CONFIDENTIAL

NUCLEAR SAFETY ADVISORY PANEL TO THE GOVERNMENT OF GIBRALTAR

REPORT ON THE SAFETY OF HMS TIRELESS WHILST UNDER REPAIR AT GIBRALTAR

EXECUTIVE SUMMARY

HMS Tireless entered Gibraltar harbour on 19 May 2000, with a leaking weld in the reactor primary circuit, and is currently berthed there awaiting repairs.

This report presents the findings of the Nuclear Safety Advisory Panel set up in response to this by the Chief Minister, Government of Gibraltar. The Panel was tasked to give an informed assessment on the nuclear safety of the submarine under repair, compared with a submarine on a normal recreational visit.

The Panel was selected for its extensive knowledge on nuclear safety, including nuclear powered submarines. The Panel used this knowledge to request, check and test the large amount of written and verbal information provided by the MoD on the proposed repairs, and to perform its own assessment.

The repair activities planned by the MoD comprise partially draining the reactor primary circuit as a necessary precursor to remaking the weld, subjecting the weld to extensive examination and then pressure testing the primary circuit. The submarine will then depart from Gibraltar under nuclear power in the normal way.

The Panel has carefully considered the MoD plans, independently identified the nuclear safety issues and sought resolution of these issues. The scope included the safety of the submarine reactor before, during and after these repair activities, and the safety of the primary circuit water and other radioactive waste to be brought ashore for temporary storage.

The following were identified by the Panel as the key factors:

- The long time since the reactor was shut down means that *HMS Tireless* is in a safer state than a boat visiting for recreational purposes, and will remain so throughout the repair period.
- The repair operations will not introduce any significant new safety risks.

- The water to be removed from the primary circuit and the other waste is of low radioactivity. The MoD has adopted good safety practice in their engineered and administrative arrangements for handling and storing it, until it leaves Gibraltar shortly after the submarine's departure.

- As planned by the MoD the weld repair is very likely to be successful. The remaining uncertainties have no safety significance but may result in programme delay.

In addition, the Panel considered the option of towing or ferrying the submarine back to the UK for repairs there. The Panel has no specialist knowledge of these seamanship issues, but concluded that the option would introduce new, higher risks to the submarine, its crew and, possibly, to coastal communities.

Before reaching these conclusions, the Panel had received a significant and sufficient amount of information from the MoD, who has been co-operative. The Panel is satisfied with the quality of the MoD safety case and the underlying safety culture. Nevertheless, it should be noted that all the above findings are largely based on the Panel's independent knowledge of the issues involved.

The Panel has therefore concluded that the proposed repair of *HMS Tireless* at Gibraltar does not raise any significant new safety or technical concerns.

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Date: 13 September 2000

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Contents

1 INTRODUCTION

Following the MoD's statement that *HMS Tireless*, currently berthed at Gibraltar, has a primary circuit defect which they wish to repair in situ, the Government of Gibraltar convened a Nuclear Safety Advisory Panel.

The Panel consists of four members, who as a group provide independent expertise on the various aspects of nuclear safety and submarine reactor technology. Details of the Panel are presented in Annex 1.

The Panel was instructed by the Government of Gibraltar to attend meetings and presentations by the MoD, study MoD documentation, seek further information and consider the MoD responses. The stated objective was for the Panel to make an independent and informed assessment of the nuclear risks posed by the MoD's intended repair activities on *HMS Tireless* at Gibraltar, and compare these to the risks posed by a submarine on a normal recreational visit to Gibraltar. Additionally the Government of Gibraltar sought the Panel's views on the options for moving the submarine back to the UK for repairs there, and the risks involved.

In the event the Panel met with and questioned MoD representatives on three occasions, and asked for and reviewed a substantial amount of documentation, which is listed in Section 8. The Panel was not permitted access to the submarine reactor compartment and has not yet inspected the berth facilities.

On 30 August 2000, the Panel formally advised the Government of Gibraltar that it had all the information needed to perform the assessment.

This report presents the Panel's findings. However in order that the nuclear safety concerns and the Panel's reasoning can be more readily understood, the report begins with several sections explaining the MoD's safety regime, the

nuclear power plant, the current state of the submarine and MoD's future plans for it.
The Panel's deliberations on the current and future levels of nuclear safety are then presented, including a comparative risk assessment, followed by the Panel's opinion of the alternative of moving the submarine back to the UK.

This report intentionally curtails and simplifies the topics whilst omitting matters of secondary importance in order to present a concise account of the key issues. The Panel also has to acknowledge that certain issues are security related. Thus the Panel's discussions and deliberations were wider and more detailed than are presented here.

2 THE MOD'S SAFETY REGIME

British civil nuclear plants are licensed by the Nuclear Installations Inspectorate (NII) consequent to the Nuclear Installations Act. The NII has set out their requirements for the avoidance of nuclear risks to workers and members of the public in a published document (Ref 26) which includes management and engineering standards, and a set of risk limits. These are intended to ensure sufficiently high standards of nuclear safety, the risk limits being based on the NII's study on the Tolerability of Risks (Ref 27).

The NII has limited jurisdiction over the Ministry of Defence (MoD) but the MoD has its own Naval Nuclear Regulatory Panel (NNRP) which have set similar standards and risk limits to those of the NII.

