NUCLEAR SAFETY IMPLICATIONS AND CONTROL OF NUCLEAR SAFETY IN DOCKYARDS

BY

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This article was originally presented by the author as a paper read to the Naval Nuclear Propulsion Symposium at R.N. College, Greenwich in April 1978 and has since been published in the Journal of Naval Science. This article seeks to introduce the reader to the concept of Naval Bases rather than Dockyards, the types of activity which may be undertaken therein, and the various groupings of tasks or events with nuclear safety implication which may result. These give rise to a selection of different aspects of nuclear safety. More than one section of Ministry of Defence (N) has responsibility in this field and the management structure is examined briefly to show how this is exercised and what standards of performance are set. The main body of the article covers the general philosophy for safety and a brief consideration of the most significant aspects in its practical application to the major areas of activity, namely refitting, refuelling, testing, radiological protection, waste disposal, and organization for an accident situation.

Introduction

The title of this article specifies activities in dockyards, but the modern concept of maintenance support embraces not only the civilian dockyards but also naval shore support. The term 'naval base', rather than 'dockyard', has in recent years become much more prevalent: it embraces all those separate, and to some extent autonomous, organizations described as support groups, which are located in one area and which are complementary to each other in the support of H.M. ships. In the submarine context, some naval bases provide repair effort only from the dockyard support group, but where an operating base is collocated with a dockyard, there is a major naval contribution which impinges on the dockyard, and must be taken into account in considering safety, in the wider interpretation of refitting.

The author cannot speak with personal authority on the difficulties experienced in a combined naval base, and indeed in discussing the implementation of the safety task no attempt has been made to stray away from the relatively simple aspects of a dockyard support group. However, it is hoped that the indications of a wider problem will provide an opening, for those with experience, to express their views in future issues of the *Journal*.

The Task

The Maintenance Task

The activities in the naval base, in connection with nuclear submarines can be split into five main groups:

(*a*) major refits, which include refuelling;

(*b*) routine dockings and essential defect periods (DEDs);

(*c*) emergency dockings and rectification of defects limiting operational capability (OPDEFs);

and, where operating facilities are available:

(*d*) the provision of assistance and overside services in maintenance periods (AMPs);

(*e*) the provision of overside services to submarines lying alongside, but not maintaining.

The major proportion of the task in resource terms is involved in the refit activity when tens of thousands of man-weeks and many millions of pounds are expended throughout the boat when undertaking the major items of planned preventive maintenance, which require dockyard resources, rectifying defects, updating equipment fits, and finally testing and setting to work the equipments and systems which together make the submarine. In the parochial area of the reactor, this will involve the large, but nevertheless regular, maintenance task of refuelling, the revalidation of equipments and systems to justify further service, major component changes such as main coolant pumps, and the rectification of defects large and small. Ultimately a new core has to be taken critical for the first time and then proved to the limits which it is designed to see in service.

The other forms of dockyard activity may have no nuclear repair content whatsoever but nevertheless they provide ample opportunity for creating potentially hazardous situations. A variety of services must be provided to the submarines from shore, whenever her installed plant is non-operational, in order to guarantee the essential reactor safety requirements. The integrity of these services must be preserved against all possible interruptions, and where more than one boat is being supported the possibility of interactions between them has to be taken into account.

The Nuclear Safety Task

The nuclear safety task, which for this purpose includes both reactor safety and radiological protection, can also be subdivided into a number of related but fairly clear cut groupings. The range of safety will vary to some extent with the type of dockyard activity considered above, but in refit all will require attention. These groupings are:

(*a*) the provision of basic services to an operating boat to replace the normal power generation, salt-water services and discharge facilities, available when in a sea-going situation and necessary to support the reactor in a safe condition when alongside. This is the standard problem of the operating base handling boats in full commission, and the arrival task for boats coming to refit;

(*b*) the assurance of core cooling and instrumentation under refit conditions, when boat systems are out of use and refitting and refuelling activities are in hand;

(*c*) the provision of assurance for safe operation in the future by control of the quality of repair, and validation for future service of component parts of the plant. It is in effect the restoration of the design standards to which the boat was built or in some cases an enhancement of them. Within this sub-division is included the refuelling operation;

(*d*) proving the physical properties of the new core, and demonstrating the satisfactory operation of the refurbished plant under all conditions;

(*e*) radiation protection directed at minimizing exposure of the workforce, monitoring and controlling individual dose receipt;

(*f*) radiation protection of the population at large by satisfactory disposal of active waste material;

and, finally, to meet that unthinkable eventuality:

(*g*) the provision of services and a nuclear accident organization to minimize the effects on naval base personnel and the general public of a fission product release, resulting from major damage or core melt down, and to provide guidance to the local civilian services on actions necessary and, in the event, the extent of any subsequent contamination of the environment.

The word 'finally' is not quite true, because considerable effort is applied by all departments within the dockyards in tackling many less well-defined or obvious risks. Although no one believes there is ground for complacency, the extent of resources and effort applied to the immediate material and radiological hazards suggests that an accident, if it occurs, is more likely to result from some outside event which has a less obvious and direct connection with the reactor plant. With this in mind a broadly based committee in each Yard is tasked with identifying all the possible hazards to the submarine which might conceivably have subsequent nuclear implications, defining ways in which these risks can be minimized, and then undertaking periodical audits to ensure that these actions have been conscientiously completed. TABLE I indicates the range of hazards that have been considered.

The emphasis on the different aspects of the safety task will vary markedly between a Yard which is solely committed to refitting and one which embraces an operating base. This is typified by the problems of power supply which have recently been experienced at Devonport. The provision and integrity of electrical services is fundamental to plant safety; its management from a common nuclear support system to a number of boats in varying states of maintenance is a continuous taxing problem. Whereas during a refit there are perhaps a dozen power connection/disconnection operations in the course of the year, the presence of the operating base has resulted in eighty operations in the same period, with an expectation that the presence of a full squadron in the next decade could increase the figure to as high as two hundred and fifty. Similarly the requirement to close up certain elements of the accident organization during Plant State A operation will be limited for refit purposes to approximately five weeks/boat. But where submarines are conducting crew training/physics tests/fast cruise as a feature of their normal harbour activities, the accident organization may be stood to for more than 50 per cent. of the time.

