until it returns for maintenance.[98]

4.73 A further factor is that naval reactor designers might be expected to have access to more sophisticated materials such as higher strength alloys. Cost might be expected to be less of a factor in the use of such materials than in commercial reactors.[99] The quantities required would be economically feasible, due to the much smaller volume required to be contained compared to a large commercial reactor.[100] The Committee has no way of verifying that more sophisticated materials have been used, but considers that it is not unreasonable to assume that they have.[101]

4.74 It was put to the Committee that naval reactors operated at higher temperatures and pressures than land-based ones.[102] If true, this would be relevant to the strength of containment, which has to resist this pressure in the event of a rupture in the pressurised elements inside the containment. However, other advice received by the Committee concluded that, on technical grounds, it was quite improbable that naval reactors would use

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98. Cdr M. K. Gahan, 'Nuclear Propulsion Systems - Technical Aspects', (Paper prepared for the Committee by the Department of Defence, February 1987), p. 8 (Evidence, p. 1300.39).

99. cf. US Congress, Joint Economic Committee, Economics of Defense Policy: Adm. H. G. Rickover - Hearing, 28 January 1982, p. 74 ('A Description of the Naval Nuclear Propulsion Program, January 31, 1982'): '... only premium products ... are used in the reactor ...'.

100. Letter from Dr J. L. Symonds, 12 February 1987, p. 4.

101. In view of the simplistic assumptions made in a few submissions about the absence of large concrete containments around warship reactors, it is worth noting that the use of concrete for containment is not without potential problems. For discussion of the way in which a molten reactor core may interact with concrete, and the uncertainties involved, see: APS Study Group, 'Report to the American Physical Society of the study group on radionuclide release from severe accidents at nuclear power plants', Reviews of Modern Physics, July 1985, vol. 57(3)(part II), pp. S59-S61.

102. Submission from Mr R. Addison, p. 4.

higher temperatures or pressures to any significant degree.[103] The Committee considered the latter advice to be far more soundly based.

4.75 The containment structure can only perform its function if it is unable to be by-passed. One possible by-pass mechanism arises where the primary circuit pressure relief valve vents direct to the atmosphere. If it vents within the containment, then any radioactivity released into the primary system is still contained from the environment. ANSTO told the Committee that for the purposes of establishing a reference accident, its

> model does assume that the primary circuit pressure relief system is within the containment, or that if the system does vent directly to the ocean, then it can be overridden in the event of a loss of coolant accident of the Three Mile Island kind.[104]

4.76 The Committee has no conclusive information on whether in United States Navy vessels the venting is within the containment or not.[105] Assuming venting is to the outside, two broad possibilities have to be considered. One involves coolant circuit overpressure in situations where there has been no accident involving fuel melt. In this situation, the potential amount of the radiation release would be small, as explained earlier in this chapter. Only in a second situation, where fuel melt has occurred accompanied by coolant circuit overpressure,

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[103] Letter from Dr J. L. Symonds, 12 February 1987, p. 4. See also for example N. Friedman, Submarine Design and Development, (Conway, London, 1984), p. 134; R. O'Rourke, 'The Nuclear-Powered Submarine', Naval Forces, 1986. vol. 7(1), p. 84; J. E . Moore and R. Compton-Hall, Submarine Warfare: Today and Tomorrow, (Michael Joseph, London, 1986), pp. 39-40. The Department of Defence in its submission, p. 12 (Evidence, p. 17) stated that naval reactors would be operating at lower temperatures and pressures in port than when at sea. The Committee preferred ANSTO's view that there would be no significant difference: (Evidence, pp. 397, 412-13).

[104] Evidence, pp. 438-39 (ANSTO).

[105] cf. Cdr M. K. Gahan, 'Nuclear Propulsion Systems - Technical Aspects', (Paper prepared for the Committee by the Department of Defence, February 1987), p. 5 (Evidence, p. 1300.36): with reference to naval reactors generally, venting is within the containment.

would the potential radiation release via this route be major. The Committee notes that even in this case, if venting is under water rather than to the atmosphere, radionuclides present in the release in aerosol form would be scrubbed by the water.[106]

4.77 A second means of by-passing the containment exists if it has been designed with a pressure relief valve.[107] The aim of such a design would be to allow a small release to the atmosphere in order to reduce pressure and thereby avert a catastrophic containment failure, which would lead to a much larger release. The Committee lacked information on whether the reactor containments on visiting warships were fitted with pressure relief valves. However, there would appear to be little need for such devices, given that the containment is designed to withstand

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106. APS Study Group, 'Report to the American Physical Society of the study group on radionuclide release from severe accidents at nuclear power plants', Reviews of Modern Physics, July 1985, vol. 57(3)(part II), p. S49. Some types of commercial reactors have suppression pools containing water as a safeguard against containment failure due to overpressurisation: ibid., pp. S82-S83, where the parameters of effective water scrubbing are considered in some detail. See also US, Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987), p. 9-8: ' ... a key determinant of whether a [containment] bypass sequence involves major or only minor offsite releases is whether the release of radioactive material occurs into a water pool or sump that can provide scrubbing of released radionuclides'.

107. See for example L. G. Danilov and others, 'Certain Results Concerning the Experience of Operation of the Nuclear Icebreaker "Lenin"' in Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Symposium on the Safety of Nuclear Ships: Proceedings, Hamburg, 5-9 December 1977, (OECD, Paris, 1978), p. 730: the nuclear powered icebreaker 'Arktika' has containment 'provided with a safety valve enabling the release into the atmosphere of the steam-air mixture which can appear inside the safety containment in the case of maximum credible accident - the tube rupture of the primary circuit'.

the full pressure following an accident.[108]

4.78 In the view of the Committee, based on the limited information available to it, there is no reason to suppose that naval reactor containment is any less effective in containing the consequences of accidents inside naval reactors than the types of reactor containment used for much larger land-based reactors is for those reactors.

Strength of the Reactor Pressure Vessel

4.79 The integrity of the reactor pressure vessel is of great importance because any leak would result in loss of coolant and the consequent risk of the fuel melting. Moreover a massive rupture of the vessel risks breaching the containment. For these reasons it has been said with respect to commercial reactors:

> Clearly, it is necessary to demonstrate conclusively that a disruptive failure of the reactor pressure vessel has a very low probability indeed.[109]

4.80 While the Committee is not in a position to have the

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[108] See para. 4.64. In 1984 AIRAC raised the possibility of venting from the containment to the atmosphere: AIRAC, 'Review of Safety and Monitoring Arrangements for Visits by Nuclear Powered Warships', p. 5 (Evidence, p. 755). The VSP(N) queried the logic behind the assumption, and at an AIRAC-VSP(N) meeting in May 1987 'AIRAC agreed that venting overpressure in the reactor compartment [ie. containment] was not a conceivable requirement' following an accident during a port visit to Australia: ANSTO, 'Visits by Nuclear Powered Warships: Radiological Consequences of Releases from Remote Anchorages', (August 1987), p. 1. It is important to distinguish this scenario from one involving venting to the atmosphere from the machinery compartments outside the (primary) containment. It was noted in para. 4.63 that these compartments, on some vessels at least, are designed to act as secondary containment. There could be a slow leakage from the primary containment to these compartments. AIRAC also raised the possibility that a warship commander might consider it necessary to vent these compartments in order to reduce the hazard to crew who might be required to enter them. This scenario is considered at para. 8.69 in the context of the adequacy of the criteria for remote anchorages.

[109] J. G. Collier, 'Light Water Reactors' in W. Marshall (ed.), Nuclear Power Technology, (Clarendon, Oxford, 1983), vol. 1, p. 269.

integrity of a naval reactor pressure vessel demonstrated to it in this way, all the available evidence indicates that reactor pressure vessels conform to very high safety standards.[110] There is no reason to assume that naval reactor pressure vessels are built to lower standards or are more prone to failure than those for land-based reactors. The point that the operating pressure is unlikely to be any greater in a naval than a land-based reactor has already been noted.

4.81 In addition there appears to no reason why the constraints imposed by having to place the pressure vessel in a ship should result in a pressure vessel of less integrity than in a land-based reactor. Conventionally powered steamships, including surface warships, have pressure vessels in the form of boilers. While the weight of the reactor pressure vessel has to be taken into account, the discussion or doubts on the effect of weight constraints on marine reactor safety have focused on the weight of shielding and containment. Compared to the potential weight of these items and the potential weight savings to be gained by skimping on safety with regard to them, the potential savings from skimping on pressure vessel safety would be small.

4.82 ANSTO told the Committee that it had confirmed with United States and United Kingdom authorities that quality assurance programs for naval reactor pressure vessels are of a higher standard than those for civil reactors.[111] ANSTO also stated that the 'design bases for the pressure vessels of the US nuclear warships reveal a design standard more rigorous' than the

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[110] Submission from ANSTO, Attachment 1, p. 6 (Evidence, p. 252); US, Nuclear Regulatory Commission, Reactor Safety Study: An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants, (WASH-1400, NRC, Washington, 1975), para. 5.3.4.2; UK, Department of Energy, Sizewell B Public Inquiry: Report by Sir Frank Layfield, (HMSO, London, 1987), para. 33.76.