In addition to requiring that all practicable measures are taken to prevent damaging releases of radioactivity to the environment, both the NII and the NNRP require that arrangements are set up, on site and with the local civil authorities, to counteract and mitigate the public effects of such a release should one occur. For Gibraltar the requirement is satisfied by two plans, one specific to Naval Base activities, while the other deals with the co-ordinated response of the MoD and the Gibraltar civil authorities. The plans are required to specify the responsibilities and actions of all the key personnel, and the way in which they interface and interact in protecting the public.

The MoD's safety regime is prescriptive and sets out definitions, procedures and requirements to cover most equipment and operations with a nuclear safety connotation. This includes the classification of submarine berths as either X or Z berths. An X berth is required to have suitable facilities and infrastructure to allow regular nuclear repair and refit work. A Z berth is one whose normal use is recreational, however, the definition in the MoD's regulatory document (Ref 33) allows for the possibility of repairs to nuclear plant, subject to the specific approval of the NNRP. The Gibraltar Public Safety Scheme (Ref 29) does not include the possibility of such repairs and this discrepancy is picked up in Section 5.1.

At Gibraltar, the recreational use of the berths is limited to a total of 55 days per year. In this context a recreational visit is short (typically 5 days at Gibraltar), with the submarine arriving and departing under nuclear power. When the submarine is alongside, the reactor is kept at operational pressure and temperature to permit it to be brought up to power quickly, and no radioactive substances are disembarked or discharged. The reactor plant conditions and state of the boat's systems that apply to a recreational visit form the datum for the Panel's safety assessment.

In order to gain NNRP's approval, safety cases specific to the planned repairs to *HMS Tireless* have had to be produced. Much of the safety documentation available to the Panel was originally produced for this purpose.

3 OUTLINE DESCRIPTION OF THE SUBMARINE PLANT

3.1 The nuclear power plant

HMS Tireless is powered by a pressurised water reactor (PWR), shown in a simplified schematic form in Fig 1.

The **reactor pressure vessel** contains the **nuclear fuel**, and water under high pressure is pumped past the nuclear fuel, collecting heat from it. This water is piped to the **steam generators**, where its heat is transferred, and is then returned to the pressure vessel to form a closed loop, called the **reactor primary circuit**.

The primary circuit pressure is controlled by a **pressuriser** which is connected to the primary circuit by a relatively small pipe. Steam in this pressuriser can be heated electrically, or cooled by a spray of cooler water. Changing the temperature of this steam bubble changes its pressure, and hence controls the primary circuit pressure.

The steam generators extract heat from the primary circuit water and use it to raise steam in a secondary circuit. This steam is used conventionally to power turbines for submarine propulsion and to generate electricity for use within the submarine.

The primary circuit is also used to remove the **decay heat** (see below) when the reactor is shut down. When the reactor is depressurised after shutdown, an installed alternative cooling route, the **low pressure decay heat removal system (LPDHR)**, can be connected up to the primary circuit.

3.2 The reactor core

During power operation the nuclear reaction occurs when neutrons collide with the uranium in the fuel to cause fission (i.e. splitting of the uranium atoms) which releases heat and further neutrons leading to a chain reaction. The chain reaction is reduced or stopped by the insertion into the reactor core of **control rods** made of neutron absorbing material. Should any of the reactor parameters exceed pre-defined limits, safety circuits automatically release the control rods to drop into the core, thus terminating the nuclear reaction. The chain reaction is started up again by the controlled withdrawal of these control rods.

The products of the nuclear fission **(fission products)** are themselves unstable and radioactive. The natural decay of this radioactivity produces heat in the fuel, even after the reactor has been shut down, although at very much lower levels than power operation and at ever decreasing rates. However, in order to protect the nuclear fuel from overheating, this decay heat has to be forcibly removed for some time (weeks) after the reactor has been shut down. The point at which the decay heat levels have fallen to a level where natural heat conduction through the submarine hull is sufficient to keep the fuel cool is called **'thermal rollover'**.

The radioactive fission products include gases and volatile material and it is the containment of these within the fuel matrix that is of major importance in protecting the public. The nuclear fuel is clad with a high integrity zirconium alloy sheath, which is impermeable to the fission products. The production process bonds these components strongly together, and this ensures that the radioactive fission products are normally retained within the fuel matrix.

An important consequence of the fuel construction is that, even after prolonged reactor operation, the primary circuit cooling water remains virtually free of fission products, although it is rendered moderately radioactive by the nuclear reaction. A further consequence is that it requires severe overheating to damage the fuel cladding before fission products can be released to the surrounding water. Mechanisms for overheating relevant to *HMS Tireless* are discussed in Section 5.2.

If, however, the fuel cladding becomes damaged, a second containment against the release of fission products to the external environment is usually provided by the primary circuit, with a third and final containment provided by the reactor compartment and submarine hull with hatches closed.

4 CURRENT CONDITION AND FUTURE PLANS FOR THE SUBMARINE

4.1 Current condition

HMS Tireless entered Gibraltar on the 19th May 2000 under diesel power, but otherwise operational in terms of crewing and weaponry, including the normal complement of torpedoes, although it should be noted that this class of submarine is not capable of carrying nuclear weapons. The submarine is berthed at 50 Berth at the mole, which is a berth normally used for routine 'recreational' visits of nuclear powered submarines, see Fig 2.