TABLE I—*Hazards investigated and assessed (Chatham Nuclear Submarine Safety Review and Audit Committee)*

1. Fire and explosion.
2. Internal flooding:
   Test procedures. Test memoranda.
   Ripout control procedure.
   Request tag-out procedure.
3. Failure of external services:
   60 Hz system. Alternative core-removal system.
   Demineralized water. Drainage of refitting docks.
   Salt-water cooling supplies. Fresh-water supplies.
4. Nuclear procedures.
5. External flooding.
6. Control of work.
7. Sabotage and malicious damage.
8. Heavy lift accident.
9. Dock caisson failure.
10. High wind accident.
11. Conventional weapon accident.
12. Lock caisson failure.
13. Collision/grounding (active).
14. Collision (passive).
15. Collision (passive) at buoy.
16. Overflying aircraft crash.

Standards and Responsibilities for Nuclear Safety in Naval Bases

In any management structure, it is important that we know for what we are responsible and to whom. With a subject as emotive as nuclear safety this is undoubtedly true; coupled with the complexities of the organization, it seems essential that this area should be clarified at an early stage. FIG. 1 provides a diagrammatic indication which the text will amplify.

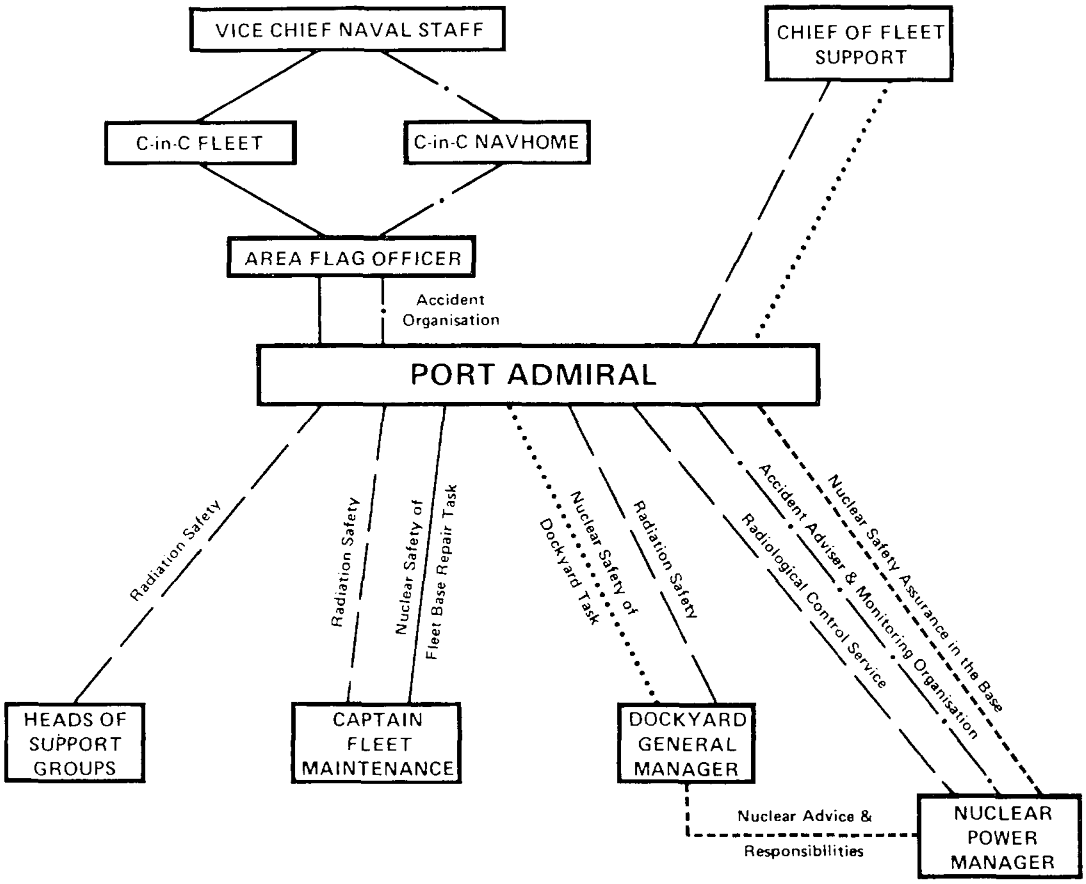

FIG. 1—RESPONSIBILITIES FOR NUCLEAR SAFETY IN NAVAL BASES

Dramatis personae

Port Admiral. As indicated in the introduction, a naval base is an amalgam of separate organizations which all contribute to the support of H.M. ships. Individually these organizations have a variety of different parent departments within the Ministry of Defence; the Port Admiral acts as a local coordinator to ensure the optimum use of resources but he carries responsibility for nuclear safety of all activities undertaken by naval base personnel. However, he does not set the standards; executive instructions are issued from a variety of sources, and in turn he is responsible to more than one higher authority. This situation may appear confusing at first sight, but it reflects the situation that expert groups lay down the policy which is then implemented by the individual parts of the MOD, being relayed down their own management lines. The concentration of these lines through one man on site provides the best possible chance that any conflicts are identified at an early stage and that activities of all groups concerned at the 'coal face' are mutually compatible and are coordinated.

Nuclear Power Manager. Port Admirals are normally able to draw on the independent advice of staff officers attributed to the Area Flag Officer, when they require detailed professional advice. However, in this context there is a need for continuous involvement of the adviser in the day to day safety activities, and this function is therefore necessarily undertaken by the Nuclear Power Manager. Although primarily a member of the Dockyard General Manager's Staff, he is also tasked as the Port Admiral's Nuclear Safety Officer and in this capacity is required to provide an assurance, independent of line management, that standards and practices are being maintained in all sections of the naval base where nuclear work is undertaken. His terms of reference in his dockyard role provide him with free access to all dockyard activities and, in this second function, this is extended into other support organizations, in particular the fleet maintenance group and the naval operating authority.

Commanding Officers. Are responsible for the nuclear safety of the plant in their vessel, and the radiological protection and accident control organization of their ship's company. Under certain circumstances they may, by mutual agreement, transfer these responsibilities to the Nuclear Power Manager acting on behalf of the Port Admiral.