[111] Submission from ANSTO, Attachment 1, p. 8 (Evidence, p. 254).

code for civil reactor pressure vessels.[112]

4.83 One way in which naval reactor pressure vessels may be less safe than their land-based counterparts relates to in-service inspection. The West German Reactor Safety Commission, for example, requires that there be sufficient space between the reactor pressure vessel and the radiation shielding to permit inspection of the vessel.[113] Naval reactors may not be designed to facilitate such inspection, partly due to space restricions,[114] and partly because requirements such as this did not exist when at least the earlier naval reactors were designed.[115]

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[112] ibid. See also D. Fishlock, 'Navy lifts veil on PWR research', Nature, 2 March 1978, vol. 272, p. 5. Referring to the non-destructive testing program for the type of reactor pressure vessel used in British submarines, the article states:

> This vessel has to be much closer to the dimensions of that of a large power-station PWR than its power output suggests to meet the Navy's specifications for military robustness. Thus it is about two-fifths of the height, one-eighth of the weight and half the thickness of the vessel specified for a 1,300 MWe PWR - for one-fortieth of the rating. Studies have included 100% ultrasonic inspection of critical parts of the pressure vessel of the longest serving Navy reactor ... .

In US, H of R, Committee on Merchant Marine and Fisheries, Disposal of Decommissioned Nuclear Submarines - Hearing, 19 October 1982, p. 17 (C. H. Schmitt, Naval Nuclear Propulsion Program) US submarine reactor pressure vessels are said to employ 'several inches' thickness of 'heavy steel'.

[113] J. Scharge and others, 'In-Service Inspection Program for the NCS-80 Reactor Pressure Vessel' in Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Symposium on the Safety of Nuclear Ships: Proceedings, Hamburg, 5-9 December 1977, (OECD, Paris, 1978), p. 286.

[114] For a journalist's description of the space constraints inside the reactor compartment of Los Angeles class submarines, see P. Tyler, Running Critical: The Silent War, Rickover, and General Dynamics, (Harper & Row, New York, 1986), pp. 137-38.

[115] cf. R. D. Klake and R. Worschech, 'NS Otto Hahn - Non-Destructive Retesting' in Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Symposium on the Safety of Nuclear Ships: Proceedings, Hamburg, 5-9 December 1977, (OECD, Paris, 1978), p. 247: the design of the NS Otto Hahn is such that , 'for structural reasons, inservice inspections of a standard comparable to that applied to present-day plants is possible only to a limited extent'.

4.84 The Committee has no information specifically on this point. More generally, the indications are that the early reactor and reactor compartment designs did make in-service inspection difficult in some respects.[116] But equally, the indications are that the penalty of longer out-of-service time was accepted, and safety not compromised.[117]

Emergency Core Cooling System

4.85 Different commercial nuclear power stations incorporate various engineered safety features such as sprays, coolers, water pools, and ice beds either singly or in various combinations to alleviate the build-up of pressure sufficient to destroy containment integrity following an accident.[118] It is difficult to generalise about the commercial use of many of these because they are features of specific designs, rather than in general use. For example, the latest West German pressurised water reactors have filtered vents from the containment which aim to filter out harmful radioactivity while allowing venting to relieve containment pressure.[119] The Committee has no information on the extent to which any of these features are relevant to, or incorporated in, the designs of naval reactors.

4.86 One safety system, however, the emergency core cooling system (ECCS) is now regarded as necessary in large land-based reactors.

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[116] e.g. see Vice Admiral Sir Ted Horlick RN, 'Submarine Propulsion in the Royal Navy', Proceedings of the Institution of Mechanical Engineers, 1982, vol. 196, pp. 70 and 76.

[117] ibid., p. 76; M. Smith, 'Turning up the power on nuclear subs', The Engineer, 1 October 1987, p. 23.

[118] APS Study Group, 'Report to the American Physical Society of the study group on radionuclide release from severe accidents at nuclear power plants', Reviews of Modern Physics, July 1985, vol. 57(3)(part II), p. S89. The various features are described ibid., pp. S81-S84.

[119] J. Varley, 'Germans take a new look at core melt consequences', Nuclear Enginering International, March 1987, p. 37. For a sugestion that US regulatory authorities do not regard containment venting as cost effective, see J. Varley, 'Putting the Finishing Touches to NUREG 1150', Nuclear Engineering International, March 1988, p. 38.

> The earliest light water reactors (as well as current ones) were necessarily equipped with systems to provide coolant makeup for normal operational losses of coolant (steam leaks, losses during refueling operations, etc.). Capability for long-term cooling of the fuel for removal of decay heat was also provided. Before 1966, however, high-pressure high-capacity systems to provide emergency coolant were not installed. Therefore, although the capability to cope with relatively small leaks or breaks existed, the unlikely break of a large primary-system component could have led to some fuel melting.[120]

4.87 It was the increasing size of reactors that was primarily responsible for raising official concern about the need to consider ECCS's, though no doubt a heightened concern about nuclear safety generally was also a factor.[121] Whether the concern would have arisen had land-based reactors remained closer in size to naval reactors is unclear. The Committee notes, however, that some form of ECCS was regarded by the 1980's as necessary for nuclear powered merchant ships.[122]

4.88 On a typical land-based reactor the ECCS includes a number of independent subsystems. These include both a high-pressure and a low-pressure water injection system.[123] According to one standard text, pumps for both would be activated about two seconds after a major loss of coolant (e.g. from a guillotine fracture of a primary coolant pipe) and water injection would commence after about 14 seconds from the high-pressure system and

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[120] W. B. Cottrell. 'The ECCS Rule-Making Hearing', Nuclear Safety, January 1974, vol. 15(1), p. 31. This article is based entirely on US experience.

[121] ibid.

[122] e.g. see International Maritime Organisation, Code of Safety for Nuclear Merchant Ships, (IMO, A XII/Res.491, 18 June 1982), para. 4.11.2. The Japanese nuclear powered merchant ship, NS Mutsu, has a type of ECCS: M. Kawasaki and S. Yaguchi, 'Safety Studies on LOCA for N. S. Mutsu' in OECD, Symposium on the Safety of Nuclear Ships: Proceedings, Hamburg, 5-9 December 1977, (OECD, Paris, 1978), p. 199.

[123] J. G. Collier, 'Light Water Reactors' in W. Marshall (ed.), Nuclear Power Technology, (Clarendon, Oxford, 1983), vol. 1, p. 266.

after about 30 seconds from the low-pressure system.[124] A further subsystem of a typical ECCS is an accumulator injection system. This consists of cooled water stored in tanks under pressure that will automatically (ie. without pumps, motor-driven valves, etc.) flow to the reactor vessel if a rapid depressurisation were to occur in the primary coolant circuit.[125]

4.89 It was put to the Committee that naval reactors lack ECCS's.[126] Of the schematic diagrams which the Committee has seen of naval submarine reactors, only one suggests the possible presence of an ECCS.[127] ANSTO informed the Committee:

> Naval reactors may or may not have emergency core cooling systems. These items are not necessarily bulky, for example the ECCS for HIFAR occupies very little space. Further, it does not follow that the lack of an ECCS for a shipboard reactor leads inevitably to a higher probability of fuel meltdown compared with a land-based system. For example, the initiating event, such as a primary coolant pipe failure, may be substantially less likely in a small, compact reactor designed to withstand battle damage.[128]

4.90 The United States Navy has pointed out that naval reactors sit 'in a source of unlimited seawater, which, if necessary, can be used to keep the reactor from overheating and

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[124] ibid., p. 276. cf. F. J. Rahn and others, A Guide to Nuclear Power Technology, (Wiley, New York, 1984), p. 505: the first sign of an accident that a plant operator receives is usually the emergency reactor shutdown or the start of the ECCS.

[125] J. G. Collier, 'Light Water Reactors' in W. Marshall (ed.), Nuclear Power Technology, (Clarendon, Oxford, 1983), vol. 1, p. 241.

[126] e.g see submissions from Mr R. Addison, p. 4; Friends of the Earth, p. 1; Cdr M. K. Gahan, 'Nuclear Propulsion Systems - Technical Aspects', (Paper prepared for the Committee by the Department of Defence, February 1987), p. 8 (Evidence, p. 1300.39).

[127] See N. Friedman, Submarine Design and Development, (Conway, London, 1984), p. 135.