Prior to this, while the boat was on passage through the Mediterranean, a small leak, which could not be isolated, was discovered in the primary circuit. In accordance with standing MoD requirements the reactor was shut down and cooled to well below its normal operating temperature and pressure, using standard approved procedures. Shortly after arriving in Gibraltar the leak was temporarily sealed against this reduced primary circuit pressure.

The reactor is now at low temperature and pressure, and the MoD estimates that the reactor decay heat has reduced to below 10kW, and that thermal rollover was achieved at about the end of June. No forced cooling using the primary circuit is now needed, although the steam generators can be used to provide further cooling, if required. The Panel noted the MoD's intention to confirm this by a rollover trial prior to the commencement of the repairs.

The MoD and their civilian contractors (Rolls Royce Marine Power Ltd (RRMP) who designed the nuclear plant originally) have investigated the exact location and size of the leak. Their combined conclusion is that the leak is due to a small crack (2mm wide) in the weld where the relatively small pipe to the pressuriser is connected to the much larger primary circuit pipework.

At the berth the crew continues to carry out routine maintenance and testing activities, including those required for the weapon safety systems. However the hotel role of the submarine has been taken over by *RFA Fort Rosalie*, berthed further down the mole, so that non-technical activities on the submarine are minimised.

4.2 Future plans

The MoD proposes to effect a permanent repair at Gibraltar, following which the submarine will depart in the normal way. This strategy requires the total removal of the existing faulty welded connection, and then the remaking of the connection. Partial draining of the primary circuit is a necessary prerequisite.

The overall repair plan involves the following stages:

1. A test to confirm that thermal rollover has been achieved.

2. Partial draining of the primary circuit, requiring the transfer ashore and temporary storage of some $24m^3$ of contaminated water, but leaving the core fully immersed, with approximately 1m depth of water above the fuel.

3. Removal of the faulty welded connection and a short length of adjacent pressuriser pipework, remaking of the welded connection, insertion of a new pipework length, weld examination during and after the welding, and then the pressure testing of the primary circuit.

4. Start up of the reactor, routine tests of the power plant and the submarine's departure from Gibraltar.

5. The immediate transfer of all stored radioactive waste arising from these activities onto *RFA Fort Rosalie* and her departure from Gibraltar.

The overall repair programme from the thermal rollover test to the submarine's departure is programmed to occupy a period of 14 weeks with *RFA Fort Rosalie* departing 11 days later.

5 THE PANEL'S ASSESSMENT

5.1 Introduction

The Panel, having gained a detailed understanding of the MoD's plans for repairing *HMS Tireless*, formed a view of the nuclear safety issues to be investigated. These issues are summarised below. The assessment of them was complex and to reach its own findings on the issues, the Panel's background knowledge had to be supplemented by further information from the MoD.

The Panel noted the discrepancy in the Z berth definitions, identified in Section 2. The Panel took the view that it is for the MoD to resolve the discrepancy, and that the Panel's assessment would not place any weight on the exact definition of the berth.

Currently almost all the radioactive material on *HMS Tireless* is contained within the nuclear fuel. The Panel's primary concern was with the continued integrity of the containment provided by the fuel cladding. In particular, the Panel wished to investigate the possibility of fuel damage as a consequence of the original leak or as a result of an accident during the repair operations.

The Panel appreciated that the viability of the whole repair plan depends on the remade welds being of high quality. In addition to the possible nuclear safety implications, the Panel wanted to assess the possibility of the crack running into the wall of the primary circuit pipework. Since the MoD has no plans in place for dealing with this eventuality, it could cause a significant delay to the overall programme.

The transfer ashore and storage of a quantity of contaminated water, and of the solid waste arising from the repair operations, also represents a significant departure from the normal berth activities. The Panel recognised the importance of both the quality of the equipment for the transfer and storage and the management of the wastes.

Lastly, the Panel insisted on gaining assurance on the quality of the safety culture underlying the MoD's safety studies and management arrangements for all the repair activities.

These aspects formed a broad agenda for the Panel's deliberations, and are the basis of the following sections.

5.2 Fuel safety

(a) Current condition of the fuel

The Panel concluded that the original small leak could not have caused any depressurisation of the primary circuit, or any significant loss of primary circuit water. Therefore the reactor plant parameters would have remained at the normal operating levels. Accordingly, the Panel accepts the MoD's statement that the reactor shutdown was controlled, using standard approved procedures. The proper management of the decay heat removal thereafter is also accepted by the Panel. The Panel's conclusion that there was no fuel damage is supported by the MoD's assurance that the integrity of the fuel is demonstrated by the daily analysis of the primary circuit water.

Given the submarine's previous operating history and the time (over 16 weeks) since the reactor was shutdown, the Panel is independently satisfied that thermal rollover has been reached and that there is currently no risk of fuel damage provided the reactor remains shutdown, ie. provided the control rods remain inserted. This confirms the similar statement in the RRMP report, (Ref 38). Inadvertent control rod withdrawal is considered in sub-section (c) below.

(b) Effects of partial draining of the primary circuit

The location of the faulty weld cannot be isolated from the primary circuit. The weld is on the top of the primary circuit pipe and partial draining of the primary circuit, so that the top half of the pipe is empty, is therefore necessary before the weld repair can proceed.