Repair Authority. The conventional repair and maintenance pattern in a naval base is for a totally naval-staffed fleet maintenance unit (FMU) to provide support to ships that are operational, while the dockyard handles the major refit task, together with routine between-refit dockings (DEDs) or major defect rectification which is outside the capacity of FMU. In refit, DEDs, and OPDEF situations, the dockyard General Manager is the repair authority, defining after discussion with all interested parties the extent of work to be undertaken, and responsible for carrying it out: at other times the Captain Fleet Maintenance, who commands the fleet maintenance group has the responsibility even if it is necessary to contract the dockyard to provide assistance. The repair authority invariably has responsibility to the Port Admiral for nuclear safety of the work it undertakes and the manpower it employs.

Outside Organizations. The detailed and direct responsibility exercised by the MOD(N) design authority, DPT(S/M), necessitates more direct lines of communication with all outposts involved in nuclear submarine operation and maintenance than is the normal practice with conventional submarines and surface ships. Although the Chief Executive Dockyards (CED) is the executive authority for the dockyards, communications on immediate technical matters are normally conducted on a direct network with DPT(S/M), with only final agreements being transmitted on the formal lines through CED.

Rolls-Royce and Associates. The principle of direct communication has been developed further by the establishment of representatives from R-R&A, the plant designer, with a small staff in each Yard, acting on behalf of DPT(S/M). In this capacity he represents DPT(S/M) in the various formal groups in the Yard which approve and control nuclear work. Concurrently, he satisfies the Company that repairs, refuelling, and testing have been undertaken in such a way that the safety of the plant and contractual obligations with regard to the replacement of the core have not been prejudiced.

Safety and Reliability Directorate (SRD), AEA. The Site Service Section provides a service to the MOD(N) as an independent on-site monitor of standards and performance in all areas where there are nuclear safety implications, and as an advisory and consultancy service on nuclear safety problems. The local Site Liaison Officer acts both as an information gatherer and as a nuclear safety adviser to Nuclear Power Manager. He is also nominated as an *ex officio* member of the groups authorizing nuclear work; this gives him an official entree to discussions on any particular topic and the right to be a formal signing member for any procedure, if he so desires or, indeed, if the Chairman requests it.

These two on-site organizations—operating as adviser to the repair authority management but quite independent of it, and with authority to stop activities, by administrative means, where they are deemed to be unsafe—provide the MOD(N) with a powerful argument that they are tackling their responsibilities in a serious manner.

Scenarios

Arrival. The criteria for berthing nuclear warships are not the subject of national policy, but require approval by the independent Nuclear Powered Warship Safety Committee. One feature is a strict limitation on reactor operation at berths in close proximity to centres of population. Although a submarine in commission is largely capable of supporting itself in the subcritical state, the use of installed plant places severe strains on the technical manpower, and plant breakdown or maintenance requirements might prejudice this ability. Power supplies are therefore a fundamental feature of any approved naval base berth, and their connection to permit shut down of the reactor is an immediate action on arrival. Facilities for handling discharge of active coolant are also required for the older design of submarine which does not have an integral discharge tank and, in the case of boats coming straight into dock, cooling water supplies are an additional necessity.

Once committed to use of the shore side services, safety of the reactor is primarily dependent on their integrity and thus their provision and maintenance is an essential part of the nuclear safety load. The dockyard has responsibility for making the necessary connections, but maintenance of electrical supplies constitutes a particular problem area. Approved berths are not, in general, allocated to a particular repair authority, and resources necessitate the use of a common power supply system, rather than independent ones, each within the control of its own authority. The dockyard has overall control of this system, and close liaison is necessary between repair authorities to allocate priorities and to ensure continuity of supply under all circumstances.

Repair Task (including testing). Repair standards are defined by the design authority, DPT(S/M), at Bath; repair authorities are required to comply with these under executive instructions of the Chief Executive Dockyards, or C.-in-C. Fleet, who tasks the fleet maintenance groups as an extension of the operational fleet. In either case, the repair authority is responsible to the Port Admiral for the nuclear safety aspects. The Port Admiral, in turn, is answerable in different management chains depending on the repair authority. Where the dockyard is leading, the Chief of Fleet Support who has responsibilities for dockyards is the Board Member concerned but, in the case of the FMG, the line is from Port Admiral to C.-in-C. Fleet, and ultimately to Vice Chief of Naval Staff at Board level.

Radiological Safety. Standards of radiological safety in the naval bases for repair and maintenance purposes are determined by the provision of the Ionizing Radiations (Unsealed Radioactive Substances) Regulations 1968 and, more recently, by the general provision embodied in the Health and Safety at Work, etc. Act 1974. Although this legislation is not entirely applicable to MOD(N) personnel, either service or civilian, the requirements set out in BR 3020, *Instructions for Radiological Protection—H.M. Ships, and MOD Units and Establishments*, provide an equivalent standard of protection which is applicable to MOD(N) staff in all situations. The sponsor of BR 3020 is the Chairman of the Naval Nuclear Technical Safety Panel (CNNTSP) who provides a direct liaison with other Government bodies concerned, and interprets the national and international regulations to ensure that the standards applied by MOD(N) remain in line with acceptable current procedures: he is advised by the Medical Director General.

The Head of each support group is directly responsible to the Port Admiral for meeting these standards in so far as they apply to their own staff or affect the base as a whole. They are required to appoint a competent person to be responsible for radiation safety within their organization. The Nuclear Power Manager is tasked to provide a radiological control service to all Support Groups, except CFM, to allow them to meet their responsibilities. The Senior Health Physicist on NUPM's staff, as the senior professional expert, is appointed Naval Base Radiation Safety Officer, in which position he has delegated authority to require conformation with the regulations, but does not carry the responsibility for meeting them.

Commanding officers are normally responsible for the radiological control of their own ship's company but, where NUPM is providing a service for the dockyard workforce, he will, by mutual consent, undertake the same task for the ship's company.

Ultimate responsibility for radiological safety in the naval base as a whole is vested in Chief of Fleet Support cutting across some of the normal management lines from the component support groups in the base, but perhaps constituting the exception that proves the rule.

Waste Disposal. This is an essential facet of radiological protection, in which the Ministry conforms explicitly to the national legislation, the Radioactive Substances Act, 1960. All disposals, both solid and liquid, are made in accordance with approvals obtained from the Radio Chemical Inspectorate of the Department of the Environment, who are guided by the national policy statement contained in the White Paper, Command 884. The Nuclear Power Manager is responsible for ensuring strict compliance with these approvals by all sections of the naval base.