[128] Evidence, p. 438 (ANSTO). HIFAR is the reactor at Lucas Heights, NSW operated by ANSTO. This reactor uses heavy water as both moderator and coolant. It differs in a number of ways from a naval pressurised water reactor.

being damaged'.[129] One inference which might be drawn from this is that naval reactors lack an ECCS of the type now used on land-based reactors. The fact that most United States Navy reactors were designed prior to the raising of the issue of ECCS's for land-based reactors adds weight to this inference,[130] although retrofitting of ECCS's is a possibility. The inference is further supported by advice from the Australian Department of Defence that the lack of any ECCS is compensated for by design features incorporating the heat sink of the sea.[131]

4.91 In the absence of definite information the Committee

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[129] 'U. S. Navy Statement on the Safety of Operations of U. S. Nuclear Powered Warships', January 1987 (Evidence, p. 238.243). A journalist's description of US submarine reactors based on interviews with shipyard workers and navy officials states: 'if anything ever happened inside the reactor that caused it to lose its coolant, automatic valves would open and the ocean flood in to stop the meltdown': P. Tyler, Running Critical: The Silent War, Rickover, and General Dynamics, (Harper & Row, New York, 1986), p. 137. See also ibid., p. 41: nuclear powered vessels were 'equipped with emergency core cooling systems whose sensors monitored the temperature of the reactor. At the first sign of trouble, the emergency system flooded the reactor with additional water'. It is said (ibid., p. 41) that the reactor pressure vessel on US submarines is sealed inside a tank of water to which boron (a neutron absorbing material) has been added. The tank is designed to act as a shield against radiation during normal reactor operation. The contents of this tank may be available for emergency core cooling purposes. Although the Committee lacks any evidence that this is the case, it is clear that the volume of water in the tank could not be sufficient to flood the reactor containment so as to immerse the core. It should be noted that in US, H of R, Committee on Armed Services, Subcommittee on Procurement and Military Nuclear Systems, Naval Nuclear Propulsion Program - 1988 - Hearing on H. R. 1748, 26 February 1987, p. 9, Admiral K. R. McKee said of Tyler's book: 'The author did a credible job of reporting on defense procurement, pretty accurate, but his understanding of submarines is abysmal. He doesn't know what he is talking about'.

[130] cf. the response of Z. Levine (US Maritime Administration) to criticism by D. Crancher (Australian Atomic Energy Commission) of the safety assessment of the nuclear powered merchant ship, NS Savannah: 'It must be remembered that Savannah was designed 20 years ago, before the advent of emergency core cooling systems (ECCS) which would reduce if not totally eliminate the probability of a core meltdown': Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Symposium on the Safety of Nuclear Ships: Proceedings, Hamburg, 5-9 December 1977, (OECD, Paris, 1978), p. 502.

[131] Cdr M. K. Gahan, 'Naval Nuclear Propulsion Systems - Technical Aspects', (Paper prepared for the Committee by the Department of Defence, February 1987), p. 8 (Evidence, p. 1300.39).

assumes that naval reactors lack the sophisticated ECCS's now used on land-based reactors. This leads to the question whether the lack of an ECCS might increase the risk of core radioactivity escaping to the environment should an emergency occur, or whether flooding is an acceptable (and existing) substitute.

4.92 The issues of most concern to the Committee were whether any naval substitute for an ECCS would operate quickly enough to be fully effective and whether it would function automatically. These points gain added significance because, as noted above in discussing the effect of the use of highly enriched fuel, fuel melting may well occur more rapidly in a naval reactor than in a commercial one.

4.93 The Committee sought further information on the use of sea water to provide emergency cooling. The Department of Defence told the Committee:

> We understand that seawater coolers utilising natural circulation are a part of the reserve cooling capacity of NPWs. However, we do not have enough detail concerning the design of such coolers to represent them accurately in diagrams of the kind shown ... [in para. 4.1].[132]

4.94 The Department did provide information which gave some indication that sea-water coolers may provide an acceptable

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[132] Evidence, p. 1300.54 (Department of Defence).

alternative to ECCS's in some circumstances.[133] However, the information was not sufficient to enable the Committee to come to any firm conclusion on whether naval reactors have effective equivalents to land-based reactor ECCS's.

Diversity and Redundancy

4.95 An important safety-related aspect of the design of land-based reactors is the provision of redundant features (e.g. a critical pump is duplicated) and diversity (e.g. not all pumps run off the same power source). It has been questioned whether the design of naval reactors is likely to be as sophisticated, due to limitations of space on vessels.[134]

4.96 In contrast the Department of Defence stated that 'there are high levels of redundancy in the systems, particularly with

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[133] See Evidence, p. 1300.54 (Department of Defence) for some detail on the physical principles on which natural coolers operate, their relationship to the primary coolant circuit, and the unlikelihood that the presence of a natural cooler creates a significant path for the escape of fission products to the environment. It should be noted that circulation of coolant in the primary circuit by means of natural convection, rather than pumps, was relied on for cooling during normal low-power reactor operations on the submarine, USS Narwhal: N. Friedman, Submarine Design and Development, (Conway, London, 1984), pp. 135 and 137. The heat generated at low power is broadly equivalent to the decay heat that would have to be removed following a reactor accident. Thus the USS Narwhal design suggests that heat removal by natural convection following an accident is technically possible. For a schematic diagram and description of the emergency sea water cooling system on the nuclear powered merchant ship, NS Savannah, see T. Matsuoka, 'Reliability Analysis of Emergency Decay Heat Removal System of Nuclear Ship under Various Accident Conditions', Journal of Nuclear Science and Technology, 1984, vol. 21(4), pp. 267-68.

[134] e.g. see submission from Mr R. Bolt, p. 7 (Evidence, 957).

the cooling, because of the battle damage aspects'.[135] Dr Symonds told the Committee:

> The compact nature of very sophisticated equipment used in the aerospace and aircraft industries demonstrates what can be done in limited space ... A personal inspection of the reactor control systems of the US submarine 'Halibut' back in the early 1960s indicated that the equipment was what would be expected in any land-based reactor of about 100 MWth. Furthermore, there was a high level of redundancy in the safety systems and in the instrumentation. Since that time, the advent of new solid-state technology would certainly allow improvement on that equipment ... and on its compactness.[136]

4.97 ANSTO, while admitting that a comparison of back-up and duplicate systems in naval and civilian reactors would require detailed design information which it did not have, suggested that 'surface ships have the room for these systems, submarines may not'.[137]

4.98 United States nuclear powered submarines are reported as having backup batteries, diesel generators and diesel-electric

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[135] Evidence, p. 194 (Department of Defence). See also US Congress, Joint Economic Committee, Economics of Defense Policy: Adm. H. G. Rickover - Hearing, 28 January 1982, p. 74 ('A Description of the Naval Nuclear Propulsion Program, January 31, 1982'): one of the key points in the program's philosophy is to 'ensure adequate redundancy in design so that the plant can accommodate, without damage to ship or crew, equipment or system failures that inevitably will occur'. See also the letter from Cdr T. Blades USN (Ret.) in US Naval Institute, Proceedings, December 1978, p. 97: each of the two reactors of the USS Long Beach has four pumps in its primary coolant circuit. This is the same number as is typically found in US commercial land-based PWRs: see the individual reactor statistics in Nuclear Engineering International, World Nuclear Industry Handbook 1988, pp. 72-107.

[136] Letter from Dr J. L. Symonds, 12 February 1987, p. 6. See also US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, p. 1058 (Admiral H. G. Rickover): 'we generally have duplicate gages on most things so if one goes wrong, we have another. We have a lot of duplication that way'.

[137] Evidence, p. 439 (ANSTO). See also Evidence, p. 1300.55 (Department of Defence).

propulsion systems.[138] The Trafalgar-class nuclear powered submarines of the Royal Navy are reported to have both primary and secondary electric emergency propulsion motors, which are supported by two diesel generators.[139]

4.99 The Committee cannot give any conclusive answer to the question of lack of sophistication and redundancy, because of the lack of technical information available to it on naval reactors.

Rapid and Frequent Changes in Power Requirements

4.100 Reactors used to power ships at sea are subject to a range of operational and performance requirements that do not apply to land-based reactors.[140] Land-based reactors are intended for full-time operation at full power. Many submissions received by the Committee pointed out that warship reactors have to support rapid manoeuvring and that the consequent changes in speed require rapid load changes to be produced by the reactor. All components of the reactor system therefore experience frequent power cycles. It is claimed that these produce a much larger number of stress cycles from temperature and pressure changes than would be experienced by land-based reactors.[141]

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138. N. Polmar and T. B. Allen, Rickover, (Simon and Schuster, New York, 1982), pp. 424, 425; US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1989 - Hearings, 23 March 1988, p. 1325 (Admiral K. R. McKee). In Australian ports, visiting nuclear powered submarines normally draw shore power, which provides a further level of redundancy.

139. R. Pengelley, 'Stealth in practice: the Royal Navy's Trafalgar-class submarines', International Defense Review, 1989, vol. 22(1), p. 30.

140. e.g. the N. S. Otto Hahn, on a typical entry up the Elbe river to her home port of Hamburg over 8 hours, experienced 60 power changes across a range between 15% to 80% of nominal power: D. Ulken and others, 'Further Development and Economic Aspects of the Integrated Pressurised Water Reactor in the Light of Experience Gained with the "Otto Hahn"' in Peaceful Uses of Atomic Energy: Proceedings of the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, 6-16 September 1971, (United Nations, New York, 1972), vol. 7, p. 293.

141. See for example submissions from Mr R. Addison, p. 4; Medical Association for Prevention of War Australia (Vic), p. 2; Australian Quaker Peace Committee, p. 2.