Lowering the water level in the reactor pressure vessel will alter the rate of decay heat conduction to the submarine hull, and will render the steam generators unavailable as a back-up cooling route. The Panel reinforce the MoD's intention to connect up the LPDHR as the alternative back-up for fuel cooling, even though the Panel is persuaded by the MoD's established technique for extrapolating the rollover test results to the reduced water level in the reactor pressure vessel.

The Panel consider that the remaining 1m of water covering the fuel will be sufficient to keep the fuel immersed in all reasonably foreseeable circumstances, including boat roll due to swell or list due to a submarine ballast tank defect.

(c) Effects of opening of containment

During the repairs the faulty welded connection will be removed, leaving a hole in the primary circuit pipe. The MoD intends to plug this temporarily, but solely to prevent debris entering the primary circuit during the repair operation. The plug is not expected to withstand the pressure from within the primary circuit that would accompany fuel overheating. The Panel therefore discounted the plug as a form of containment following faults.

The MoD intend that hatches between the reactor compartment and the outside environment will usually be open to allow service cables and pipes to enter. The Panel noted the MoD's standard requirement that it must be possible to close these hatches within 10 minutes. Quick release couplings are always included, and practice drills are regularly carried out. However, the Panel recognised that having a direct path from the reactor to the outside environment places total reliance on the continued integrity of the fuel cladding to contain the fission products.

The Panel considered a number of events that could possibly overheat and damage the fuel. Overheating of the fuel can result from an inadvertent raising of the control rods or as a result of a major impact on the submarine. Additionally, a severe fire in the reactor compartment that could be initiated by the welding operations, might have the potential to result in fuel overheating.

The Panel was aware of the administrative and physical safeguards to prevent inadvertent raising of the control rods. The MoD confirmed the four independent and diverse means of preventing operation of the control rod raising mechanisms after the reactor has been shut down. The Panel scrutinised the details of these safeguards and is satisfied that they are sufficient.

On the topic of severe impact, the Panel examined the MoD's statement that analysis has shown that the submarine can be claimed to survive, without reactor or fuel damage, all except very large impacts. These very large impacts are anyway assumed to damage the back-up containments normally provided by the primary circuit and the submarine hull with closed hatches.

The Panel considered that, in practice, the very large impacts would be limited to those from a large aircraft crashing directly on the submarine or a ship moving at speed colliding with the submarine, although seismic and other potential external hazards were considered. The Panel judged an aircraft crash to be extremely improbable, and the use of tugs positioned between the submarine and other vessels moving in the harbour renders the ship collision similarly improbable. The Panel recognised that some hazards originating within the submarine could also cause a major shock but noted that all these very low risks are also applicable to a recreational visit. The Panel also noted that the MoD had identified these risks, but has not quantified them specifically for Gibraltar.

The Panel considered that some further safeguards for the more likely but lesser impacts should be sought, so that the risk is as low as practicable. The only identified such impact is toppling on to the submarine of the mobile crane that is to be deployed on the mole adjacent to the submarine. As a result of the Panel's opinions the MoD has undertaken to minimise the use of the crane in this way, so that it will normally be parked well away from the submarine, with each use being specifically sanctioned by a responsible authorisation group.

The Panel reviewed the amount of flammable substances within the reactor compartment and considered that it would not be sufficient to cause fuel damage, noting that the fuel remains surrounded by a considerable amount of coolant water within the pressure vessel, all of which would have to be boiled off before the fuel temperature could rise.

The Panel was also satisfied with the MoD's intention to station a dedicated fire sentry, with fire-fighting equipment, in the reactor compartment before welding commences and to remain there until each weld has cooled. This will be in addition to the normal fire detection and fire fighting arrangements provided on the submarine.

Overall the Panel consider that the risk of fuel damage during the repair period is remote enough to be acceptable.

5.3 Weld repair

The Panel scrutinised the MoD's detailed plans to re-establish the welded connection to its design strength by:

- removing a short section of pipe at the pressuriser branch.
- exposing and removing the existing cracked section for further study.
- removing the remainder of the existing faulty weld.
- inserting a new connection stub specially designed to facilitate welding.
- welding up the joint by adding layer upon layer of weld.
- applying appropriate examination techniques (ultrasound, radiography, and dye penetrant crack detection) at defined stages during the build up of the weld and on completion.
- creating a smooth internal surface inside the new connection.
- welding in a new short length of pipe to complete the route to the pressuriser.
- subjecting the whole primary circuit to cold and then hot pressure tests, in accordance with international pressure vessel standards.

In response to the Panel, the MoD confirmed that a quality assurance test for the repair had been set up whereby selected certificated welders were required to achieve two successful welds in an identical set of pipework in a mock-up of the relevant part of the reactor compartment. The MoD also stated that no heat treatment of the welded area (before or after welding) will be required.

The Panel is satisfied that the above arrangements represent good practice with sufficient levels of quality control of the welding and weld examination. It found nothing novel or particularly challenging in the welding process, apart from the slightly restricted access (~ 450mm) in one direction from the weld. The technique to be used for making the weld (Tungsten Inert Gas) is universally accepted as an improvement on the original technique. Working practices will not be hindered by radiation exposure considerations.

The Panel appreciated that total failure of the replacement weld when the reactor is started up at the end of the repairs could have a nuclear safety significance, even though the submarine systems are designed to deal with such an eventuality. The Panel consider that the three procedures involved - welding, weld examination and pressure testing - will provide sufficient defence in depth against a defective weld surviving undetected through to the reactor start-up, and conclude that no significant additional safety risks will arise during reactor start-up and operation prior to the departure from Gibraltar of *HMS Tireless*.