Nuclear Accident Organization. Policy is prepared by CNNTSP, working in conjunction with sections of the MOD, the National Radiological Control Board, Ministry of Agriculture, Fisheries, and Food (MAFF), Department of Environment and other involved Government departments. The ramifications of a nuclear accident are clearly likely to extend outside the confines of any particular naval base and are therefore the concern of the Area Flag Officer, who is responsible to C.-in-C. Naval Home Command (CINCNAVHOME), and ultimately the Vice Chief of Naval Staff as the superintending Board Member.

Site Safety Justification

The absence of statutory provisions over mobile reactors, and the potential hazard from an accident, requires the MOD(N) to involve itself, in a very direct manner, with plant safety at all times. Although it has defined the standards to be met in naval base activities and the responsibilities of individuals in the management chain down to a relatively low level, it still demands clear explanation of how these requirements will be implemented. These explanations *in toto*, when approved, represent the site safety justification; it is only valid so long as operating and management practices conform to the agreed documents.

The individual explanations of different facets of the task are described as Safety Reports. They are prepared by the repair authority and define how all those tasks with a nuclear implication, which have been specified by MOD(N), will be undertaken. The subject matter is examined in detail, including design philosophy and operating practice, but in particular the possibilities and ramifications of failure are probed at depth: each report requires MOD(N) approval. To ensure the widest range of experience is applied to the subject, an independent assessment of each report is provided to MOD(N) by the Safety and Reliability Directorate (SRD) of AEA.

A detailed audit of all features of the safety task is conducted every three years by CNNTSP, as the Safety Adviser to the Board of Admiralty. In this task he is assisted by MOD Headquarters staff from DPT(S/M) and CED, as well as SRD representatives. This activity seeks to confirm that the necessary material state and the personnel and organizational requirements are being retained, and hence justify confidence in continued operation of the site. It will also identify any new areas for which safety reports should be prepared.

Suitable training and experience of key post holders is a fundamental feature of the site justification. The MOD(N) formally identifies the qualifications required for a wide range of posts involved with nuclear safety and, in some, demands to approve the incumbent personally. By this means it is possible to ensure that an appropriate level of knowledge is available to deal with problems that arise. The repair authority applies a similar philosophy to a range of junior supervisory grades.

Training of the industrial labour force in specialist techniques and practices is also undertaken before they are employed on nuclear work. Specification of requirements and interpretation of Ministry of Defence standards is the responsibility of the Nuclear Power Manager.

Implementation of Safety Requirements

Having mentioned the interaction that can exist between two repair authorities operating in the same area, further examination will in general be restricted to the dockyard organization. Similar arrangements are employed in the fleet maintenance group and note will be made where there is any merging of activities.

Although the Nuclear Power Manager is tasked to provide assurance that all nuclear safety requirements are satisfied, it is well established that, ultimately, safety is in the hands of the man doing the job. The option of having all work with nuclear implications undertaken by staff directly responsible to Nuclear Power Manager, and thus giving him responsibility for ensuring safety, has been considered, but it is not a practicable solution. The wide scope of tasks which would be covered would impinge on many trades and sections of the naval base; in almost every case it would represent only a very small fraction of each centre's total load; this would make separation of staff uneconomic, and where more than one repair authority existed, would cut right across normal management lines. Except, therefore, in the special cases of refuelling and some plant testing, when direct authority by the Nuclear Power Manager is considered desirable, safety controls and activities are grafted onto the normal management structure. Once the material state of the base has been established, the implications of nuclear safety are very largely identified as the activities and interactions of the Nuclear Power Manager's Staff, the Nuclear Power Department, and the remainder of the conventional organization. There is no possibility that every facet of this relationship will be examined. Many readers may recognize a quote from BR 3018, 'In carrying out the refit of a nuclear submarine, the potential hazards of a reactor accident, the problems of working in radiation fields, the complexity of the equipment and systems make necessary a rigorous standard of organization and control. This control is exercised by means of comprehensive documentation for both the nuclear refitting and overall ship testing phases . . .'. Our procedures are indeed contained, controlled, and administered by a welter of paper which experience has shown to be necessary. It would be time wasting to examine them in depth in an attempt to convince the reader that every loophole is covered: this is the function of the detailed audit procedure which has been mentioned. It is the intention to do no more than indicate the basic principles involved, in the most significant areas.

The limited autonomy that still exists in the Royal Dockyards results in some variations in the way the task is undertaken in each: the reader will appreciate that the author's view is coloured by experience at Chatham.

Safety philosophy and Refitting Organization

This is built around the concept of unanimous agreement by a group of experienced officers, normally at professional level, on any action which could conceivably have nuclear safety implications. Although sounding, at first, like a recipe for total stagnation, this process ensures that every action is debated in a forum of qualified engineers, and that rash enthusiasm is controlled. The agreed decisions are published in documents described as 'procedures'; these are mandatory instructions to the workman on the prerequisites, preparations, and basic steps in the required order necessary to ensure nuclear safety. The practice is equally applicable to repair tasks, refuelling, or testing. These groups are described as procedure authorization groups (PAGs) and the experience and qualification of the members are carefully specified by MOD(N). In each case, they will include representatives of the organizations undertaking the task, the ship's staff where appropriate, and the Nuclear Power Department.

Where a relatively large number of submarines may be in port at any time, possibly under the care of two repair authorities, the problem is compounded. It is possible that the nuclear activities of individual PAGs or, indeed, individual repair authorities may be safe, but mutually incompatible. This problem is dealt with in the first instance by the Nuclear Power Manager's membership of all PAGs, GM's and CFM's. This primarily provides assurance of repair standards and philosophy, but also gives preliminary warning of possibly conflicting activities. Additionally, a Safety Coordinating Committee, with representatives from CFM and the Squadron Commander and under the personal Chairmanship of the Nuclear Power Manager, is set up to meet on a regular and emergency basis to resolve programme clashes which might prejudice nuclear safety.

The PAG process identifies 'the how' for every task with nuclear safety implications, but other essential parts of the equation are identification of the jobs to which this process should be applied, and assurance that the work is undertaken in the defined manner.

