Force;
  (*b*) Intelligence gathering;
  (*c*) Surveillance operations.
(3) Group Deployments are periods spent outside NATO waters with the submarine forming part of a mixed Task Group.

## The Duties of Nuclear Propulsion Plant Operators

The uniformed submarine operator's task goes far beyond the operation of tried and tested reactors fitted in submarines in full commission. Whilst this occupies an important and significant part of his career, he also becomes involved at other times in many facets of reactor and propulsion plant design, build, maintenance and repair, not to mention disposal. This is both correct and appropriate since the key to safe operation lies in a full and detailed understanding of design principles and building, maintenance and repair. Conversely all these activities demand the contribution of an experienced operator if the necessary high standards are to be maintained.

Before examining the operation of plants in service these other activities of the operator are outlined.

### *Design and Manufacture*

It has always been the practice to leaven design teams and manufacturing overseers with a small proportion of naval operators. Their contribution to good design was well demonstrated by the success of the SWIFTSURE Class. In addition a number of naval operators find their way—by hook or by crook—into civilian firms and are employed in these areas when their naval careers come to an end. In this capacity they continue to make a valuable contribution to the nuclear submarine programme.

### *Installation and Setting to work*

At this point in a submarine's life, the operators, as part of the established crew, form an integral part of the shipbuilder's Dockside Test Organization set up to monitor, control and operate the plant. As these activities progress from system to system, the ship's staff improve their own knowledge and experience until they are capable of completing the Power Range Testing of the plant and subsequently taking the submarine on contractors' sea trials, during which period it still belongs to the shipbuilder.

### *Refitting*

During refit the operator transfers some of his responsibilities to the repair authority during the reactor refuelling. However, he retains responsibility for overall submarine safety and operation of all systems and so plays a vital part in the total refitting task. The testing and setting-to-work phase of a refit generally mirrors the same period during build with the operators forming part of the test organization.

Turning now to the operation of the nuclear plant of a submarine in commission, it is important at the outset to understand that the propulsion plant operator's task extends beyond operation at sea and encompasses control of the plant whilst operating or shut-down in harbour. In addition, his duties go beyond the safe operation of the propulsion plant and must take account of the non-nuclear hazards associated with submarine operation.

### *Non-Nuclear Hazards*

A nuclear submarine dives deeper and is propelled faster than earlier conventional vessels and these capabilities are being continually developed. This calls for skilled operation and maintenance of a variety of systems and equipments to ensure that the submarine remains at all times within its justified speed, attitude, and depth envelopes.

The biblical tribulations of fire, flood, and famine remain as submarine hazards today; except that is for famine which has been generally eradicated, unless the engineers allow the ship's refrigerator to break down! Fire has always been a major hazard in any warship packed with electrical equipment and employing oil and steam at high pressures and temperatures. In a submarine this situation is exacerbated by the contained atmosphere and even more cramped conditions. Flooding has always presented a particular hazard to submersibles and this is increased in nuclear submarines where the regenerative steam cycle and high electrical loads call for large quantities of cooling sea water piped around inside the pressure hull.

The nuclear operator must always be prepared for these hazards and in controlling the reactor plant he must be constantly vigilant to ensure that his submarine and the reactor within it remains dry, fire-proof, safe, and available to dive, move, and fight.

### *Operation of the Propulsion Plant at Sea*

The reactor and its systems are operated to approved procedures in both normal and emergency modes. The skill and training of the operator goes beyond ensuring that these procedures are correctly followed. He must also ensure that the correct procedure is invoked at the correct time to maintain the reactor in a safe condition, particularly under break-down conditions, and to provide the required propulsive power as rapidly as possible.

From consideration of the total task of operating a propulsion plant in a submarine environment some idea can be obtained of the multiplicity of responsibilities of the operators. In particular their submarine responsibilities whilst watchkeeping on the propulsion plant and their duties above and beyond this watchkeeping task.

### *Responsibilities and Duties of Selected Personnel at Sea*

The watchkeeping organization of a RESOLUTION Class submarine is given at TABLE VII. It can be seen that the Marine Engineer Officer is at the apex of the manpower structure for propulsion plant operation, the Electrical Panel Operator is a responsible senior rating in the middle management and the Main Machinery Space Engineering Mechanic is at the base of the structure and, in all probability, in his first submarine job. It is of interest to consider their duties and responsibilities at sea and to separate them into watchkeeping, management, maintenance, and general duties functions.

TABLES III to V set out their duties, which are subdivided into their watchkeeping task and other general tasks and responsibilities. What becomes immediately evident is the magnitude of these general tasks and responsibilities. It may be thought that watchkeeping on the propulsion plant would represent the major task: in fact, it represents an eight-hour daily commitment whilst the remainder of the tasks have to be fitted in and around this watchkeeping. This fitting-in does not diminish their importance and may often result in a twelve- to sixteen-hour working day.