The MoD assumes that replacing the weld will be successful first time. The Panel considers that the regular inspection of the weld as it is being built up should give early detection of a faulty weld, but a delay for repairs of up to two weeks may ensue.

The MoD programme of activity also assumes that the crack travels through the body of the existing weld. Until the defective weld is cut out and examined, there remains a small, but finite, chance that the crack runs into the parent primary circuit pipe. The MoD has not fully prepared for this contingency, which would require a modified repair scheme and further training of the welders. The Panel is concerned that this would cause a delay of perhaps two months.

5.4 The transfer and storage of radioactive waste

The anticipated radioactive waste arisings include:

- about $24m^3$ of contaminated primary circuit water falling into the Low Level Waste category.

- less than $1m^3$ of low activity liquid waste from general flushing operations.

- about $12m^3$ of solid waste falling into the Low Level or Very Low Level Waste category.

The contaminated primary circuit water will be transferred from the submarine to two purpose built Portable Effluent Tanks (PET) located on the mole adjacent to the submarine. Each PET is capable of carrying $9m^3$. The water will then be decanted from the PETs into drums each capable of containing $0.18m^3$, but which will only be two thirds full. The MoD therefore expect to fill some 200 drums, which will be stored in an existing building nearby, designated as the Active Waste Management Facility (AWMF), or in an ISO container alongside that building.

The remaining liquid waste will be carried to the AWMF in carboys. The solid waste will be wrapped and carried ashore to be stored in drums in the AWMF, with about 150 drums being required.

The drums for both liquid and solid wastes conform to International Atomic Energy Agency Safety Series 6 Regulations, which are appropriate for the application.

All the drums and carboys, and therefore all the radioactive waste will be loaded on to *RFA Fort Rosalie* for transport to Devonport in the UK, where the waste will be disposed of within existing authorisations.

The Panel has reviewed the extensive documentation provided by the MoD to address the safety of the on-site transfer and storage of the contaminated water. The MoD documentation included:

- the management arrangements for all aspects of the transfer and storage, including individual and group responsibilities, and for monitoring and auditing throughout.
- the use of suitably qualified, experienced and competent personnel.
- the safety assessment of the transfer and storage arrangements, including the identification of all the potential challenges to safety and the necessary safeguards, in particular, to avoid spillages in the harbour and/or onto the mole.

The Panel considers that the MoD has set in place sufficient measures to minimise the possibility and quantity of spillages, and that the risks arising from handling and storing the radioactive wastes will be very low.

5.5 Safety management

In reviewing the safety documents provided by the MoD either initially or in response to the Panel's requests, the Panel was able to form a view on the underlying quality and scope of the documentation and of the site management arrangements to satisfy the MoD safety regime.

The Panel is able to confirm that the safety studies and safety management arrangements are comprehensive, consistent with good modern practice, and equivalent to those required by the NII for civil nuclear facilities in the United Kingdom. The Panel noted that the MoD risk assessments for *HMS Tireless* were based on studies originally prepared for the environment of the Naval Base at Devonport, but is satisfied that they can reasonably be applied to Gibraltar. The safety cases and management arrangements for the repair itself and for the radioactive waste are specific to Gibraltar.

The Panel recognised that the Gibraltar Public Safety Scheme (Ref 29) was drawn up for recreational submarine visits and considered whether it would be sufficient to cover the repair period. In relating the adequacy of the contingency planning in the Scheme to radiological incidents and releases that could possibly arise during the repairs, the Panel considered that:

- In the eventuality of damage occurring to the nuclear fuel cladding and in the absence of any high energy accompanying process (eg. explosion), the size of any radioactive release would be small and its dispersion very localised (most probably confined to the reactor compartment).

- In the event of an unplanned reactor start up (ie. control rod withdrawal) or inadvertent criticality of the fuel, the fission product release would differ from that of a recreational visit, in that the volatile radio-iodine would be largely absent, so immediate prophylactic measures (potassium iodate tablets) to the public at large would not be necessary.

- A reactor incident following completion of the repairs would present a similar hazard to that of a submarine on a recreational visit, for which the contingency plans cater.

- The transfer and temporary storage ashore of the radioactive wastes introduces risks that are considered by the Panel to be very low and within the capacity of the presently installed contingency plans.

The Panel therefore considers that the Gibraltar Public Safety Scheme provides sufficient contingency in terms of emergency planning arrangement for the period of the repairs. The Panel concludes that the proposed repairs do not require an alteration to the Scheme and reiterates its finding that it considers the risk of occurrence of any of the types of incidents listed above to be extremely small.

5.6 Other safety issues

(a) Weapons

The Panel noted that the torpedoes have limited shelf lives, and sought confirmation that the extended stay at Gibraltar will not cause these to be exceeded. The MoD's response that the current safety clearance of some of the torpedoes will expire at the end of this year was seen as uncomfortably close to the planned departure date of late December. However, the Panel was able to accept the MoD's assurance that the torpedo safety clearance can be extended by six months, and that the safety clearance review is currently under way.

(b) Radiography source

The source for the weld radiography will be Ytterbium-169, with a half-life of 30 days. It will be delivered by the RAF. The source is owned by RRMP and will be used under the control of their operators. During the time it is in Gibraltar it will be stored in the submarine reactor compartment. The transport, use and storage of the source will comply with the applicable Gibraltar and United Kingdom legislation. The Panel is satisfied with these plans.