4.101 While there seems to be no doubt that ship reactors are subject to more frequent and perhaps more rapid changes in power demand than are land-based reactors, there does not appear to be any evidence that this increases the accident risk. Because the need to accommodate rapid power changes is known, it is taken into account at the design stage.[142] ANSTO, in discussing the reactivity changes necessary for rapid alteration of power level, argued:

> the associated changes in primary coolant circuit temperatures and pressures are quite small, and it is considered unlikely that they would substantially modify component reliability and integrity in comparison with similar land-based plant.[143]

4.102 In contrast, Britain's Chief Naval Engineer Officer in 1982 said that the comparison with land-based reactors was not valid, but that special measures were needed to ensure safety:

> Thermal cycling from frequent power changes is of course part and parcel of the day to day operation of a submarine reactor plant and poses problems of a different order from those in a land power reactor. The extension of core

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[142] e.g. see US, H of R, Committee on Armed Services, Subcommittee on Seapower and Strategic and Critical Materials, Defense Department Authorization and Oversight - Hearings on H. R. 1872, 6 March 1985, p. 184 (Admiral K. R. McKee); US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, p. 1044 (Admiral H. G. Rickover); Cdr M. K. Gahan, 'Naval Nuclear Propulsion Systems - Technical Aspects', (Paper prepared for the Committee by the Department of Defence, February 1987), p. 7 (design of attack submarines) (Evidence, p. 1300.38); N. Friedman, Submarine Design and Development, (Conway, London, 1984), p. 134 (effect of design provision is that 'large changes in power plant load correspond to relatively small changes in temperature, so rapid manoeuvring does not entail large thermal stresses'). The design of the nuclear powered merchant ship, NS Savannah, included a 'steam dump' system which was 'designed to permit rapid manoeuvring and changes in demand on the propulsion system without appreciable change in reactor power level': C. K. Beck and E. G. Case, 'Safety of Nuclear Ships' in International Atomic Energy Agency, Nuclear Ship Propulsion: Proceedings of a Seminar held at Taormina, 14-18 November 1960, (IAEA, Vienna, 1961), p. 130.

[143] Evidence, p. 443.449 (ANSTO).

> life brought to prominence consideration of thermal fatigue in certain pipework and fittings. Considerable programmes of work to identify the mechanism of the process in stainless steel resulted in a much improved appreciation of methods of detail design to avoid susceptibility to thermal fatigue. It is probably not generally realized that it is possible to suffer incipient cracking from thermal variations of as little as 10°C under certain loading conditions.[144]

4.103 The Committee notes that, apart from pipework problems, rapid power increases can also lead to cladding failure. For this reason one standard text on commercial reactors stated in 1983:

> Current operational practice is to limit the rate of any imposed power increases; for example, PWRs are limited to increases of 5 per cent per hour up to 93 per cent power, then progressively 3 percent per hour, and finally 1 percent per hour up to full power.[145]

4.104 Improved fuel-manufacturing techniques have done much to ameliorate this problem for commercial reactors,[146] but the Committee has no information on this point relevant to naval reactors.

4.105 A member of the United States Nuclear Regulatory Commission has suggested that in one respect the varying power drawn from naval reactors creates less problems:

> we ought to remember that the reactors we are working with are something like 30 to 50 times larger than the ones in the Navy. The Navy reactors tend to run most of the time at relatively low power, whereas with the commercial reactors you are trying to push everything you can out of them. So, in many

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[144] Vice Admiral Sir Ted Horlick RN, 'Submarine Propulsion in the Royal Navy', Proceedings of the Institution of Mechanical Engineers, 1982, vol. 196, p. 73.

[145] J. G. Collier, 'Light Water Reactors' in W. Marshall (ed.), Nuclear Power Technology, (Clarendon, Oxford, 1983), vol. 1, p. 279.

[146] ibid.

ways it is a more difficult problem.[147]

4.106 One aspect of this related to decay heat, which, as already explained, must be removed to avoid fuel melting even after a reactor is shut down. In a land-based reactor, the decay heat at the time of shutdown may be about 10% of total heat at full power, falling to about 6 or 7% after one second, and about 0.6% after a day.[148] One factor in determining the amount of decay heat present at shutdown is the reactor operating history in the period prior to shutdown.

4.107 Unlike commercial land-based reactor output, marine reactor output is typically varied due to changes in ship propulsion requirements. The reactor of a warship in port would normally have been run at fairly low power while entering the port, and even lower power once berthed or anchored. This will reduce the amount of decay heat present in the reactor, which in turn will reduce the scope of a loss of coolant accident and

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[147] US, H of R, Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment, Nuclear Regulatory Commission Budget Request for FY 1984 and 1985 - Oversight Hearings, 22 February 1983, p. 43 (V. Gilinsky). cf. US Congress, Joint Committee on Atomic Energy, Subcommittee on Legislation, Naval Nuclear Propulsion Program - 1976 - Hearing, 18 March 1976, p. 23 (Admiral H. G. Rickover): 'The average power level in port in a [Naval] nuclear propulsion plant is about 100 times less than that of a [land-based] commercial nuclear powerplant'.

[148] UK, Department of Energy, Sizewell B Public Inquiry: Report by Sir Frank Layfield, (HMSO, London, 1987), para. 5.34. One standard text states that for a reactor operating at 2800 Mw(t), the decay heat is 100 Mw(t) one minute after shutdown, 37 Mw(t) one hour after shutdown, 10 Mw(t) one day after shutdown, 7 Mw(t) one week after shutdown, and 3 Mw(t) one month after shutdown: J. G. Collier, 'Light Water Reactors' in W. Marshall (ed.), Nuclear Power Technology, (Clarendon, Oxford, 1983), vol. 1, p. 264.

allow increased time to respond before fuel melting occurs.[149]

Degree of Operator Control

4.108 There are two reasons why United States nuclear powered warships rely less on automated controls than land-based plants. The first derives from the need to balance reactor safety against vessel safety. The second results from a deliberate preference for less automation by the warships' designers.

4.109 If a vessel's reactor shuts down, the vessel may be left in a potentially hazardous navigational situation, particularly in heavy seas where any auxiliary power for the propulsion plant may be inadequate for the vessel's needs. The sudden unexpected loss of reactor power in a submerged submarine may have dangerous implications for the submarine's safety. This scenario provides the basis for one theory to account for the loss of the USS Thresher in 1963.[150] The balance between ship safety and reactor safety can be a matter requiring careful judgement and not readily susceptible to automatic control. It is said that, since the loss of the USS Thresher, a 'battle-short' mechanism has been provided in submarines to override the automatic reactor shutdown

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[149] e.g. see D. Okrent, Nuclear Reactor Safety: On the History of the Regulatory Process, (U. of Wisconsin, Madison, 1981), p. 84: if the nuclear powered merchant ship, NS Savannah, operated at limited power for 24 hours and then suffered a complete loss of coolant accident, a period of 2 hours would elapse before fuel melting would occur. In port entry conditions the ratio of power used to total power would be lower for a nuclear powered warship than for the NS Savannah. A typical port entry speed of, say, 10 knots represents about half of NS Savannah's speed at full power, but a third or less of a nuclear powered surface warship's speed at full power. As the power required for higher speeds rises much more quickly than the increase in speed, considerably less than one third of maximum power is needed to propel a ship at one third of its maximum speed. As indicated in footnote 142 above, however, alterations in reactor power level may not relate directly to alterations in vessel speed.

[150] J. E. Moore and R. Compton-Hall, Submarine Warfare: Today and Tomorrow, (Michael Joseph, London, 1986), pp. 38-39 (small loss of water-tight integrity of the hull combined with sudden loss of reactor power). See also N. Polmar and T. B. Allen, Rickover, (Simon and Schuster, New York, 1982), pp. 433-34 for this and other theories involving a loss of reactor power on the USS Thresher.

if an operational emergency demands that reactor power be maintained.[151]

4.110 The Committee has no information on whether nuclear powered surface warships are similarly equipped. But because they all have more than one reactor the need to override would be much reduced, and possibly entirely absent. Nor does the Committee have firm information on whether what is in effect the manual override of a reactor safety system is disabled as part of port entry procedures.[152]

4.111 The requirement to override would seem unnecessary for vessel safety in these circumstances:

> Following an automatic reactor shutdown, enough steam power would be available to allow the vessel to avoid hazards, come to a halt and, if necessary, to anchor. It should also be noted that NPW submarines run their diesel engines when navigating in confined spaces

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[151] ibid., p. 39. See also the Guardian (London), 3 March 1988, p. 1 'Catalogue of faults in UK nuclear subs'. The British navy's rationale for what it calls a 'Battle Short Switch' is described in some detail by Captain J. Jacobsen RN and others, 'The Safe Operation of Nuclear Submarines', Journal of Naval Science, 1979, vol. 5(2), p. 85.