TABLE III—*Duties and Responsibilities: Marine Engineer Officer*

| *Watchkeeping—At sea—Routine Responsibilities* | | *In harbour—Duties and responsibilities* |
|---|---|---|
| Propulsion availability<br>Maintenance of ships services<br>Submarine safety<br>Advice to the Command<br>Damage control and firefighting<br>Evolutions, watchkeeper training<br>Water chemistry and husbandry<br>Atmosphere control<br>Health physics and nuclear safety<br>Oversight of all watchkeepers<br>Oversight of machinery compartments maintenance and defect repair<br>Reactor safety checks | Overall responsibility for ME department<br>Management of watchkeeping<br>Watertight integrity<br>Advice to the Command<br>Reduction of all fire-hazards<br>Training—professional<br>—nuclear and propulsion<br>Routine reports and returns<br>Up-dating of documentation<br>Planning defect repair and maintenance | Engineer Officer of the Day<br>Planning for maintenance and defect repair<br>Manpower allocation<br>Reactor safety<br>Liaison with repair authorities<br>Ensure continuous electrical supplies<br>Continuation training—on-board<br>—classroom<br>—simulator<br>Watertight integrity<br>Notice for sea<br>Stores<br>Visits by MOD and contractors<br>Leave, recreation |

TABLE IV—*Duties and Responsibilities: P.O. Electrician Electrical Panel Watchkeeper*

| *Watchkeeping—At sea—Routine Duties* | | *In harbour—Duties and responsibilities* |
|---|---|---|
| Correct running of electrical generating machinery<br>Correct application of SOPs and EOPs<br>Maintenance of battery charge<br>Training of other watchkeepers<br>Advice to Engineer Officer of Watch<br>Writing up logs<br>Evolutions | Main Battery maintenance and cleanliness<br>Control of electrical junior ratings<br>Procurement of stores<br>Professional training of junior ratings<br>Supervision of electrical compartment cleanliness<br>Maintenance of heavy electrical rotating machinery and switchgear<br>Electrical damage control specialist firefighter<br>Recreational cinema projectionist<br>Member of ship's welfare committee | Shut-down watchkeeper. Overall control:<br>Electrical supply and distribution<br>Reactor safety<br>All fluid and electrical system states<br>Damage control<br>Watertight integrity<br>Repair procedure administration<br>Training<br>Procurement and return of stores<br>Maintenance work<br>Supervision of junior ratings<br>Main battery cleanliness and charges<br>Defect returns<br>Electrical damage control specialist firefighter |

TABLE V—*Duties and Responsibilities: Marine Engineering Mechanic Engine-Room Watchkeeper*

| *Watchkeeping—At sea—Routine duties* | | *In Harbour—Duties* |
|---|---|---|
| Numerous hourly log readings<br>Bilge pumping<br>Feed water transfer and salinity checks<br>Lub. oil transfer<br>Cleaning<br>Watertight integrity<br>Operating auxiliary machinery<br>Carrying out operating procedures<br>Evolutions<br>Providing creature comforts to the watch | Routine maintenance duties cleaning<br>Cleanliness of living spaces<br>Washing up and other domestic duties<br>Operating ship's laundry<br>Firefighter<br>Self-training and advancement | Watchkeeping—Compartment rounds<br>Bilge pumping<br>Cleaning<br>Water transfer<br>Salinity checks<br>Firefighter<br>Operation of systems<br>Under supervision, repair procedure administration<br>Training<br>Basic maintenance and defect repair<br>Cleaning<br>Storing ship<br>Assisting skilled craftsmen<br>Member ship's football team<br>Leave and recreation |

## *Operation of the Propulsion Plant in Harbour*

In harbour reactor operating falls into two distinct parts. First, the continued safe control of the plant in its shut-down condition with the added problems of over-side electrical supplies and reduced manning and, secondly, the safe conduct and control of repair procedures which may involve the use of freeze-seal techniques as boundaries to major surgery and unusual and complex system line-ups and derived electrical supplies.

The watchkeeping commitment is reduced with routine control of the plant being carried out by one senior and one junior rating. However, submarine and propulsion plant safety necessitates the presence on board of a full seagoing watch. In practice this means that each propulsion plant operator has to spend every third or fourth twenty-four hour period on board. TABLES III to V show the harbour duties of selected personnel. Here, watchkeeping duties are shown which would be carried out by some but not all of the qualified personnel for those positions. Again, the outstanding feature is the multiplicity and variation in the tasks together with the important responsibilities loaded on to the young men in the middle and lower management.

The books of reference and other documents defining the duties of the Marine Engineer Officer and his staff are shown in TABLE VI.