5.7 Risk comparison

A normal recreational visit of a submarine to Gibraltar lasts 5 days, with risk accruing at a constant rate per day. The MoD currently limit such visits to a total of 55 days per year, and have assessed the corresponding risk to the closest member of the public to be well within the NNRP risk limits.

In comparing the MoD's proposals for *HMS Tireless* with a recreational visit, account must be taken of the following:

- Forced decay heat removal was only required for the first 40 days of the stay (ie. until heat could be removed naturally, as described in Section 3.2).

- For some 30 days during the repair there will be an open route from the nuclear fuel to the outside environment (closeable by the crew within 10 minutes).

- During the final 7 days the submarine will be in a normal recreational mode.

The MoD risk data shows that in the first 40 day period the risk rate will have been reducing from the normal recreational visit level.

The MoD has conservatively assessed the daily risk rate following thermal rollover to be some 15% of the recreational daily risk rate. The Panel from their own experience accept this as reasonable. Earlier sections of this report have concluded that there is no appreciable increase in risk during the repair operations, even while there is a normally open route from the reactor fuel to the outside environment.

The Panel is therefore able to accept the MoD's conclusion that the daily risk rate posed by *HMS Tireless* will not exceed, and will generally be significantly lower than, that from a normal recreational visit.

However, the Panel has adopted an alternative approach which takes account of the very much longer stay, expected to be around 200 days. Based on the above data, the Panel has concluded that, by the time *HMS Tireless* has departed, it will have presented an accumulated public risk that is about the same as the MoD's annual allowance for recreational visits.

6 MOVING THE SUBMARINE TO THE UK

The Panel does not have expertise on the towing or ferrying of submarines and so has used judgement. The Panel debated internally and with the MoD, the alternative of moving the submarine back to the UK under her own (diesel-powered) propulsion, under tow, or carried on board a towed barge or specialist self-propelled vessel

The salient points that emerged are that the submarine's diesel generators were not originally intended for such a passage and the speed would be low (less than 5 knots). The submarine's diesel fuel tank would require replenishment during the passage, which would be a difficult process because the submarine is not designed for this. The MoD do not wish to undergo the risks for a journey of more than 1,200 miles including crossing the Bay of Biscay.

Submarines are inherently unstable under tow in that there is a tendency for the submarine to yaw from side to side by increasing amounts. In addition, a submarine has very little freeboard and, in the MoD's view, it would be very hazardous to replace the tow if it should break in a storm. The Panel shared the MoD's concern that the submarine could become stranded on the European coast. The Panel agreed that a wrecked submarine would pose a significantly greater threat to the environment and local population than one berthed at Gibraltar.

Carrying the submarine on a cradle on a barge effectively out of the water was recognised by the Panel as presenting significant nuclear safety problems and risks. Approval for the operation would take some time (a number of months) during which *HMS Tireless* would have to remain at Gibraltar, accruing further risk. The Panel discounted this option.

The Panel concludes that moving the submarine back to the UK for repairs would introduce new and higher risks to the submarine and crew and possibly the European coastal communities, although the Panel notes that the MoD has not quantified these risks.

A final consideration is whether repairing the submarine in the UK would be significantly safer than at Gibraltar. The Panel takes the view that Devonport offers no particular advantage, since submarine docking (or defuelling) available there would not be helpful in controlling risks, and would not be used. The fact that new waste handling and storage arrangements will need to be set up at Gibraltar was not seen as a significant disadvantage in comparison with Devonport.

7 CONCLUSIONS

1. The Panel's dominant concern was with the continued safety of the fuel in the reactor pressure vessel. This can only be jeopardised by overheating of the fuel, as a result of a reactor plant fault or a major impact on the submarine, or other damaging external event (eg. earthquake).

2. Pertinent reactor plant faults comprise inadequate decay heat removal or inadvertent raising of the control rods. At the current very low level of decay heat, loss of forced cooling of the fuel is not of concern. The Panel

is satisfied that the depth of the defences to prevent inadvertent raising of the control rods is sufficient.

3. A major impact or other damaging external event is considered by the Panel to be very unlikely, and *HMS Tireless* is no more vulnerable on a daily basis to such an event than any nuclear powered submarine on a recreational visit. The Panel made a recommendation on limiting the use of the mobile crane near the submarine, which the MoD accepted. The Panel concludes that these events will not contribute a significant safety risk.

4. The Panel reviewed the weld repair and examination procedures and concluded that they are very likely to produce a high integrity weld. When the pressure tests are also taken into account, the risk of weld failure after reactor start up is considered to be acceptably low.

5. The Panel has identified a small possibility that the MoD has misdiagnosed the location of the crack to be repaired. This would only be apparent a few weeks into the repair, and could cause about two months delay. Alternatively, the production of a faulty weld repair could cause a delay of up to two weeks. In neither case would there be a significant safety risk.

6. The Panel also reviewed the MoD's engineered and administrative arrangements for dealing with the waste, including the mildly contaminated water that is to be removed from the submarine's primary circuit. These arrangements were considered to represent good safety practice and the Panel is satisfied that this activity represents a very low safety risk.