[152] Information based on hearsay and passed to the Committee is that, on British submarines at least, the 'battle-short' mechanism is for use only when the submarine is submerged. Captain J. Jacobsen RN and others, 'The Safe Operation of Nuclear Submarines', Journal of Naval Science, 1979, vol. 5(2), p. 85 state that 'the use of the Battle Short Switch is inhibited in harbour'. This leaves unclear the question of its availability in port approaches. J. Edwards and Cdr K. F. Tucker RN, 'Royal Navy Requirements and Achievements in Nuclear Training', Journal of Naval Science, 1978, vol. 4(3), p. 168 in discussing the scram override state: 'Reactor safety must always be important, however, for the protection of the crew and the environment and, in harbour and close to land, environmental considerations and public safety must make such reactor safety paramount' (emphasis added). The Department of Defence was not able to provide the Committee with any more specific information on the point: Evidence, p. 1300.55 (Department of Defence).

such as a harbour.[153]

4.112 The significance of overriding an automatic shutdown will vary according to the reason for the shutdown. The Committee has no information on the frequency of, or reasons for, automatic shutdowns of United States Navy reactors.[154] For British submarines it was said in 1979:

> An operating submarine can expect (statistically) a scram every 22 weeks and the mean time to recovery of propulsion power is measured in minutes.[155]

4.113 Even where automatic shutdowns are not spurious, it does not follow that a safety hazard, as opposed to some other kind of

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[153] Evidence, p. 1300.56 (Department of Defence). cf. H. Fock and E. Schwieger, 'Experiences with Otto Hahn under Specific Operation Conditions' in Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Symposium on the Safety of Nuclear Ships: Proceedings, Hamburg, 5-9 December 1977, (OECD, Paris, 1978), p. 711:

> Tests made during the commissioning phase showed that the [nuclear powered merchant] ship [Otto Hahn] after a scram can operate with fully opened turbine throttle for about three minutes. As under manoeuvring conditions the maximum load is only 60% of full power, the steam capacity is adequate to bring the ship in [sic] a safe condition.

[154] cf. N. Polmar and T. B. Allen, Rickover, (Simon and Schuster, New York, 1982), p. 424: 'most submarines have experienced reactor scrams, some of which have put the submarines in precarious situations'. The statement refers to US submarines, but only one example is spelt out: the Polaris submarine, USS Von Steuben, experienced a scram while its diesel auxillary was out of service for maintenance, leaving the vessel on the surface without power.

[155] Captain J. Jacobsen RN and others, 'The Safe Operation of Nuclear Submarines', Journal of Naval Science, 1979, vol. 5(2), p. 84. Of the scrams experienced during a five-year period, 29 of 106 are ascribed to operator error, with a further 39 being 'operator induced scrams to meet Operating Procedural requirements'. Spurious scrams (ie. those due to malfunction of the reactor protection system) 'are rare and to date occur once every 3 and a half reactor-operating years': ibid. With respect to recovery time, see also H. P. Alesso, 'Some Aspects of Nuclear Physics and Safety Design for Operational Needs of Nuclear Powered Ships', Naval Engineers Journal, December 1987, vol. 89(6), p. 81: 'it takes less than one second for a reactor to "scram", but it requires greater than one-half hour to return to power'. Contrast N. Polmar and T. B. Allen, Rickover, (Simon and Schuster, New York, 1982), p. 434: for US submarines, the interval of time to allow restoration of power after a scram has been reduced to six seconds.

reactor damage, will occur if the shutdown is overridden. Nor does it follow that, assuming operator decision is required to override, that decision will be made in a way that prejudices reactor safety so as to put the public at risk.[156]

4.114 The Committee recognises that the ability to override an automatic reactor shutdown distinguishes naval from other reactors. From the limited information available to it, however, the Committee does not regard the difference as of major significance to the likelihood of an accident.

4.115 The United States Naval Nuclear Propulsion Program has adopted as one of its avowedly conservative design criteria:

> Simple system design, so that minimum reliance must be placed on automatic control. Reliance is primarily placed on direct operator control.[157]

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[156] e.g. for a vessel several kilometres off shore approaching a port it may decrease the hazard to the port population if the automatic shutdown is overridden and the vessel steered away from the coast, in the event of an incident that would normally trigger automatic reactor shutdown. cf. A. P. Honeywell and E. A. Saltarelli, 'Safety Audit of N. S. Savannah's Commercial Operations' in International Atomic Energy Agency and others, Proceedings of the Symposium on Nuclear Ships, Hamburg, 10-15 May 1971, (GKSS, Hamburg, 1971), p. 197: among the incidents reported was a

> departure from Technical Specifications by Captain's orders to provide for greater safety of ship operations when encountering rough weather following a reactor scram at sea less than 6 miles off shore. The departure from Specifications involved reducing the effectiveness of a power range channel scram until such time that the ship was in less dangerous waters.

[157] US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, p. 891 (Admiral H. G. Rickover). In US Congress, Joint Committee on Atomic Energy, Subcommittee on Legislation, Naval Nuclear Propulsion Program - 1976 - Hearing, 18 March 1976, p. 28, Admiral Rickover gave as an example:

> Suppose a young draftsman decides to require four valves in a safety system where two could do the job. His logic is that if two are good, then four are better. But as a result, the operator has trouble keeping track of what valve is in what position and this could lead to a mistake or incident by inadvertently opening the wrong valve.

The reason for this is the belief that 'undue reliance on automation and computers for control can impair safety'.[158] At the same time great effort is put into designing reactors and their operating procedures so that the plant can be safely operated.[159] Operator selection, training and inspection, and

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158. 'Comments by Admiral H. G. Rickover, USN, Director, Naval Nuclear Propulsion Program in Meeting with Members of the President's Commission Commission on the Accident at Three Mile Island', 23 July 1979, p. 30, incorporated in US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1981 - Hearings, 13 March 1980, p. 2108. Four reasons are given for this. First, for a computer to assist it must be programmed properly. This in turn requires that the accident sequence be foreseen, yet most major problems result from unexpected events. If the sequence can be foreseen, it is considered better to take steps at the plant design stage to obviate the particular risk. The program's emphasis has been not on more complicated or sophisticated control, but on designing and building a simple, stable plant that makes fewer demands on the control system and operators. Such a plant allows operators to develop a feel for plant performance and to recognise abnormal conditions in time to take corrective action. Second, in accidents the operator must have essential information in an understandable form: a computer can operate as an undesirable filter. Third, computers constitute an additional source of malfunctions which can mislead operators. Fourth, the use of automation and computers leads reactor operators to rely on the 'magic' they provide, and diverts attention from other areas.

159. See for example, ibid., p. 10 on the concept of 'sailor proofing' of Navy reactors, which means:

> the designer must assure that the plant, its equipment and its procedures are such that the sailors who will operate the plant can be expected, realistically, to understand, operate and maintain it properly. The concept also requires that the plant be designed to accommodate, insofar as practicable, operator errors that may occur - that it be 'forgiving' ... .

See also US, H of R, Committee on Armed Services, Subcommittee on Seapower and Strategic and Critical Materials, Hearings on National Defense Authorization Act for FY 1988/1989 - H. R. 1748, 10 March 1987, p. 321 (Admiral K. R. McKee): the design of Navy reactors so that they can be operated safely by a high school graduate.

operating instructions are also given close attention.[160] This contrasts with the situation that used to prevail with commercial reactors in the United States.[161]

4.116 On the other hand, greater reliance on operators can be seen as increasing the risk of operator error. It was claimed in many submissions that the possibility of human error was a major factor in increasing the likelihood of a reactor accident.[162] The Committee's attention was drawn to 1985 press reports stating that the crews of three United States vessels had failed their

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[160] See for example US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, pp. 892 ff. (Admiral H. G. Rickover); US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1984 - Hearings, 17 March 1983, pp. 919-21 (Nuclear Regulatory Commission): operator selection, training and discipline inferior for commercial reactors compared to naval reactors. In J. Bell, 'Nuclear safety need [sic] a rethink', New Scientist, 11 April 1985, p. 28 the views are reported of a researcher on classifying human errors with the aim of reducing them. Within this framework, the Three Mile Island accident is treated as involving knowledge-based error: the operators did not understand in time what was going on. The simpler, less automated design of naval reactors, coupled with the lengthy naval training on a prototype of the reactor actually to be operated suggest that naval reactor operators are less likely to make errors based on failure to understand what is happening that the operators described by this author.

[161] US, Report of the President's Commission on the Accident at Three Mile Island, The Need for Change: The Legacy of TMI, (Washington, 1979), p. 49: TMI operators trained to required standards but these 'standards allowed a shallow level of operator training'. See ibid., pp. 70-71 for the report's recommendations for improvement.

[162] e.g. see submissions from Assoc Prof P. Jennings, p. 1; Scientists Against Nuclear Arms (ACT), p. 1 (Evidence, p. 779); Scientists Against Nuclear Arms (WA) and Medical Association for the Prevention of War (WA), p. 8 (Evidence, p. 794); Nurses Against Nuclear War, p. 1; Coalition Against Nuclear Armed & Powered Ships, pp. 4-5 (Evidence, pp. 1376-77); Mr J. Ingersoll, p. 2. See also Evidence, p. 443.449 (ANSTO):

> We are not aware of evidence to support the suggestion that naval reactors place greater reliance on manual systems than do civilian reactors. If they do, then increased oportunities for operator errors to occur would certainly be a likely consequence.

reactor safety tests.[163]

4.117 What was not drawn to the Committee's attention was that the failures were believed to be the first since the United States Navy began to use nuclear powered ships; that a second try is permitted before drastic action is taken and the crews all passed on their second try; and that the tests are said to be amongst the most stringent in the Navy, with even a minor mistake leading to failure.[164] Viewed in the light of this additional information, the tests appeared to the Committee as further evidence of the degree to which safety is a major priority in United States nuclear powered ships.[165]

4.118 The Committee was also referred to a 1979 press report containing allegations that the United States Navy's training program for reactor operators is deficient in a number of respects.[166] A separate set of allegations relating to health and safety violations in a Navy reactor training unit was investigated in 1980 and found not to show any basic weaknesses in the

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[163] Submissions from Assoc Prof P. Jennings, p. 1, citing West Australian, 30 April 1985, p. 31, 'US Navy Ships Fail the N-Test'; Coalition Against Nuclear Armed & Powered Ships, p. 4 (Evidence, p. 1376), citing New York Times, 28 April 1985, p. 26, 'Crews of 3 Navy Ships Fail in Nuclear Safety Tests'. See also Evidence, p. 847 (Scientists Against Nuclear Arms); submission from Mr R. Addison, p. 7.