TABLE VI—*Books of reference and other documents required by the Marine Engineer Officer*

| *No.* | *Title* |
|---|---|
| QRRN | Queen's Regulations for the Royal Navy |
| BR 3000 | Marine Engineering Manual |
| BR 3001 | Marine Engineering Technical Instructions |
| BR 2551 | Weapon and Electrical Engineering Manual |
| BR 2553 | Weapon and Electrical Engineering Practice |
| BR 3018 | Technical Organization and Administration of Nuclear Submarines |
| BR 3019 | Nuclear Reactor Accidents |
| BR 3020 | Instructions for Radiological Protection |
| BR 3030 | Radiological Controls for Nuclear Submarines |
| TP 740 | Water Chemistry Control of Naval Nuclear Propulsion Plant |
| TINS | Technical Instructions for Nuclear Submarines |
| ATOMIC Books | Set of books for each class of submarine describing the nuclear plant; its design, construction, operating limits and theory of operation |
| Standard Operating Procedure | Set of books for each class of submarine detailing specific normal and emergency operating procedures for each and every primary, secondary and ship system |

## The Execution of Nuclear Propulsion Plant Duties

### *The Greatest Single Factor*

The safety of the plant and submarine lies in the hands of the operator: hence the long closely controlled and monitored training detailed below. It is no overstatement to describe the operator as the greatest single factor; anything which affects his efficiency could affect plant and submarine safety.

All operators are human, even some marine engineer officers! No human can behave or be expected to behave as a machine. It is important that, when the total task of an operator is formulated with a mix of procedures, routines, and duties, he is not expected to behave as a programmed machine all the time. The reactor panel operator who stares fixedly at his panel for want of stimulation or the junior engineering mechanic who spends unending watches on dreary non-nuclear and very often dirty jobs are two extreme examples of what can happen with poor man management.

A man needs sufficient motivation and a settled environment in which to harness his talents and maintain peak efficiency. The naval operator is not isolated from the pressures of society and in many ways these pressures are greater for him than for many others in a more settled environment. The burden of responsibility that these young men carry and are expected to carry, particularly when the plant is shut down, is greater than that of most of their peers either in the rest of the Royal Navy or in civilian life.

There is no doubt that we have relied on the loyalty of our naval operators in the past, in the same way as we do today and will do in the future. When coupled with their stamina for hard work this has enabled us to operate our nuclear submarine fleet to high operational and safety standards. Long may this tradition for loyalty and dedication to duty last.

### *The Environment*

Unfamiliarity with the living and working conditions on board a Nuclear submarine makes it difficult to obtain a good understanding of plant operation and the physical conditions under which operators must maintain consistently high levels of performance.

The average complement of a fleet submarine is 12 officers, 46 senior and 53 junior ratings. Each rating has his own private accommodation in the shape of one small kit locker and a bunk measuring 6′ 6″ × 2′ with a free height of 1′ 6″. Trainees additional to this complement, of whom there are generally twenty or so are not so well off. They live in temporary bunks scattered amongst the reload torpedoes in the torpedo stowage space. The senior ratings communal mess for forty-six people is a compartment 30 feet × 10 feet in which all meals must be taken in three sittings. Officers live in multi-berth cabins which bear a remarkable resemblance to the couchette sleeping car of continental railways.

For containment reasons the forward tunnel door is kept shut except for access. This creates something of a barrier between the propulsion staff (known colloquially as the Black Gang) and the rest of the crew. Behind this door is the tunnel and beneath that the reactor compartment. Ironically, the one machinery compartment that is light, dry, warm, and immaculately laid out is the only one which is unmanned. Beyond the reactor compartment, the machinery spaces contain a dense conglomeration of plant, machinery, pipe systems, and electrical equipment. With the exception of the manoeuvring room, from which the propulsion plant is controlled, this conglomeration is crammed into spaces leaving little room for watchkeeping and even less for maintenance and repair. Many of the controls are necessarily placed in awkward corners which can only be reached by young, fit contortionists impervious to burns, oil, water, and conditions where the temperature may be up to 100°F and the relative humidity close to 100 per cent.

These taxing conditions place heavy demands on both the personnel seeking to meet the necessarily high standards of operation and the equipment performance. It would be an exaggeration to suggest that these conditions are representative of all machinery spaces at all times in all nuclear submarines. Nevertheless, anyone wishing to contest the thesis that machinery space environment leaves much room for improvement would do well to spend some weeks watchkeeping eight hours a day in the engine rooms and turbo-generator rooms of the Valiant and Resolution Class submarines. Undoubtedly watchkeeper performance would be enhanced if environmental conditions could be improved.