The scope of work to be achieved in a planned period in the dockyard is largely known well in advance of arrival. All tasks are vetted by the Nuclear Power Manager to identify those which have a nuclear safety implication and a logical programme of activities (the nuclear logic) is prepared based on the prerequisites of each activity. Once agreed by the PAG, this logic is mandatory: it is incorporated into the plan for the rest of the boat which may have to be amended to meet its requirements. Every activity in this nuclear logic will be subject to control by a procedure prepared by the repair authority. All of these tasks, and any others in which the worker may be subjected to radiation, will be further controlled for radiological safety by instructions from the Health Physics Staff. The need for these precautions is identified in the planning stage and communicated to the worker by means of coloured work instructions. However, it is the fate of any organization doing the work to be subjected to the late requirements for additional items originating from design or administrative authorities, or revealed in wake of other work. As an added safeguard to ensure that such work does not escape the detailed assessment of possible effect on the nuclear plant, no work instruction, unless specifically cleared of nuclear implications by earlier NPD action, is authorized until it has been countersigned by the responsible NPD officer to the effect that appropriate procedural and/or radiological protection is specified; ship's staff approval to proceed is also required. Both these authorizations are dependent on action within a specified time.

The onus for nuclear safety now rests on the man doing the job. However, any single activity probably involves not only a number of men, but a variety of different centres. It is therefore necessary to appoint an individual to liaise between the various centres and accept overall responsibility for the sequential aspects of the procedure. He is technically appointed by the repair authority with the agreement of the commanding officer, but in practice he is detailed by the PAG and will normally be a supervisory grade from the lead centre, so that he is in a position to provide direct control over a major part of the work: occasions will also arise for activities of an operational type, when this 'Coordinator' is drawn from Nuclear Power Department or ship's staff. Whilst responsibility now rests with the management of the workforce, it is not sufficient, or even always possible, to demonstrate by final test that the job has been satisfactorily completed: the way the work was undertaken, particularly in respect of cleanliness, is often highly significant. It is therefore necessary for the

Nuclear Power Manager, fulfilling his role of providing assurance of safe practices, to operate an on-site inspectorate to monitor adherence to the detail of the procedures and compliance with the relevant specifications around the clock. This work is undertaken by the Nuclear Standards Branch, who are the arbiters of 'quality' and 'standards' in their widest sense in the context of reactor plant in the dockyards.

A particularly important aspect of this monitoring is undertaken both ashore and afloat in connection with welds in the reactor system pipework. Achievement of consistent and satisfactory results is only possible by rigorous attention to detailed procedures, and the employment of welders whose skill in undertaking similar welds has been developed and demonstrated by satisfactory welds undertaken in a similar configuration and with the same difficulties of access. Welds are normally finally assessed by conventional double wall radiography but this represents only a small if important part of the total checks undertaken to ensure a quality result. A perfect radiograph will not be accepted as evidence of a sound weld without a substantial quantity of supporting evidence that it was achieved in accordance with the detailed weld procedure. To maintain as a matter of course this strict conformance with proven practice, step by step, auditing action is undertaken on up to 25 per cent. of all primary circuit welds.

The interpretation of radiographs remains to some extent an art, and certainly requires considerable experience and regular application of the assessing skills. To provide the necessary assurance of consistent and valid interpretation, all primary system welds have to be approved by unanimous agreement of a committee of 'three wise men', The Primary Weld Acceptance Group, (PWAG), evaluating each weld against the standards prescribed by the design authority. This group comprises the Head of the Nuclear Standards Branch, the Dockyard Welding Superintendent, and a welding surveyor from Rolls-Royce and Associates, the reactor plant designers.

Other aspects of quality assurance 'on the job' are undertaken by Standards Branch. The rigorous checking of certification for all material to be fitted into the reactor plant, and the maintenance of satisfactory working conditions in which high standards can be achieved, are important features. Under the heading of Compartment Administration, they exercise control over the numbers working in the compartment, ensure that levels of cleanliness inside the primary circuit, when open and in the compartment, are appropriate to the work in hand, and supervise and advise on working practices in the nuclear environment.

Refuelling

Completion of refuel is one of the major milestones in the refit programme but because of the size of the work package, and the commitment to early start in this area, it seldom appears on the critical path. The manner in which it is repeatedly completed to the exact date planned two years in advance suggests that the problems have all been resolved. While there is no doubt a measure of truth in this view, it is perhaps more correct to say that the problems still exist but we know how to tackle them.

Refuelling operations involve the storage, movement and disposition of new and irradiated fuel, contaminated components, materials, and radioactive sources with the accuracy necessary to remove and install items in the core. These operations require a heavy investment in equipment and facilities, and their provision is part of the initial equipping of the refuelling site.

Safety reports are raised which define the nuclear safety philosophy and its application and justification in each area of the refuelling task, and these reports are examined and ratified periodically by the Safety Working Party (SWP). The SWP is responsible to the Ministry of Defence (Navy) for, *inter alia*, approval of nuclear safety aspects of refuelling activities; it exercises a close liaison with the refuelling yards through a Refuelling Safety Sub-Committee (RSSC).

The RSSC assesses the safety reports and justifications, from which the on-site refuelling safety instructions will derive. Clearance of safety reports by the RSSC gives the Yard the right to adopt the philosophy and methods outlined in them for immediate use in drawing up its local control documentation. Formal ratification of the safety reports by the SWP follows, upon advice of the RSSC.

The refuelling task provides a greater than normal risk of a nuclear hazard situation developing. It is in fact so totally involved with nuclear safety that it is established practice for NUPM to exercise direct line management responsibilities over the whole task.

Nuclear safety standards are maintained on site by comprehensive control documentation which has to be formally approved by the Refuelling Procedure Authorization Group (RPAG) before use. Refuelling control charts and procedures are proved during training and previous refuels, and the refuelling branch is required to carry out its task only by working step by step in accordance with these documents.

Prior to the event, a complete simulated refuel is carried out by the teams in a shore training rig; this work includes qualification of the teams by RPAG observation during the training runs, and qualification of the refuelling directors and assistant directors at the end of training, by written and oral exams. The RPAG team observing the simulated handling of fissile material and undertaking the examinations will include *ex officio* members from DPT(S/M), R-R&A, and SRD, so that outside authorities will have an up to date picture of current standards and practices. This training and examination is a firm requirement, no matter how short a time has elapsed since they were last employed on the task.

Handling highly irradiated and contaminated components creates many problems in respect of the safety of the refuelling staff and other dockyard workmen. Shielding can be maintained in much of the equipment by incorporating lead sections in its design but this results in very heavy and bulky equipment with attendant handling dangers. The other important shielding medium used is water. Irradiated modules have to be kept cool as well as shielded, and so operations involving the modules are carried out, wherever possible, using remote handling tools, working through water; it is imperative for safety to maintain the required level of water at all times during such operations. Variations in water level in the reactor pressure vessel and refuelling stack up could occur through the primary circuit pipework; great care is exercised to establish and maintain a refuelling boundary which is inviolate without the permission of the RPAG.