[164] New York Times, 28 April 1985, p. 26, 'Crews of 3 Navy Ships Fail in Nuclear Safety Tests'.

[165] Contrast US, Report of the President's Commission on the Accident at Three Mile Island, The Need for Change: The Legacy of TMI, (Washington, 1979), p. 49: civilian reactor operators could be licensed even though they had failed those parts of their examinations that dealt with emergency procedures and equipment.

[166] Submission from Prof W. J. Davis, p. 14 (Evidence, p. 461), citing Enlisted Times, December 1979: 'Instructor quits, says teachers don't know their stuff'. See also Evidence, p. 611 (Prof W. J. Davis).

unit's operations.[167] Given this, and the general high regard in which the United States Navy's training program is held in comparison to the training of civilian reactor operators,[168] the Committee does not attach significance to an isolated press item reporting criticism of naval nuclear training.

4.119 It was also pointed out to the Committee that more than one of the operators on duty at the time of the 1979 accident at the Three Mile Island reactor were former United States Navy reactor operators.[169] This point has been addressed by the director of the United States Naval Nuclear Propulsion Program. While rebutting the criticism of the training provided, he also argued that operator training was only one element of the program and that other essential elements were staffing levels, supervision, auditing and qualification, and re-qualification for the

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167. US, Senate, Committee on Armed Services, Subcommittee on Strategic Forces and Nuclear Deterrence, Safety Oversight for Department of Energy Nuclear Facilities - Hearings, 27 October 1987, pp. 209-10, summarising US, General Accounting Office, GAO's Analysis of Alleged Health and Safety Violations at the Navy's Power Training Unit at Windsor, Connecticut, (EMD 81-19, November 1980):

> In 5 of the 17 allegations, procedures or safety standards were violated, including one case with the potential for a serious personnel injury. None of the five violations involved radiation exposure to personnel, and all were investigated by Windsor facility officials at the time they occurred. In GAO's opinion, none of the events forming the bases for the 17 allegations, including the 5 cases in which violations occurred, were indicative of basic health- and safety-related weaknesses in the facility's operations.

The GAO made no recommendations to the Department of Energy relating to the facility arising from its analysis.

168. See for example P. Bayne, 'Nuclear Navy a Factor in Shaping U. S. Facilities', New York Times, 25 May 1986, sec. 22, p. 26; US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Plans for Improved Safety of Nuclear Power Plants Following the Three Mile Island Accident - Hearing, 19 September 1979, pp. 46-47, and 53 (Dr C. Starr, Electric Power Research Institute); US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1984 - Hearings, 17 March 1983, pp. 919-21 (Nuclear Regulatory Commission). For a detailed description of the US Navy's nuclear training program, testing and inspection of its reactor operators and auditing of the program, see US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, pp. 892-917.

169. Evidence, p. 611 (Prof W. J. Davis).

specific plant to be operated.[170] Particular stress has been placed on the much higher level of supervision and the ability to impose naval discipline.[171]

4.120 It seems clear that the United States Navy's operators are required to operate less automated equipment than their civilian counterparts. But it seems equally clear that the former are far better trained and supervised than the latter. As a result the Committee does not consider that naval reactors should be any less safe than land-based reactors due to their being less automated.

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[170] 'Comments by Admiral H. G. Rickover, USN, Director, Naval Nuclear Propulsion Program in Meeting with Members of the President's Commission Commission on the Accident at Three Mile Island', 23 July 1979, p. 18, incorporated in US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1981 - Hearings, 13 March 1980, p. 2096. See also US, H of R, Committee on Government Operations, Nuclear Regulatory Commission - The Rogovin Report - Hearing, 13 February 1980, p. 17 (M. Rogovin):

> In the nuclear Navy reactor program, enlisted men serve as reactor operators but they are supervised on the spot by engineer-officers 24 hours a day. Operators of the larger and vastly more complicated commercial plants and their supervisors are the equivalent of these enlisted men. The extra training and experience they have acquired in the commercial program often cannot suibstitute for an engineering background. Training alone cannot make control room operators into the equivalent of the Navy's 'engineer officers of the watch'.

[171] US Congress, Joint Economic Committee, Economics of Defense Policy: Adm. H. G. Rickover - Hearing, 28 January 1982, p. 59 (Admiral H. G. Rickover):

> The senior watchstander at Three Mile Island had been in a nuclear ship. But the difference is that in the Navy we truly supervise. We require proper watchstanding. We check on everything. I get reports all the time, every week, from every one of our ships. In the civilian nuclear industry, there are no similar reports to one central authority. There is no equivalent supervision. One of the serious things wrong at Three Mile Island was the lack of supervision and carelessness in operation.

See also US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1982 - Hearings, 4 March 1981, pp. 537-38 (Admiral H. G. Rickover).

Age of Vessels and Design

4.121 The increasing average age of the United States nuclear powered fleet raises the question whether its past safety can be expected to continue.[172] In 1986 the director of the Naval Nuclear Propulsion Program told a Congressional Committee;

> the nuclear fleet has grown from 90 ships in 1970 up to 149 ships today. In that period, the average age of the ships has gone from 5 to 15 years. To put that in perspective, these ships were originally designed for a 20-year lifetime. Now I am asked to make them go for 30 years, but they were designed for 20 years. We have a large fleet approaching its original design limit.[173]

4.122 In 1980 the then director said 'thus far we have not seen anything which would cause the nuclear plant to limit the

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[172] Submission from Mr R. Addison, p. 7. See also Tasmania, Assembly, Debates, 9 December 1987, p. 5580 where Dr R. Brown said that as the USS Long Beach is the oldest nuclear powered surface warship, one can assume its reactors are the least safe of those in current use. cf. S. Novak and M. Podest, 'Nuclear Power Plant Ageing and Life Extension: Safety Aspects', International Atomic Energy Agency, Bulletin, 1987, vol. 29(4), pp. 31-33. This article deals only with commercial reactors, with respect to which it notes: 'Current methods of testing, monitoring, and maintenance are not adequate for coping with the ageing issue' (p. 33). It also notes that over long periods of time there occurs a gradual change in the properties of materials which:

> can affect the capability of engineered components, systems, or structures to perform their required function. ... All materials in a nuclear power plant can suffer from ageing and can partially or totally lose their designed function. Ageing is not only of concern for active components (for which the probability of malfunction increases with time) but also for passive ones, since the safety margin is being reduced towards the lowest allowable level (p. 31).

[173] US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1987 - Hearings, 18 March 1986, p. 1072 (Admiral K. R. McKee). See also ibid., p. 1073, where it is said that the surface ships in the program are now required to remain in service for up to 45 years.

lifetime of a ship'.[174] The USS Nautilus was decommissioned after 25 years service, but the decision to do so was not based on anything to do with the reactor.[175]

4.123 The Committee has no information on whether or how the latest ideas on reactor safety developed by civil regulatory authorities and the civil reactor industry have been incorporated in naval designs. The fundamental design of United States Navy reactors currently operating is over 20 years old.[176] Not all the changes which have occurred during that time relating to commercial reactors would necessarily be applicable to small naval reactors. In the absence of evidence, a conservative assumption should be made and a 20 year old reactor design regarded as less safe than the latest design. Of course, less safe is not the same as unsafe, as shown by the fact that regulatory authorities permit the continued operation of ageing civil reactors.

Collision Risks

4.124 The risk that a nuclear powered ship could be involved in a collision, grounding or similar maritime accident is an obvious and major difference between naval and land-based reactors.[177] These risks do not have to be taken into account for land-based reactors. The magnitude of these risks is considered in the next chapter in discussing the naval reactor accident

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[174] US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1981 - Hearings, 13 March 1980, p. 2239 (Admiral H. G. Rickover). See also Vice Admiral Sir Ted Horlick RN, 'Submarine Propulsion in the Royal Navy', Proceedings of the Institution of Mechanical Engineers, 1982, vol. 196, p. 76: due to increased understanding of the mechanism of crack initiation and growth, increased experience of naval reactor operation, and improvements in non-destructive testing techniques enabling in-service inspection 'the steadily increasing demands of the nuclear safety authorities for demonstrable validation of safety have been met'.

[175] ibid., p. 2239.