Table VII—*Resolution Class Propulsion Watchbill*

| *Position/ Watchkeeping Category* | *Rank/Rate* | *On-board Training* | *Board* | *Duties* |
|---|---|---|---|---|
| EOOW<br>Category A1 | Officer<br>Fleet Chief PO | Over 3 months | FLOTILLA | Responsible to Command for correct supervision of watch, ship and reactor safety and maintenance of propulsive power |
| Chief OW<br>Category A2 | Fleet Chief, Chief or First Class artificer | Over 3 months | FLOTILLA | Deputy to EOOW and, in his absence from manoeuvring room, duties as EOOW |
| Reactor Panel Operator<br>Category B | First or Second Class Artificer | Over 3 months | SHIP | Reactor operation and control |
| Electrical Panel Operator<br>Category C | Second Class Artificer<br>Chief or Petty Officer Electrician or Leading Electrical Mechanic | 8 weeks | SHIP | All ship and reactor system electrical supply and distribution |
| Propulsion Panel Operator<br>Category D | Marine Engineering Mechanic (MEM) | 6 weeks | SHIP | Throttle control, operation of other ship and propulsion systems |
| Marine Engineering Artificer<br>Category B | First or Second Class Artificer | Over 3 months | SHIP | Correct operation and control of all machinery outside manoeuvring room. Water chemistry |
| Turbo-Generator Watchkeeper<br>Category D | Leading Marine Engineering Mechanic (LMEM) | 6 weeks | SHIP | Control and operation of turbo-generators and other machinery |
| Engine-Room Watchkeeper<br>Category C | Second Class Artificer or Petty Officer Marine Engineering Mechanic (POMEM) | 8 weeks | SHIP | Overall responsibility for all machinery in engine room |
| Engine-Room MEM<br>Category D | MEM | 6 weeks | SHIP | General engine-room duties |
| Motor-Room Watchkeeper<br>Category D | Electrical Mechanic | 6 weeks | SHIP | General motor-room duties |
| AMS2 Watchkeeper<br>Category D | LMEM | 6 weeks | SHIP | Control of diesel generator and air purification and conditioning equipment |

## *The Watchkeeping Task*

Table VII sets out the watchbill for a Resolution Class submarine with a synopsis of the watchkeeping tasks for each position. Whilst the section entitled 'The Duties of Nuclear Propulsion Plant Operators' demonstrated the varied nature of the duties of nuclear plant operators, this section endeavours to knit together most of the propulsion activities by describing the major activities that can occur in a typical day back aft.

The day starts with those unfortunates who have to work from 0001 to 0400. This watch sees the completion of reactor safety checks which, because of their interaction with the plant protection, are only completed when the Commanding Officer has satisfied himself that the operational scene allows them to go ahead. The following watch sees the completion of the first of three sets of steam-generator chemistry readings, the results of which may call for chemical addition or even blow-down, which being a noisy operation calls for close liaison with the

Command. This watch also sees a thorough cleaning and tidying ready for the day ahead and, throughout all this, the distillers, the water-transfer system, the bilge system, the HP air compressors and many other equipments are being operated to ensure that the submarine is at all times in the best of material health.

The forenoon is the busiest time on board with planned maintenance, whole-ship evolutions and drills and routine operation all going ahead. This is also the time for sampling and analysis of the primary-circuit water and it may well also be the time at which the submarine is taken through its full depth range to check the sound propagation conditions. This evolution calls for system changes and full checks for leak-tightness.

The afternoon is a good time for settling down from the busy period that has just passed and is a time when the large bearing of trainees are everywhere questioning and examining, reading and learning. Whole-ship drills in the evening invariably involve the propulsion watch. Fire, action damage, emergency operation of systems, flood, and personal injury are typical of these drills and, if the operational scene permits, will also involve propulsion in emergency, drill scrams of the reactor, and control surface failures. Under drill conditions it is often difficult to credit each hour with as many as sixty minutes.

Such periods of phrenetic activity are generally followed by periods of steady operation which permit the routine business of plant and system manipulation to continue. Thus a day passes as a changing mixture of routine, drill, and emergency operation. To this, of course, must be added the immediate changes of plant state dictated by rapid operational changes, for at all times the propulsion plant is available to respond to the demands imposed upon it by the Submarine Commanding Officer.

## The Quality of Nuclear Propulsion Plant Operators

It is evident that naval operators must be mature, reliable, appropriately trained, and experienced. In comparison with a conventional ship's propulsion watchbill, this leads to a rich mix of officers, skilled artificers, and mechanics. Thus with the introduction of nuclear propulsion there was an explosion in both the numbers of men and the training required for submarine branch engineering personnel. The importance of experience as one of the ingredients of a safe and efficient corps of nuclear operators cannot be over-emphasized, and in this context it is worthy of comment that at the start of the nuclear programme the success of the operation rested heavily on the experience and operating discipline which existed in the conventional submarine fleet. The operating disciplines required for submarine safety are precisely those demanded for nuclear safety; meticulous attention to detail, use of comprehensive mandatory written procedures, formal qualification by courses and practical demonstration of knowledge and ability on board, regular evolutions to exercise emergency procedures and high standards of material quality. While operating experience has now been built up in the nuclear submarine fleet, advantage is still taken of the experience gained in conventional submarines.

Overall schemes of training defined in BR 3018, '*The Technical Organization and Administration of Nuclear Submarines*' are illustrated in FIG. 1 and TABLE VIII and comprise both professional and practical training.