7. Before reaching these conclusions, the Panel obtained a significant amount of MoD information, including large elements of its safety case and safety assessment for the activities. The Panel is satisfied that a

sufficient amount of information has been made available to it. It is also satisfied with the quality of the MoD's work and the underlying safety culture.

8. Finally, the Panel reviewed the various options for taking *HMS Tireless* to the UK for repairs there and found no overall safety advantages.

9. The Panel noted a documentary inconsistency in the Gibraltar Public Safety Scheme regarding the definition of a Z berth at Gibraltar. This is for the MoD to resolve, but does not affect these conclusions.

10. Other parts of the Gibraltar Public Safety Scheme do not require amendment of contingency measures to allow for the proposed repair.

11. The Panel's considered assessment is that the MoD's planned repairs on *HMS Tireless* will be sufficiently safe, presenting a risk to the Gibraltar population broadly equivalent to that accrued over the annual allowance for recreational visits.

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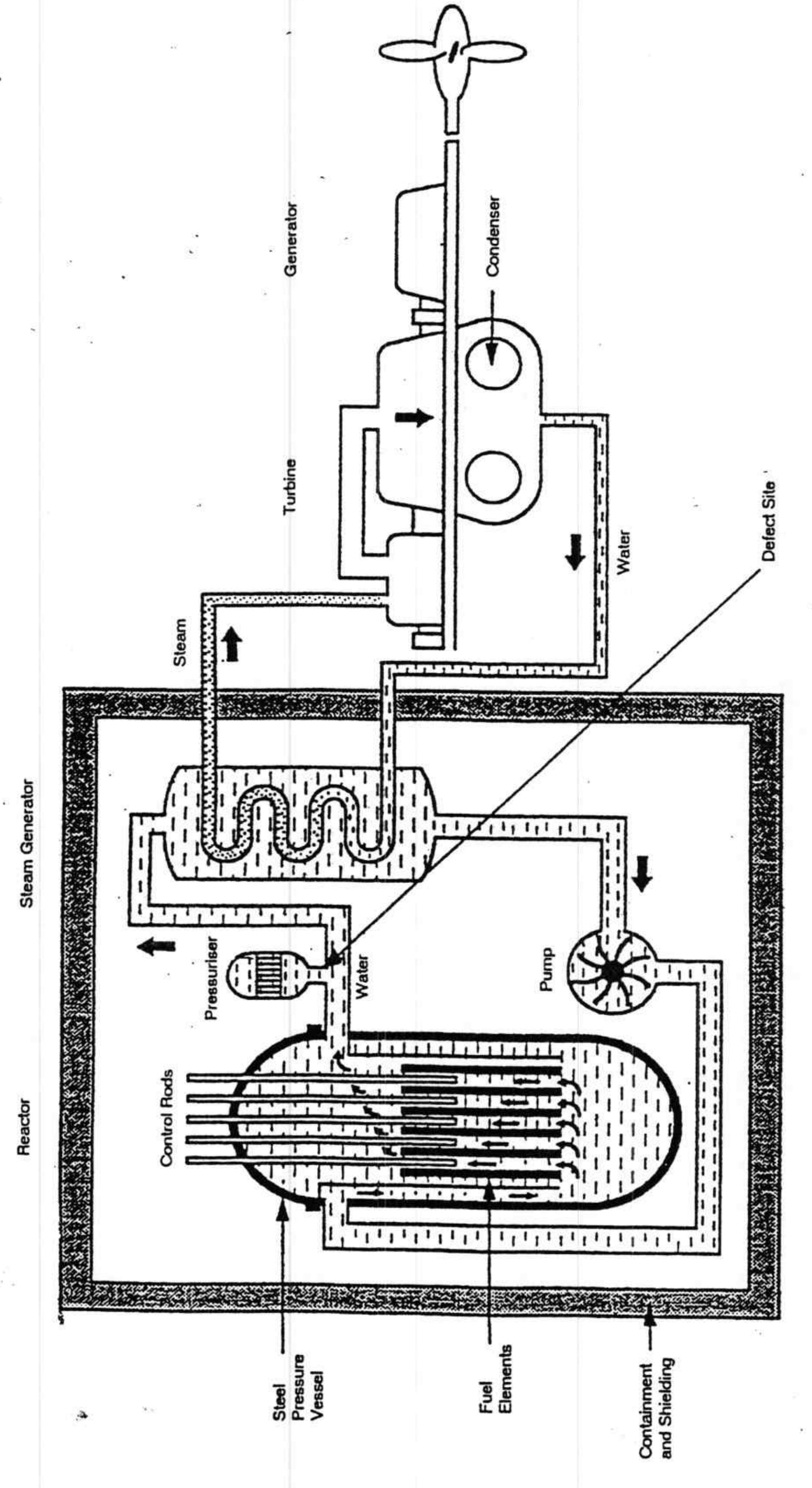