[176] US, H of R, Committee on Appropriations, Subcommittee on the Department of Defense, Department of Defense Appropriations for 1988 - Hearings, 30 April 1987, p. 960 (Admiral K. R. McKee).

[177] e.g. see Evidence, pp. 980-81 and 999-1001 (Mr R. Bolt).

record, and in chapter 7 in discussing the appropriateness of the current reference accident.

4.125 While mobility adds to risk in this way, it operates to decrease risks in other ways. Unlike a land-based reactor, a damaged naval reactor can be moved. The ability to move the reactor following an accident affects only the consequences of an accident, not the likelihood that it will occur. But mobility also reduces accident likelihood in some respects.

4.126 Accident likelihood is typically measured in reactor years. Unlike a land-based reactor, a naval reactor is not present in port every day of the year. Were a lot of visits to occur, Australian ports could experience several reactor years during a single calendar year. In practice this has not happened. In the nine years 1980-1988 inclusive, Australian ports had a total of less than two reactor years of exposure to the risk of a reactor accident.[178]

4.127 The mobility of naval reactors further reduces the likelihood of an accident in an Australian port in that reactor fuel handling,[179] repairs, servicing, testing and so forth occur elsewhere. No equivalent to the risk at land-based reactors arising from on-site storage of spent fuel arises as part of port

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[178] Calculation based on visit dates as set out in Appendix 3, counting the day of arrival as a full day, but not counting the day of departure. Allowance has been made for the fact that all surface vessels have multiple reactors, and it is conservatively assumed that all reactors would be operating at all times during port visits. The year with the most reactor visiting days was 1983 (175 reactor port days); those with the least were 1987 (28 reactor port days) and 1988 (nil); the average for the 9 year period was 73 reactor port days per year (ie. 20% of a year).

[179] On the risks in refuelling see generally H. G. Schafstall and others, 'Safety Aspects for Fuel Element Handling on Board of Nuclear Ships' in Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Symposium on the Safety of Ships: Proceedings, Hamburg, 5-9 December 1977, (OECD, Paris, 1978), pp. 317-29.

visits to Australia.[180]

Effects of Capsizing

4.128 There is no doubt that naval reactor safety systems would need to be capable of operating in difficult circumstances, even with the ship in a capsized or partially capsized condition. The Committee lacks direct information on this aspect of naval reactors.[181] However, the international safety code for nuclear powered merchant ships requires that the reactor fast shutdown (scram) system has to be capable of shutting down the reactor at angles of up to 90 degrees and has to be capable of maintaining shutdown at all angles.[182] It is not unreasonable to suppose that naval nuclear vessels meet the minimum standards set out in the code for nuclear merchant ships, particularly as both the United States and the United Kingdom were involved in the development of this code.

Storage of Hazardous Substances Near the Reactor

4.129 A land-based reactor is unlikely to be located in proximity to a store of conventional explosives, nuclear weapons,

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[180] See US, Nuclear Regulatory Commission, Reactor Safety Study: An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants, (WASH-1400, NRC, Washington, 1975), pp. 23 and 29 on the magnitude of the total accident risk that is attributable to spent fuel. See also UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987), para. 27.25: one of the five 'most radiologically damaging design base accidents' is attributable to spent fuel storage.

[181] cf. Evidence, p. 375 (ANSTO not aware that safety systems would not work, nor that they would work).

[182] International Maritime Organization, Code of Safety for Nuclear Merchant Ships, (IMO, A XII/Res.491, 18 June 1982), para. 4.3.1.4.

or inflammables such as aviation or missile fuel.[183] A naval reactor is in a warship which may hold some or all of these items, thereby increasing the risk in comparison to a land-based reactor.[184] The increase may be due to one of these items starting an accident sequence that eventually affects the reactor. Or it may be due to the presence of these items increasing the consequences should a reactor accident occur.

4.130 The safety of warship magazines and nuclear weapons are considered in chapter 11. The conclusion reached there is that degree of safety is very high. From this it follows that the Committee does not consider that the risk of an accident to a naval reactor is increased to a significant degree by the presence in the same ship of conventional or nuclear weapons.

4.131 The possibility of a fire hazard due to the presence of inflammables is presumably highest on an aircraft carrier, due to the possible presence of large quantities of aviation fuel. At the same time the size of aircraft carriers permits inflammables to be stored well away from the reactors. While the Committee has not investigated the point, it considers that the location of, and safety precautions taken with respect to, inflammables are likely to be such as would not lead to a major additional hazard to reactor safety.

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[183] But see International Atomic Energy Agency, Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident: Report by the International Nuclear Safety Advisory Group, (IAEA, Vienna, 1986), p. 44: one of the main challenges for firefighters at the 1986 Chernobyl reactor accident was to prevent the spread of the subsequent fire to the flammable materials stored on-site, such as diesel oil, stored gas and chemicals.

[184] e.g. see submissions from Mr R. Addison, p. 4; Scientists Against Nuclear Arms (ACT), pp. 3-4 (Evidence, p. 781-82).

FACTORS TENDING TO MAKE NAVAL REACTORS SAFER

4.132 By way of introduction, the Committee notes that submissions critical of the present position made no acknowledgement of the engineering conservatism and concern for safety that are generally recognised to have been a feature of the United States Naval Nuclear Propulsion Program.[185] The Program has been criticised on military grounds for adhering to tried and proven reactor technology, rather than adopting novel or cheaper technical solutions in order to obtain maximum advantage over potential enemy units.[186]

4.133 The United States Navy has every reason to place a very high priority on reactor safety. The effect of a single reactor accident in 1979 at Three Mile Island was to jeopardise the future of civil nuclear power in the United States. The United States Navy could not afford a similar effect following a naval reactor accident, because such a high proportion of its major

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[185] e.g. see R. G. Hewlett and F. Duncan, Nuclear Navy 1946-1962, (U. of Chicago, Chicago, 1974), pp. 334-39. See also US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, pp. 1044-45 (Admiral H. G. Rickover), where eight different examples of conservatism in design are given. See also p. 1072 for an illustration of conservatism in the comparatively long time allowed for response to an accidental loss of feedwater to the steam generators on Navy reactors. The design used for reactors of the Three Mile Island type was such that the reaction time was very short - well under 2 minutes. This was considered an important factor in the TMI accident, and the design has since been altered to allow a longer reaction time: see D. W. Crancher and R. H. Nelmes, 'Accident at the Three Mile Island Power Station', Atomic Energy, July 1980, pp. 3-4. The design of Navy reactors has always provided for the longer reaction time.

[186] e.g. see US, H of R, Committee on Science and Techonlogy, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, pp. 1047-48 (Admiral H. G. Rickover): P. Tyler, Running Critical: The Silent War, Rickover, and General Dynamics, (Harper & Row, New York, 1986), pp. 55 and 97.

fleet units are nuclear powered.[187] The entire submarine-based nuclear deterrent, for example, depends on nuclear propulsion.

4.134 In the aftermath of the reactor accident at the Three Mile Island nuclear power station, the widespread response of Congressional and other inquiries was to ask why the United States Navy could operate reactors safely when the nuclear power industry could not.[188] It is said, as evidence of the general regard in which United States naval nuclear safety is held, that no country responded to the Three Mile Island accident by cancelling or postponing visits by United States nuclear powered

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[187] e.g. US, H of R, Committee on Armed Services, Subcommittee on Procurement and Military Nuclear Systems, Naval Nuclear Propulsion Program - 1988 - Hearing on H. R. 1748, 26 February 1987, p. 2 (Admiral K. R. McKee):

> Reactor safety is a big deal, and is particularly important to us, because when you put all the rhetoric aside, we operate on the basis of public confidence. We are allowed to do the things we do simply because of the public's confidence. That confidence is a function of our safety record.

[188] e.g. US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, p. 887 ff (Admiral H. G. Rickover); US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1981 - Hearings, 26 February 1980, pp. 194-96 (Nuclear Regulatory Commission); US Congress, Joint Economic Committee, Economics of Defense Policy: Adm. H. G. Rickover, 28 January 1982, pp. 1 and 59 (Senator W. Proxmire), p. 3 (Senator H. Jackson); US, H of R, Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment, Nuclear Regulatory Commission Budget Request for FY 1984/1985 - Oversight Hearings, 22 February 1983, pp. 42-43 (Nuclear Regulatory Commission); P. Bayne, 'Nuclear Navy a Factor in Shaping U. S. Facilities', New York Times, 25 May 1986, sec. 22, p. 26; T. C. Joerg, 'Chernobyl at Sea?', US Naval Institute, Proceedings, December 1986, p. 86. Note also how one trenchant critic of US commercial nuclear power development, operation and regulation uses the superior standards and practices that apply in the Naval nuclear program as one basis of his criticism: see D. Ford, The Cult of the Atom: The Secret Papers of the Atomic Energy Commission, (Simon and Schuster, New York, 1982), pp. 40 and 66 (use of prototypes), pp. 53 and 61 (quality of Rickover's supervision), p. 64 (in scaling up from small Navy reactors to large commercial ones, safety compromises allowed to occur so as to cut costs).

warships.[189]

4.135 In the context of the Three Mile Island accident, Admiral Rickover, the head of the United States Naval Nuclear Propulsion Program, was asked in 1979 if a meltdown could happen to a Navy reactor. He replied:

> It could happen but our plants, the plants that I am responsible for, are so designed there is much more time to take action. We have never experienced anything of the sort. We also have emergency systems for taking care of that situation.[190]

4.136 Turning to specific factors, submissions critical of current contingency planning naturally referred primarily to those factors in the design and operation of naval reactors which might render them less safe than land-based reactors. In the course of considering these factors some indication has been given of some respects in which the Committee considers that naval reactors may be safer. Some further respects are worth mentioning.