Airborne contamination is a constant source of danger as radioactive material becomes detached from surfaces as they dry out. This hazard is controlled as far as possible by keeping surfaces wet and submerged and otherwise, by specialized bagging techniques, and by atmospheric control in the work area.

Surface contamination on tools and installed equipment can present difficulties; if allowed to build up on common usage items, it would very quickly present a serious radiological problem, and close examination of circuit components due for re-use might not be practicable. The ability to decontaminate or at least reduce the levels of activity is therefore essential: the necessary facility is operated by the refuelling branch who also provide a service to the rest of the nuclear refitting organization.

It has become established practice to carry out refuelling on a basis of round the clock shiftwork. Although not strictly essential, the need to revert to a totally safe unmanned condition at the end of each working day, would be so time consuming that progress would be very slow. The potential for hazard situations is such that supervision is provided at a level and on a scale that is more than generous by normal standards to ensure that every activity, whether in the boat or ashore, will be covered. Retracing ones steps could be difficult, if not impossible and the ability to confirm that every step was undertaken, exactly as specified, is essential.

After agreement and establishment of the refuelling boundaries, the ship's staff do not participate in the refuel activity, except in so far as they operate the alternative shoreside decay heat removal system until the last module is removed. Although they are continuing to exercise a measure of responsibility for long term nuclear safety through the repair PAGs, the immediate nuclear safety problem is inside the refuelling boundary. It is therefore the practice to transfer the responsibility for nuclear safety to the Nuclear Power Manager, representing the Port Admiral, for the period of the refuel. This action is taken very formally and involves, *inter alia*, identification of the management chain by which the Port Admiral will exercise his responsibility, indication of MOD(N) approval, and authority for dockyard staff controlling the refuel operation to exercise executive control over the ship's staff.

A practical aspect of this responsibility is the requirement to monitor the source range instrumentation at all times that fissile material is in the reactor. The repair state of systems inside the hull will necessitate the use of temporary instrument supplies and racks for much of the refit: although temporary they have the integrity of other nuclear supplies. Instruments are made available in either the manoeuvring room, the ship's shoreside control centre or the reactor access house, whichever is appropriate to the authority concerned.

Test and Trials

Each dockyard operates a dockside test organization (DTO) whose task is to demonstrate that all aspects of the submarine equipment meet their specified performance standards. The DTO will direct and supervise the execution of all tests, providing the supporting organization and services, including the preparation of test documentation. This will be authorized by test groups consisting of specifically nominated, experienced engineers who must achieve the standard unanimity in their decision on how testing is to be undertaken, before approval is given.

Testing of the reactor plant is undertaken by the reactor test group (RTG). This is the key group from the nuclear safety aspect and has overriding authority where nuclear safety or the operation of the propulsion plant as a whole is involved. They are authorized to nominate those tests which they will undertake and also indicate tests from other groups which they consider may have nuclear implications and whose approval is therefore subject to their endorsement.

Unlike the building yards, operation of the plant is only undertaken by ship's staff and at this stage of the refit, the Commanding Officer has overriding responsibilities for safety. He can therefore decline to carry out a particular activity if he believes it to be unsafe, but such a situation should never arise since differences of opinion should have been ironed out at the RTG meeting. Every test group member has the right to stop a test if he considers it unsafe and also to require a test to be re-run if he considers the results to be unsatisfactory.

Testing invariably reveals defects which must be rectified before work can proceed; approval to work on a system which has been or is under test is normally handled by 'rip-out report' procedure, which provides a quick method of authorizing work for immediate action. An essential feature of this process is that of maintaining nuclear safety while carrying out the work, ensuring that relevant precautions or limitations are imposed in the same way as if the task was part of the original work package: authorization is only provided by the RTG which includes a senior NPD officer. Where the defect is significant in nature, testing will be suspended and the system or part of it will be transferred to Refit PAG control for formal procedural documentation to be raised and actioned.

In order to maintain a comprehensive record of any event which might affect plant safety or performance, either in the immediate or long term future, out of the ordinary events are the subject of incident reports raised by the repair authority, in conjunction with commanding officers. The design authority consider the implications of such an incident, consulting their design and safety advisers, and will make recommendations for any further action either technical or administrative.

The design authority commence their detailed interest in the test phase by approving the index of all tests to be undertaken and indicating which test documents are to be submitted for formal approval, which results are to be agreed by DPT(S/M) before acceptance, and where other authorities are to be involved.

The testing philosophy seeks to prove, so far as it is possible, all equipment dependent on, or connected with, the reactor, before taking it critical. The programme is compiled to check progressively individual systems for completeness, pressure integrity, cleanliness, and cold operation, culminating first in the primary circuit hydrostatic test undertaken at just above the minimum safe pressurization temperature; then, after final lagging, operation of the entire plant at design temperature is demonstrated, before taking the plant critical. Prior to this final stage, it is necessary to establish the integrity of the containment boundary, designed to withstand and remain, effectively, leaktight under the pressures generated in the maximum design accident. A fully instrumented test identifies leakage into systems, or simply through the bulkhead glands: One per cent. of total volume/day is permitted.

A new unproven core, partially proved systems, and ship's staff operators who in spite of continuation training will be out of practice and may be expected to be below the usual level of efficiency is a situation requiring particular caution. During the initial approach to criticality and subsequent power range testing (PRT), representatives of DPT(S/M) and SRD will be in attendance as additional safety assessors and will participate as full members of the RTG. In addition, the DPT(S/M) representative will monitor the operating performance of the crew in order to be satisfied that the operating procedures are being correctly interpreted and the plant is being operated in a safe manner. Critical operation is not permitted until MOD(N) has been satisfied that all necessary validation, repair, and test work has been satisfactorily completed, and a formal authorization indicating any limitations and particular safety precautions has been issued. These will include the automatic trips on power level and power rate increase which will be adjusted to operate at figures markedly lower than the normal levels, the incorporation of a fission product monitor in the primary sampling system to give early warning of any lack of core integrity, and restriction on the permissible iodine inventory under test conditions to reduce the hazard in the event of an accident.

Radiation Protection

The responsibility for the control of hazards from ionizing radiation lies, as for other hazards, with the occupier of a factory or the controlling authority; in the case of the MOD it is the Commanding Officer or Head of Establishment.