### *Professional Training*

The degree and application courses for general list officers at the Royal Naval Engineering College, Manadon meet the requirements of the Council for National Academic Awards for Honours and Degrees and those of the professional institutions for Chartered Engineer status. Starting in September 1978, officers now take an electro-mechanical degree course biased to either electrical

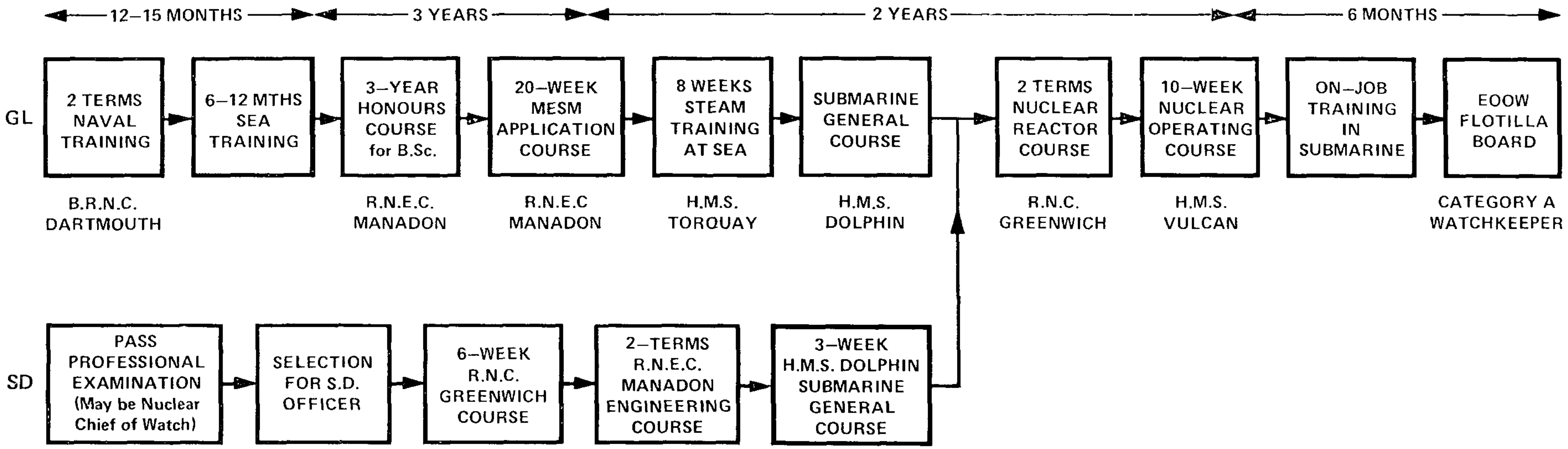

FIG. 1—TRAINING UP TO FIRST COMPLEMENT BILLET OF GL AND SD ENGINEER OFFICERS (MESM)

or mechanical engineering in the third year. Further professional qualification in nuclear engineering is achieved by successful completion of the post graduate Nuclear Reactor Course at the Royal Naval College, Greenwich. This course, originally modelled on U.S. Navy practice, gives the officers a good knowledge of the theory of nuclear engineering practice both generally and specifically as applied in the pressurized-water plant fitted in Royal Navy submarines. It is the linchpin of the whole professional nuclear engineering training programme and sets the standards against which the other professional nuclear engineering courses are pitched. In spite of periodic doubts in some quarters on the need for such a depth and breadth of nuclear engineering knowledge by plant operators, the course has retained much of its original form reaffirming that such a standard is essential for plant operators aspiring to the position of Marine Engineer Officer of a nuclear submarine, a post carrying responsibility for plant safety and availability under the many circumstances in which submarines find themselves.

While officers on the special duties list are generally qualified to technician engineer status, many of them prove their professional ability by qualifying on the Nuclear Reactor Course and are then able to proceed to Marine Engineer Officer of a nuclear submarine if they prove themselves in the subordinate officer billets at sea.

The successful completion of the Nuclear Reactor Course carries with it the award of a post-graduate diploma and a Master's Degree is awarded on completion of the Nuclear Advanced Course. This course is not specifically required for naval operators.