4.137 The first is standardisation. In 1987 it was said that the 107 commercial reactors then licensed in the United States were operated by 55 different utilities and very few were

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[189] V. C. Thomas jr, 'Setting the Record Straight: Allegations and Reactions', Sea Power, September 1983, vol. 26(10), p. 58. Similarly, the ability to visit foreign ports was not affected by the Chernobyl accident: US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1988 - Hearings, 11 March 1987, p. 891 (Admiral K. R. McKee).

[190] US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, p. 1074.

similar.[191] It has come to be generally accepted that greater standardisation would lead to greater safety, apart from its more direct economic benefits, and the promotion of greater standardisation of commercial reactors is a major objective in the United States.[192] In contrast the United States Navy's larger number reactors consist of only a small number of designs built by a small number of suppliers.[193]

4.138 With a larger number of virtually identical operating reactors the lessons learned from one reactor can benefit others and lead to, for example, more effective preventative maintenance.[194] Standardisation also makes more viable greater expenditure on design, testing, devising operating procedures and manuals, and the provision of more thorough training and

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[191] US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1988 - Hearings, 19 March 1987, p. 13 (L. W. Zech, Chairman, NRC). See also US, Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987), pp. 9-4 - 9-5:

> Almost every containment associated with each of the hundred-odd existing U. S. LWRs has been individually designed and constructed ... . The details of the performance of most engineered aspects of the containments ... will vary from one plant to another because of different design details, different operating history, different test and maintenance protocols, and different emergency operating procedures.

[192] See for example US, H of R, Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment, Nuclear Regulatory Commission Budget Request for FY 1984 and 1985 - Oversight Hearings, 9 February 1984, pp. 86-88 (Nuclear Regulatory Commission).

[193] US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1981 - Hearings, 13 March 1980, pp. 2240-43 incorporates a table indicating the type and source of the reactor on each USN vessel. The type 5 submarine reactor of Westinghouse is shown to have been used by 97 vessels. Apart from the USS Long Beach, all the cruisers are powered by the same reactor type from General Electric.

[194] 'Comments by Admiral H. G. Rickover, USN, Director, Naval Nuclear Propulsion Program in Meeting with Members of the President's Commission on the Accident at Three Mile Island', 23 July 1979, p. 29, incorporated in US, H of R, Committee on Appropriations, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1981 - Hearings, 13 March 1980, p. 2107. See also US, H of R, Committee on Armed Services, Subcommittee on Military Installations and Facilities, Civil Defense Aspects of the Three Mile Island Nuclear Accident - Hearings, 14 June 1979, pp. 238-39 (Dr J. P. Wade, Department of Defense).

inspection.[195] When a number of reactors of the same type are to be built it becomes less un-economic to have, as the United States Navy does, a land-based prototype built and operated to discover design flaws.[196] The United States Navy also uses its land-based prototypes to train its reactor operators under both normal and casualty conditions.[197] In comparison, the ability to provide hands-on training in civilian nuclear power stations is limited by the economic need to continue generating electricity.

4.139 Related to standardisation is the number of reactors acquired by the United States Navy compared to individual electric power utilities. The then Chairman of the Nuclear Regulatory Commission said in 1983:

> The Navy can define quite well what it wants and has been in the business of procuring complex, highly technological equipment, whereas I don't think the utilities have been. Therefore, the utilities I think got into quite a bit of a problem with their procurement ... . When I say procurement, I mean with regard to getting the construction of the plant properly oriented in quality as well as productivity. Whereas the Navy has for a long time had quality as its central

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195. ibid., pp. 28-29 (incorporated at pp. 2106-07).

196. US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, p. 891 (Admiral H. G. Rickover): use of land-based prototypes is one of the examples of the Naval Nuclear Propulsion Program's conservatism in design. The operation of the prototype continues with a lead-time of two to three years over the production reactors for the full reactor lifespan, allowing flaws which only show late in the life of a reactor to be detected on the prototype before they occur on the reactors installed on vessels: US, Senate, Committee on Armed Services, Department of Defense Authorization for Appropriations for FY 1985 - Hearings on S. 2414, 4 May 1984, pp. 3687, 3697 (Admiral K. R. McKee).

197. US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, pp. 892, 912-13 (Admiral H. G. Rickover).

focus.[198]

Relative to commercial reactors, cost is less of a factor in the pursuit of quality in naval reactors.[199]

4.140 The relatively compact size of warships, particularly submarines, can add to safety in some respects. Clearly it facilitates close supervision and discipline of operators. The compact nature of naval reactor control rooms reduces the possibility that important readings will be overlooked.[200] Because the reactor operators not only work but also live in close proximity to the reactor and depend, especially in a single reactor submarine, on the reactor for their own safety they can be expected to have a high regard for safety. They can also be depended on to demand safe equipment.

4.141 The point has already been made that naval reactors are designed to withstand combat stresses such as depth-charging, and

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[198] US, H of R, Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment, Nuclear Regulatory Commission Budget Request for FY 1984 and 1985 - Oversight Hearings, 22 February 1983, p. 43 (N. J. Palladino). It is said that the long-time head of the US Naval Nuclear Propulsion Program, Admiral Rickover, had a chronic distrust of the quality of the workmanship and materials of equipment suppliers: see N. Polmar and T. B. Allen, Rickover, (Simon and Schuster, New York, 1982), p. 489 where the example is given of nuclear plant pipe welds that had to be X-rayed and certified by the supplier, but the naval reactors staff then made its own X-rays as a double check.

[199] T. C. Joerg, 'Chernobyl at Sea?', US Naval Institute, Proceedings, December 1986, p. 86: better safety record of naval reactors has come about 'through the expenditure of high premiums in material acquisition and manpower training'.

[200] US, H of R, Committee on Appropriatons, Subcommittee on Energy and Water Development, Energy and Water Development Appropriations for 1982 - Hearings, 4 March 1981, p. 537 (Admiral H. G. Rickover):

> The commercial reactor companies tend to spread their control room out over a large area so no one person can see all the instruments. We don't do that. We design our control rooms so one man can see all the instruments. In the Three Mile Island plant some of the instruments were located so you couldn't even see them at all.

For the ways in which poor commercial reactor control room design contributes to operator error, see T. B. Sheriden, 'Human Error in Nuclear Power Plants', Technology Review, February 1980, pp. 26-28.

to survive battle damage.[201] As the director of the United States Naval Nuclear Propulsion Program said in 1985:

> we cannot afford a ship that could become a greater hazard to the crew than to the enemy if it sustains battle damage.[202]

CONCLUSIONS

4.142 Pressurised water reactors in warships and on land operate on the same physical principles. Beyond this, the differences between land-based and naval reactors are as significant from the point of view of safety as are the similarities. The discussion in this chapter has illustrated that there is no simple answer to the question whether naval reactors are less safe than land-based reactors.

4.143 As explained in the previous chapter, assessment of risk requires a consideration of both the likelihood that a given accident will occur and the consequences were it to do so. These two elements may move in opposite directions when comparing naval to land-based reactors. For example, even if the likelihood of a given accident involving a naval reactor is higher, the overall risk may still be lower because the much smaller size of the naval reactor ensures that consequences of that accident are bound to be much less than for the corresponding land-based reactor accident.

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[201] As a further illustration, it is said that the reactor design used on the merchant ship, NS Otto Hahn, lacked the shock-restance which would be required if it were to meet military specifications: N. Battle, 'PWR Plant Development for Marine Propulsion', Nuclear Engineer, January-February 1984, vol. 25(1), p. 12.

[202] US, H of R, Committee on Armed Services, Subcommittee on Seapower and Strategic and Critical Materials, Defense Department Authorization and Oversight - Hearings on H. R. 1872, (DOD Authorization of Appropriations for FY 1986), 6 March 1986, p. 184 (Admiral K. R. McKee).

4.144 Ultimately whether lesser consequences were outweighed by higher likelihood of occurrence could only be resolved by a quantitative risk assessment.[203] The Committee lacks the detailed data necessary to attempt any quantitative risk assessment, as explained in the previous chapter. However, it appears on the best qualitative assessment that the Committee was in a position to make that the reduced consequences of a naval reactor accident are unlikely to be outweighed by any greater likelihood that the accident will occur. This is particularly true in the context of the limited type of port visits that take place in Australia.

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[203] cf. the view of ANSTO (Evidence, p. 438), which

> makes no claims on the relative 'safety' of naval versus land-based reactors. We do believe, however, that the hazards to the nearby public resulting from contained, meltdown accidents is less for the shipboard reactors than for land-based nuclear power stations.

The reasons for this are given as the ability to move the naval reactor and its lower fission product inventory.