Since 1961, ionizing regulations have required that persons are appointed to exercise special responsibilities with regard to radiological hazards. This has recognized that unlike many conventional hazards, the measurement of radiation, the assessment of risk, and the application of radiological controls are functions which are too specialized for line management to undertake completely and are therefore to be exercised on behalf of management by persons who are not directly in the line management but who take their authority from the occupier.

This principle is exercised within the MOD by the appointment (under the authority of BR 3020) of Radiation Safety Officers, with delegated authority from the Head of Establishment and competent persons, to supervise the carrying out of the instructions and assist in applying them.

In practice this leads to the formation of a specialized health physics section who carry out the radiological protection task on behalf of the workers line management. The line management in turn can show that it carried out its obligations if the radiation safety aspect of the work is covered, not by them but by the specialist section. There is no change in the responsibility of the Head of Establishment.

The regulations for working with radioactive materials are *The Ionizing Radiations (Sealed Sources) Regulations 1969* and the *Ionizing Radiations (Unsealed Radioactive Substances) Regulations 1968*. These instructions were made under the Factories Act 1961 and are now included under the umbrella of the Health and Safety at Work, etc. Act 1974. Although this legislation is not binding on all sections of the Ministry of Defence (Navy), BR 3020 *Instructions for Radiological Protection—H.M. Ships and MOD Units and Establishments* provides an equivalent standard of protection and is applicable to all persons not subject to the Factory Acts. It is these regulations which health physicists and radiation safety officers apply on behalf of management.

The Ionizing Radiation Regulations have always included details of the precautions which need to be applied by management, and have included specific responsibilities of workers in respect of looking after themselves, their colleagues, and equipment issued. These are now underlined by their inclusion in the Health and Safety at Work, etc. Act 1974.

Radiological protection therefore depends on the management and workforce taking the correct precautions, as detailed in the regulations, and they have a specific responsibility so to do. The Health Physics Branch, acting on authority from the Head of Establishment provides the equipment and know-how necessary, carries out the monitoring, and advises on the necessary precautions from waste disposal to shielding, from transport of radioactive materials to the provision of an emergency monitoring organization.

The particular problems of radiological safety which are of concern in the refitting task arise as a direct result of the type of nuclear reactor in service and on the range of refitting work carried out. A PWR has two characteristics which determine the radiological protection measures necessary:

(*a*) The primary circuit cleanliness is controlled by a water chemistry regime and strict cleanliness control whenever the circuit is opened. Coupled with the integrity of the fuel elements, these features effectively result in radioactive contamination by Cobalt_{60} alone: other short lived products are present but of less significance.

(*b*) The nature of the refitting task requires direct handling of primary circuit components, and considerable stay times within an active area which is limited in working space and offers little opportunity for the introduction of aids to dose reduction such as shielding or remote handling equipment.

The lengthy half life of Cobalt_{60} (5·2 years) related to the non-critical periods which the reactor enjoys results in a steady build up of activity on a 'saw-tooth' profile, and progressively higher levels at each refit. Currently the first refits of fleet submarines are giving a dose burden of approximately 1000 rad to the workforce; second refits, which are just starting, are anticipated to produce a burden in excess of 1500 rad, if no adjustment of working practices is introduced, without taking into account any additional dose arising from increased validation activities.

These levels of dose have until now been accommodated by the workforce using conventional dockyard industrial arrangements, but the resources in reserve are not great and changes may well be necessary to cope with the programme of second refits. The possible advent of more stringent personal dose limitations suggested by International Commission on Radiological Protection, Publication No. 26 (ICRP 26) would create major problems for dockyard management since the scope for significant reductions does not appear to exist, even if far-reaching changes in working practice are implemented.

Dose control has two major elements:

(*a*) The shift-by-shift, day-by-day, maintenance of the record of dose received by each individual. To be of any value it must be possible to inform centre supervisors of the dose each man still has available, in time to give a steer on where efforts should be concentrated to reduce dose receipts. This activity, together with the day-to-day control necessary to ensure that no one exceeds the statutory limits, constitutes a major administrative task.

(*b*) The positive reduction of the total dose burden. Control of doses to the individual only has the effect of spreading the dose amongst more men. Whilst this is necessary to ensure that personal doses to individuals do not exceed statutory limits, real reduction in total dose is a function, firstly, of the limitation of the actual time spent in contact with the work and, secondly, reduction of the dose rate by shielding or decontamination.

Decontamination of the primary system was undertaken in *Dreadnought* where levels were considerably higher than in the remainder of the fleet: the results were significant in terms of total reduction in the overall dose but the price paid, both in cost and delay to the refit, were high. Although the ability to repeat the operation is retained, a heavy dose burden is involved in preparation for decontamination and the lower levels of initial contamination which we are currently seeing do not justify this approach: more economic tactics are necessary. Chatham is currently engaged in jacketing *Valiant's* primary circuit in 2 cm of lead to produce an anticipated 30 per cent. reduction in dose burden for the period in which it can remain in place.

Finally, there is good discipline. A long established fact is the difficulty of maintaining close supervision in the reactor compartment. Dose problems, the demands of men in many varied locations outside, and the bother of dressing and other controls militate against frequent visits by supervisors to the reactor compartment. However unsatisfactory, this is one of the problems that has to be faced: in general, it means that except for important closely monitored activities, more dependence is placed on the individual workman than in other work, and nowhere is this more evident than in personal responsibility for sensible restriction on exposure.

Radioactive Waste Disposal

Radioactive waste arising from the refit of nuclear submarines is subject to the provision of the Radioactive Substances Act 1960. This act, jointly administered by the Radiochemical Inspectorate of the Department of the Environment, and the Ministry of Agriculture, Fisheries, and Food, controls the keeping and use of radioactive materials and the disposal of active waste. The methods of disposal available are published in Command 884, but the D. of E. Inspectorate must first issue approval for any particular route.

Very low levels of activity may be disposed of to contractors tips or down the public sewer; marginally higher levels are buried on site in controlled pits or discharged to the tideway. Strict limits are imposed on quantities/rates of activity disposed of by these means, and actions are carefully monitored by the D. of E. Inspectorate. The approval for use of burial pits required a guarantee of control of the site for 25 years after finally filling in the area.