Figure 1: Schematic Illustration of a Pressurised Water Reactor

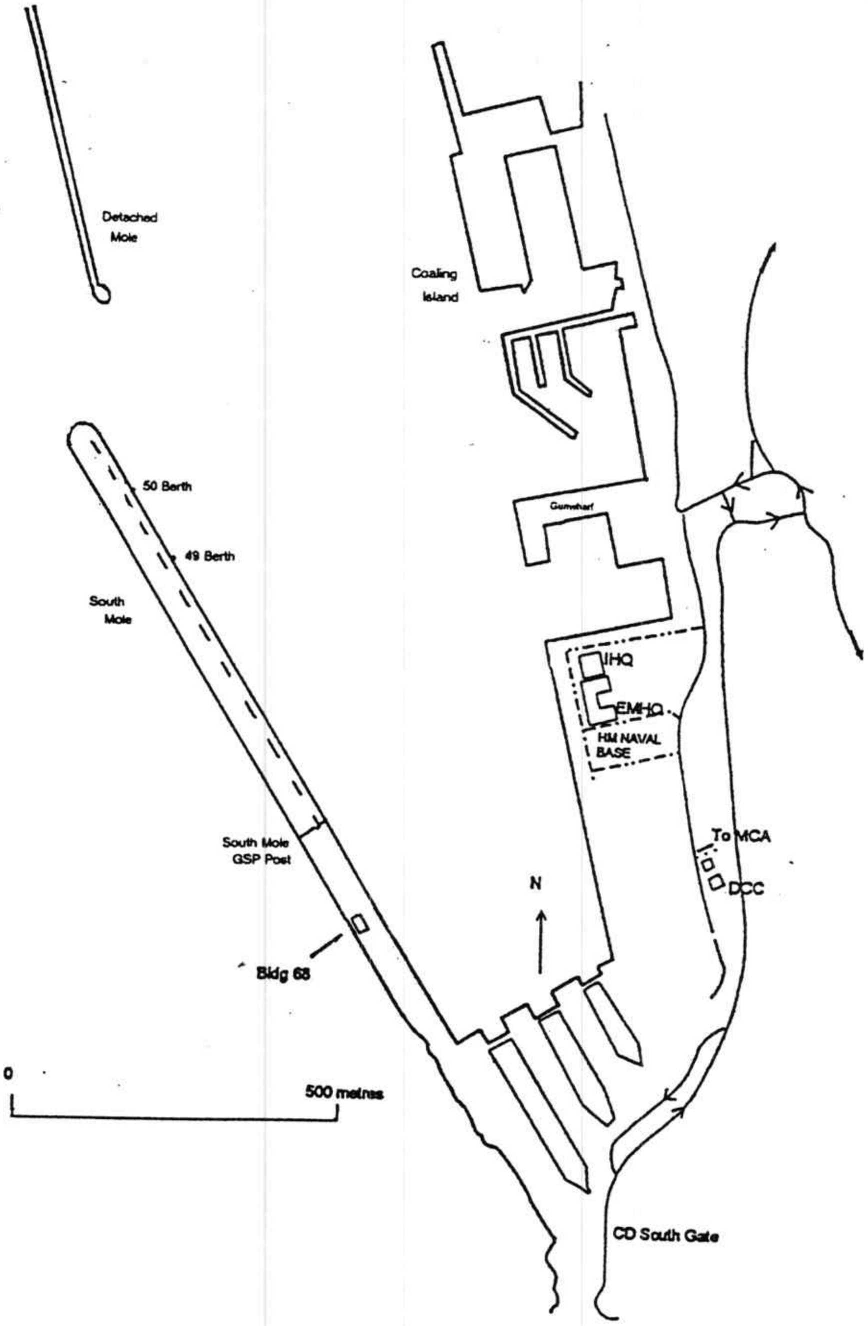

Figure 2: Location of 50 Berth

ANNEX 1

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Peter Davidson has a Master's Degree in Engineering. He has been with NNC Ltd for 31 years. From 1969 to 1985 he worked on the safety design and assessment of existing and new civil nuclear power stations, and the production or review of safety cases. From 1986 to the present he has carried out a similar role on shore-based facilities supporting nuclear-powered submarines, and on non-nuclear projects. For the past 5 years he has been an Independent Member of the Nuclear Safety Committee at Devonport Royal Dockyard Ltd, and an Independent Member of the Nuclear Site Safety Committee at Devonport.

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John Large is a Chartered Engineer, Fellow of the Institution of Mechanical Engineers, Affiliate Member of the Institution of Civil Engineers, Member of the British Nuclear Energy Society and Fellow of the Royal Society of Arts. From the 1960s through to the 1980s he undertook research on behalf of the United Kingdom Atomic Energy Authority on reactor fuelling and other nuclear systems at Brunel University, where he was a full-time member of the Academic Staff. Since the late 1980s he has headed the Consulting Engineers, Large & Associates which has been involved, amongst other things, with a number of nuclear propelled submarine projects in the United Kingdom, the United States and the Russian Federation.

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Charles Milloy is a Chartered Engineer, a Member of the Safety and Reliability Society and of the Institution of Structural Engineers. He is the leader of the Ove Arup Risk and Safety Group. He has been responsible for risk and safety assessments and the preparation of safety cases for a broad range of engineering projects for over 20 years. He has completed numerous qualitative and quantitative risk assessments in the nuclear, oil and gas, defense, chemical, construction and transportation industries. He is the author of numerous technical papers.

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Alan Martin holds a Master of Science Degree in Radiation Studies and is a Fellow of the Society for Radiation Protection. He has over 40 years experience in radiological protection. He has provided independent expert advice on the safety of nuclear discharges to the environment in several European countries. Within the United Kingdom, he has undertaken a wide range of radiological safety commissions for the nuclear industry, the regulatory authorities, consulting and contracting organisations. He is the author of textbooks on radiation protection.