The other half of the rich mix is provided from the mechanical and electrical artificer branches. During their artificer training both specializations are educated

TABLE VIII—*Artificer Training Pattern for Streamed Nuclear Training*

| *Rate* | *Training* | *Watchkeeping Category* |
|---|---|---|
| Apprentice | 4-year Artificer Craft training at H.M.S. *Fisgard* and *Caledonia* including 1 year at sea as an apprentice | |
| 3rd Class Artificer | 1 year at sea to gain experience.<br>Join Submarine Service.<br>5-week general Submarine course at H.M.S. *Dolphin* | |
| Acting Second Class Artificer | H.M.S. *Sultan* 7-week Nuclear Propulsion Short Course (Senior Rates) | Category C |
| | H.M.S. *Vulcan* 5-week Junior Nuclear Operators' Course (Engineering or Electrical) (TPS) | |
| | On-job training at sea to qualify as: Main Machinery Space or Electrical Watchkeeper (Panel Operators) (OPS) | |
| | Sea experience 9–24 months.<br>Qualify as shut-down watchkeeper.<br>Recommended for Long Course (*) | |
| Confirmed Second Class Artificer | H.M.S. *Sultan* 18-weeks Nuclear Propulsion Long Course | Category B |
| | H.M.S. *Vulcan* 4 weeks Senior Nuclear Operators' Course (Engineering or Electrical) (TPS) | |
| | On-job training at sea to qualify as: MEA of the Watch or Reactor Panel Operator (OPS) | |
| First Class Artificer | Sea experience as Category B Watchkeeper 12–24 months approx. (*) | Category B |
| | On-job training for Nuclear Chief of the Watch | |
| | Flotilla Board for Nuclear Chief of the Watch | |
| Chief Artificer | Complement billet as Nuclear Chief of the Watch at sea and in shore training billets (*) | Category A2 |
| Fleet Chief Artificer | At sea as EOOW | Category A1 |

to at least ONC standard and many achieve HNC during later studies. Their skill training is recognized by all the major trades unions and they achieve technician status as 1st Class artificers. Successful completion of the nuclear Propulsion Long Course (NPLC), which is a prerequisite for Category B watchkeepers, is now recognized as the educational qualification for special duties list officers. Those ratings who are awarded an HNC and have four years seniority as a 1st Class artificer qualify for technician engineering status. Those mechanics who show educational and skill aptitude can be selected for mechanician courses and successful completion of these courses carries the same recognition as the equivalent artificer courses.

### *Qualification and Maintenance of Nuclear Operating Standards*

The qualification of naval operators is closely controlled and monitored at all stages. A Standing Committee for the Training and Qualification of Naval Nuclear Power Plant Operators has been established and is responsible for setting the standards for training and qualification. The committee is chaired by the Chairman, Naval Nuclear Technical Safety Panel and all proposed schemes of training and qualification have to be approved by it.

The present scheme of training is based on a typical nuclear plant as fitted in H.M.S. *Churchill*, which is basically the same as the plants fitted in the SSBNs and SSN02 to 06. From 1980 type training will be conducted where the trainee will be taught the plant which is fitted in the submarine in which he will serve initially. There will be three parallel streams: SSBNs and SSN 02–6; SSN07–12; SSN13 (*Trafalgar*) onwards.

The computer-controlled dynamic simulators now at H.M.S. *Vulcan* and the Clyde Submarine Base, Faslane (FASMAT) form an integral part of this training. The simulator at H.M.S. *Vulcan* is being replaced shortly by three separate simulators situated at H.M.S. *Sultan* and designed to deal with the three streams of type training. It is planned that naval training will then cease at H.M.S. *Vulcan*.

At the selection points shown (*) in TABLE VIII men have to be formally recommended from sea for further training. On-job training and formal qualification are vital parts of the scheme and cover the knowledge and experience required to bridge the gap between the training performance standard achieved at the end of formal training and the operational performance training required before a man can carry out his job. At each stage in his training a man's performance is monitored and assessed by:

(*a*) written and oral examinations, the standards of which are monitored externally;

(*b*) written and oral boards during on-job training, standards being monitored by squadron officers.

Flotilla Qualifications Boards for Engineer Officer of the Watch and Nuclear Chief of the Watch (Category A Boards) are chaired by the Squadron Senior Engineer Officers who have to be licensed before they can grant Category A watchkeeping certificates.

This licence is granted by the Central Plant Control Authority, the MOD headquarters body with overall responsibility for setting nuclear safety standards in all aspects of plant operation, repair, maintenance, commissioning, and modification.

After initial qualification, an operator's competence is monitored by his own ship's officers and all operators have to carry out a minimum number of hours continuation training on the simulator situated at Faslane. This simulator consists of two separate trainers: FASMAT I for SSN's 02–06 and SSBNs; FASMAT II for SSN07. A third trainer will be added for H.M.S. *Trafalgar* in due course. The training sessions are assessed by the Commander FASMAT who in turn has to satisfy Flag Officer Submarines that satisfactory operating standards are being maintained throughout the Submarine Flotilla. In addition to maintaining the operators' individual competence, particularly in emergency procedures which cannot be practised on board, the simulators fulfil a vital function in training and exercising the operating watch as a team and the ship's complement of operators as a whole. Perhaps most importantly, the simulators with their permanent training staff under the Commander FASMAT can ensure that common operating practices and standards are in force. Finally Commanding Officers and their ship control officers of the watch attend training sessions to familiarize themselves with operating procedures and the interplay between the nuclear plant and submarine control.