Moderately active waste is packed into concrete drums for disposal at sea. The design of drums has to meet the requirements of the Ministry of Transport (for shipping purposes) and the Ministry of Agriculture, Food, and Fisheries (for sea contamination criteria). This category includes used primary circuit resin which, with the exception of fissile material, represents the highest activity levels handled as waste.

Irradiated fissile material is transported by rail to Windscale in specially designed used-core transport packages, carried on a custom made transport vehicle. It is invariably accompanied by a police security guard and a technical safety team.

Limitations on the quantity of radio nuclides discharged to the river necessitate ion-exchange treatment for all contaminated water before disposal. Similarly, it is necessary to sort solid waste to extract the high-level constituents with the object of reducing average levels of the remainder to a level where it can be buried on site. This manual sorting process is a potential source of airborne hazard: it is conducted under controlled conditions in a special facility, operatives using air hoods.

Nuclear Accident Organizations

If we suffer a reactor accident there is no way of forecasting with any accuracy what the size of the release is going to be and the direction in which the radioactive cloud will move, and the rapidity of its dispersal will depend entirely upon the local weather conditions. A pre-arranged emergency scheme is therefore essential. It is MOD(N) policy to assume that fission products will leak from the containment, that they will constitute a radiation hazard to health, and that they may move in any direction. It will take up to twelve hours from the time at which the accident occurs before a realistic estimate of contamination can be made from the information obtained by radiation monitoring.

The criteria for maximum immediate hazard is that associated with inhalation of active iodine. The standard or most probable accident will permit a stay time in the open air of twenty-four hours at 600 yards from the submarine, taking account of inhalation dose and direct radiation from the cloud. Exposed foodstuffs, free range eggs and milk, produced at greater distances will produce significant doses in slower time. Direct gamma exposure will only be a serious hazard to those who are on board or in very close proximity to the submarine. A more severe accident is possible but less probable, and is restricted in its magnitude by limitations imposed on the permitted level of iodine in the core. A policy of less immediate but controlled evacuation of personnel in the downwind sector beyond the 600 yard radius will provide an ample degree of immediate safety in the event of the more serious accident situation.

The fundamentals of the accident organization are based on these simple facts, and can be summarized as:

(*a*) Berths are carefully chosen so that no member of the public lives within the 600 yard radius (evacuation area).

(*b*) An immediate evacuation plan is prepared for the ship's company and all those members of the repair authority workforce who work within the evacuation area, with protection and slower time evacuation for the remainder of the workforce.

(*c*) An emergency monitoring organization is available, partly on site and partly on call, to provide detailed information on the extent of contamination for the use of both naval and civilian authorities.

(*d*) A local Liaison Committee is established between the Naval Command and the local Civil Authorities to provide an information bridge and to create the administrative machinery for the protection of the population against the lower contamination levels which may occur outside the naval base, in the event of an accident.

Details of the necessary organization and reaction are published in nuclear safety (NUSAFE) orders, prepared by the local Naval Command and subject to MOD(N) approval. They provide details of the immediate procedures for protection of those within the base, the monitoring organization by which the Command will obtain the necessary information on which to base its decisions, and the creation of a Nuclear Accident Headquarters. They are complemented by a public safety scheme, prepared in conjunction with the civil authorities which explains the hazard to the civilian population and defines civil organizations for implementing public safety measures.

Control of the Accident Organization is exercised by the Port Admiral through the Incident Commander, who has direct responsibility for all executive decisions in respect of the whole naval base. He is advised by the senior dockyard management including the Nuclear Power Manager and the Senior Health Physicist. Direct communication links are maintained between the Naval Headquarters and the Civil Accident Headquarters, normally established in a local police station.

Each base operates a Local Emergency Monitoring Organization which is equipped to undertake accident monitoring on site or with a specially equipped vehicle in a fully mobile capacity outside the base perimeter. (Additional monitoring support is also available from the central Naval Emergency Monitoring Organization and the Naval Radiological Protection Service, both at Gosport.) The local organization operates from the Emergency Monitoring Headquarters within the base, which provides a limited Health Physics Laboratory facility, and a control centre from which both on-site and mobile monitors outside the base can be directed by radio and/or telephone links, their findings plotted, and the results analyzed and passed to the Incident Commander.

Under conditions of greater than normal potential hazard, which are defined by NUPM and are generally associated with reactor operation in plant State A, the Nuclear Accident Organization is activated. Emergency Monitoring Headquarters is manned around the clock and the civil authorities are advised of the increased state of preparedness. Where submarine movements are involved, extreme precautions are invoked to ensure that no possibility of grounding or collision will exist including the provision of a specially equipped nuclear safety tug. Certain other material facilities are also provided to reduce any release/spread of fission products, or otherwise improve personnel safety: they will have already been brought to a state of readiness before the organization is closed up. These are:

(*a*) *Dockside Installed Radiac Systems* (*DIRS*)—provides an immediate warning of a rise in radiation levels at the dockside and some indication of the severity of the accident: it is monitored in PRT HQ and the Emergency Monitoring HQ.

(*b*) *Spray Drench System*—a remotely operated facility for enveloping the submarine, in way of the reactor compartment, with a water spray to precipitate iodine and other volatile fission products in the event of a rupture of the containment.

(*c*) *Fan Filter Units*—fitted on submarine hatches to ensure that fission products which may have leaked into the secondary containment are trapped in the filters. A slight vacuum is maintained in the secondary containment of the submarine so that there is a tendency for leakage from outside the submarine inwards, rather than the reverse.

(*d*) *An Exclusion Area*—is established around the submarine. The boundary of the area is outside the calculated 100 R/hr gamma doserate line, resulting from a maximum design accident. Access within the area, including the submarine, is restricted to authorized personnel only who are strictly limited in number: each is equipped with an accident dosimeter which can be interpreted on site. Under accident conditions, personnel within this exclusion area are at highest risk; after evacuation, they can be readily segregated for detailed dose assessment and medical attention.

(*e*) *A Reception Centre*—available for immediate manning by medical and monitoring staff in the event of an accident, for assessment and decontamination of personnel from the Exclusion Area, and others who may have suffered contamination.

Conclusion

It is clear that the limit imposed by the organizers on the length of this article has been far exceeded and it would only aggravate the fault to produce a wordy conclusion. Dr. Johnson is reported as saying on some occasion 'I apologize for writing such a long letter, I didn't have time to write a short one'. The reader will, I trust, forgive this somewhat wordy coverage of the naval base safety scene. The problem remains one of precising without stripping off all the flesh on the bones.