### *Submarine Sea Training*

No amount of academic and professional training, qualification boards, and continuation training on simulators can overcome the problem of ensuring the safe operation of a nuclear submarine by the whole crew acting as a team after a period out of full commission for some months. These periods will arise during refits and extended maintenance and repair periods. To meet this situation all nuclear submarines which have been out of operation for more than three months are put through a series of work-up drills which start with documentary evidence that the necessary simulator training has been recently completed and continue with a phased series of clearances for the submarine to proceed to sea, to operate dived in shallow water, to operate in the deep ocean and finally to demonstrate its operational capability. These clearances are granted by the Captain Submarine Sea Training (CSST) who commands a team of qualified nuclear operators who spend considerable time on board each submarine and observe demonstrations of all operating modes, both normal and emergency. CSST trains and qualifies submariners in all aspects of submarine operations and sets high standards. A 'Good' pass in CSST language is excellent by any other name and is rarely awarded.

Throughout the remainder of submarine operating time, each vessel is under the administrative responsibility of a parent squadron which again contains qualified nuclear operators and which advises, checks, and monitors operator performance regularly. Qualified operators joining a submarine in full commission must satisfy the Commanding Officer and the Marine Engineer Officer that they are capable in their watchkeeping billet and if they have been out of practice for six months or are not qualified on the particular plant they are joining must sit a formal requalification board. Understandably this continual subjection to re-examination is far from popular but is found to be necessary.

This persistent performance monitoring and auditing with its compulsory operational checks and clearances after periods of inactivity is the final link in the chain that aims to ensure that all naval operators consistently reach the required levels of competence and knowledge.

## Operating Experience

### *A Statistical Summary*

Mr. Disraeli's views on statistics are well known but nevertheless statistics can serve to illustrate the outstandingly successful operation achieved in the last fifteen years, both in terms of personnel achievement and plant performance.

### *Naval operators*

The sheer size of the Royal Navy's nuclear undertaking can be judged to some degree by considering the number of operators absorbed by it. Some 367 naval officers destined to become Engineer Officers of the Watch have successfully completed the Nuclear Reactor and Nuclear Advanced Courses at the Royal Naval College, Greenwich, while the Royal Navy's Marine Engineering School at H.M.S. *Sultan* has seen 1600 senior ratings and 1400 junior ratings pass through on their *ab initio* training. The current annual throughput at H.M.S. *Sultan* is 170 senior and 275 junior ratings.

The constitution of qualifying boards for Engineer Officer and Chief of the Watch have already been described. The statistics show that approximately 600 officers and senior ratings have successfully qualified. The failure rate at these boards is about 10 per cent. and failure after two appearances invariably leads to employment in less demanding roles.

The statistics for continuation training are equally impressive with all crews currently meeting the minimum requirement of 18 hours per man per year, with no two sessions more than six months apart. The continuation training facilities at the FASMAT complex are in practice used an average of 22·8 hours per man per year and this figure is achieved by regular sessions from 0800 to 2200 each day. Outside the manoeuvring room, training is also arranged in water-chemistry and radio-chemistry techniques.

Of course, training statistics are not necessarily a measure of excellence but considered with plant performance data they go a long way towards satisfying the need for evidence that nuclear submarine operation is acceptably safe now and likely to continue to be so.

TABLE IX—*Causes of Reactor Scrams*

| *Cause of Scram* | *Number of Scrams* |
|---|---|
| Operator error | 29 |
| Shut down during instrumentation checks | 17 |
| Automatic protection system irresponsibility | 21 |
| Operator induced scrams to meet operating procedural requirements | 39 |
| TOTAL: | 106 |

### *Operating Statistics*

The Royal Navy has now amassed some 82½ reactor years of operating experience during which time there have been no nuclear incidents leading to radio-active release. This is a record for justifiable pride but any warm feelings of achievement are constantly exposed to the cool breeze of assessment, examination, modification, and change as necessary to ensure that bad habits and slack practices do not creep in.

Reactor system down-time is an insignificant proportion of total operating time. An operating submarine can expect (statistically) a scram every 22 weeks and the mean time to recovery of propulsion power is measured in minutes. A break-down of the causes of scrams over the last five years makes interesting reading and is at TABLE IX. Spurious scrams, that is reactor shut-down which can only be attributed to an irresponsible malfunction of the reactor protection system, are mercifully rare and to date occur once every 3½ reactor-operating years.

### *Incident Reports*

It is important that human or material failures which lead to reactor operation outside normal limits are reported, recorded, and assessed. Each occurrence is reported as an incident and the circumstances which constitute an incident are closely and comprehensively defined. These incident reports are vitally important since they may lead to reconsideration of the basis for continued safe operation of the reactor plant. They are also of value because they provide a valuable guide for the removal of errors of fact and style in operating and repair documentation and for modifying operator training to avoid recurrent errors. Finally they provide a useful corpus of practical operating experience to the designer.

To date some 712 incident reports have been rendered and TABLE X shows the breakdown of the first 435 by system and effect.

TABLE X—*Incident Reports: Analysis of Effects*

| *A* | *B* | *C* | *D* | *Total* | *System* |
|---|---|---|---|---|---|
| 10 | 40 | 14 | 28 | 92 | Primary Electrical |
| 6 | 12 | 4 | 9 | 31 | Secondary Electrical |
| 8 | 6 | 1 | 45 | 60 | Primary Mechanical |
| 63 | 10 | 15 | 57 | 145 | Secondary Mechanical |
| 7 | 43 | 6 | 51 | 107 | Operator Error |
| 94 | 111 | 40 | 190 | 435 | Total |

Effect Key:
A Full power not available.
B Steam propulsion not available for up to 1 hour.
C Steam propulsion not available for more than 1 hour.
D No operational limit, i.e. submarine not at sea or notice for sea not impaired.

## Nuclear Safety and Operational Performance

We have seen that nuclear safety requirements impinge on almost all facets of nuclear submarine operations in peace time and, in view of the role of the submarine in wartime, it is worth examining the interplay of nuclear safety, submarine safety, and operational effectiveness in peace and war.

Once the submarine is at sea, the nuclear propulsion plant is able to dispense with many of the nuclear safety requirements which, because of the hazard to the general public, attend it in harbour. In general the nuclear safety requirements at sea enhance the reliability of the propulsion and enable the submarine to fulfil its role as a major war vessel. However, situations do arise when the interests of nuclear safety run counter to the needs of submarine safety and the command can be faced with awkward decisions. The first and most obvious conflict arises when the maintenance of propulsion becomes paramount for ship safety and some sacrifice of automatic reactor protection may be required. At its lowest level this conflict can arise over the timing and conduct of reactor safety checks. During these checks the responsibility of the automatic reactor protection system is reduced by the deliberate tripping of guardlines, reducing the logic to one out of two or two out of three. The conduct of the tests introduces the possibility of errors in procedure, many of which may result in reactor scram or loss of propulsion. Submarine Captains are naturally wary of reactor safety checks and, as we have seen, generally consign them to a period of steady low power operation at a fixed depth—usually during the small hours. To give him sufficient flexibility, the intervals of these checks have wide margins. In wartime the Captain will be even more wary and will give even closer consideration to the conduct of reactor safety checks.

The conflict arises in a still more acute form when the submarine is in danger of sinking from collision or an uncontrolled depth excursion and depends upon propulsion to save the ship. Under these conditions when full power astern or ahead is ordered, the possibility of spurious scram by the automatic protection system is enhanced because operating limits may be momentarily exceeded during transient operation and because the system may be subjected to physical shock or the loss of electrical supplies. This is just the time when a spurious scram could be fatal to survival and operating procedures therefore call for the battle short switch to be made. This places reactor protection solely in the hands of the operators. The corollary to this logic—that, if the ship is in danger, the reactor could also be and so requires the quick response of the automatic protection system—finds as little favour with submariners as it does with all authorities concerned with reactor safety. It is also relevant that the use of the battle short switch is inhibited in harbour.

The automatic protection system does impose a severe discipline on the officer of the watch in the control room and, of course, the Captain in the everyday conduct of their duties. They must know the power levels that can be obtained in each machinery state and they must know all the implications of changing the machinery state, and should they make a mistake they will at best receive the comments of the Engineer Officer of the Watch and at worst an inadvertent scram. There are many traps for the unwary Officer of the Watch which can lead to power failures and/or scrams. Examples of these include rapid astern manoeuvres on surfacing or careless use of the telegraphs.

In wartime the use of the battle short switch is dictated by more far-reaching considerations. Apart from the safety of the submarine when it is threatened either by self or enemy induced hazard, consideration will also be given to operation of the battle short switch at just those times when the chance of the submarine prosecuting its target may be at risk. While there can be no set rules, the Captain is unlikely to risk the success of his mission through an inadvertent and unnecessary scram. In the presence of the enemy he is likely to make the battle short switch, knowing that the removal of automatic protection reduces the nuclear safety margins and yet confident in the ability of his operators to maintain propulsion without exceeding safe limits. In making this decision, he will take that confidence from the knowledge and experience of his operators accumulated through the taxing demands of nuclear safety in peacetime.

These are the more obvious examples of conflict between nuclear safety and operational requirements. Situations more difficult to resolve arise regularly even in peacetime when in situations of emergency the Captain must weigh up the advice of his Marine Engineer Officer and his own assessment of the operational scene to come to a difficult decision quickly—sometimes very quickly. In meeting these moments of decision he, and all his operators, rely upon their thorough knowledge of the implications of the actions they may take and there is no doubt that the standards of operator qualification and performance dictated by nuclear safety assurance enhance the operational performance of the Submarine Flotilla in peace and war.