DISSENT BY SENATOR DUNN

APPENDICES

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APPENDIX 1 TO SENATOR DUNN'S DISSENT

(Evidence, p. 247)

AAEC SUBMISSION TO THE SENATE STANDING COMMITTEE ON FOREIGN AFFAIRS AND DEFENCE *ATTACHMENT 1*

CONSIDERATION OF ACCIDENTS TO NUCLEAR POWERED WARSHIPS

Background

Despite the excellent safety record and the high degree of protection inherent in the design and quality of nuclear propulsion plant, the remote possibility of an accident causing the release of radioactive material cannot be ignored. In the interests of public safety it is prudent to consider the consequences of hypothetical accidents and to make emergency arrangements to protect the public.

2. It is physically impossible for any reactor accident to result in an atomic bomb type explosion. However, it is nevertheless conceivable that serious accidents could result from component failures, material faults, design weaknesses, human errors or deliberate human acts.

3. The AAEC approach to this problem has been to review the various possible accident mechanisms, discarding those which it is considered could result only in trivial activity releases and those with probabilities so low as to be considered incredible (ie, of no practical significance). This procedure identifies a range of credible and significant accidents, and in the particular case of warship reactor systems, leads to a single Reference Accident (contained loss of coolant - see paragraph 11) which is considered to represent an upper limit of risk in terms of its probability and consequence. This Reference Accident, is used as the basis for judging the acceptability of berths and also for planning emergency procedures. The emergency planning does not take account of accidents judged to be incredible (e.g. uncontained loss of coolant accidents).

4. Quantitatively, this procedure is tantamount to evaluating for each hypothetical accident a Mean Annual Severity (defined as the product of the estimated release of iodine-131 to the atmosphere and the estimated annual frequency of this release) as a measure of risk which is based upon probabilistic grounds.

Contained Reactor Accidents

Reactivity Accidents and Start-Up Faults

5. Naval PWRs are heavily undermoderated with close thermal coupling between fuel and moderator, and therefore possess strongly negative and rapid reactivity feedback characteristics. Hence, perturbations in both coolant temperatures and power level are strongly self-correcting. This has been substantiated by published results of the SPERT (Special Power Excursion Reactor Test) experiments in which severe reactivity transients were induced in highly enriched, water moderated cores.

6. Accidents involving the uncontrolled addition of reactivity at any credible rate (for example, as a result of a fault during the withdrawal of the control rods) would therefore be terminated

by this self-regulating characteristic of the reactor before the energy release was sufficient to cause primary circuit rupture. The maximum rate of reactivity addition is limited by design to comply with well known international standards such as the IEEE (Institute of Electrical and Electronic Engineers) Standards endorsed by both the USNRC and US Navy. In addition, the protective system is designed to monitor for such faults and shut the reactor down. However, in the unlikely event of a failure in the protective system coincidental with the fault in the control system the power transient could be sufficient to cause some minor damage to the fuel in the form of local hot spots. From estimates made for similar reactor systems by the Safety and Reliability Directorate of the United Kingdom Atomic Energy Authority (UKAEA), based on analysis of component failure statistics, it has been concluded that the frequency of this combined failure would be less than 10^{-4} per reactor-year. Trivial quantities of volatile fission products would be released into the primary coolant. However, these fission products would normally be contained within the primary circuit and could only be released if a direct path existed from the primary circuit to the environment. This would require, for example, a simultaneous leakage in a heat exchanger and the condenser, the probability of which in a naval installation would be extremely small and would in any case have to be coupled with the unlikelihood of the initial fault, i.e. four unrelated faults each of low probability would be necessary to incur a release to the sea.

7. The possibility of a reactivity excursion of a similar type to that which caused the destruction of the small experimental SL-1 boiling water reactor in 1961 at the then USAEC's Idaho National Reactor Testing Station can be discounted since:

(a) For all conditions relevant to operation in Australian ports the rates or reactivity addition would be limited by the maximum control rod withdrawal rate and by the design of the plant to rates which are orders of magnitude slower than that necessary for an SL-1 type accident.

(b) The Naval reactors are operated by disciplined crews complying with detailed operating manuals. In addition, assurances have been given that no maintenance will be carried out in Australian ports. These considerations preclude the possibility of the situation which led to the SL-1 accident, which occurred during manual reassembly of the central control rod following an extensive maintenance and plant modification program. The reactor, including its protective system, was not fully commissioned during this operation and there was disregard of essential maintenance instructions. Similar maintenance operations to those carried out on the SL-1 reactor at the time of the accident could in any case only be undertaken in special home bases possessing the necessary staff and facilities.

(Evidence, p. 249)

8. It is also relevant to note that in the SL-1 accident the relatively flimsy reactor building was not breached and there is therefore no reason to suppose that the stronger containment of a warship reactor would be damaged in any reactivity accident.

Loss of Power Supplies

9. Naval PWRs, like all other reactor systems, are designed to fail safe in the event of a complete loss of supporting electrical power supplies in accordance with standard practice such as the IEEE Standards. Decay heat would be rejected to a sea-water cooler by means of natural circulation.

Fuel Handling Accidents

10. The conditions of entry into an Australian port will not permit fuel handling. Furthermore, such operations are impossible in Australian port since they would require facilities which are available only at specially equipped dockyards.

Contained Loss of Coolant Accidents

11. Failure of the primary circuit piping causing a range of leak rates of reactor coolant in excess of the make-up capacity is considered credible. This might cause overheating and possibly melting of the reactor core. Fission products would be released into the containment and under the driving force of the high pressure, escaped coolant would slowly leak into the atmosphere until the pressure in the containment was again reduced to atmospheric.

12. The most likely cause of serious reactor coolant leakage would be a failure of pipework. In approximately 2×10^3 reactor-years of nuclear operating experience there has never been an accident of this type in a light water power reactor system. Nevertheless, experience of pressure plant in non-nuclear industry has shown that pipework failures can occur in plant designed to Class 1 standards[1]. Most recorded failures are minor leaks, incipient defects detected by inspection and failures under test. Also on record are some major in-service failures of conventional plant which in a nuclear reactor might conceivably have led to fuel damage.

13. Conventional plant standards are lower than are acceptable for light water nuclear plant for which the former USAEC published special requirements[2]. Therefore, in applying conventional plant failure statistics to nuclear plant, consideration must be given to these differences and there is no doubt that many of the recorded failures would not have occurred in nuclear plant because of higher standards of design, fabrication, inspection and operational control. From a survey

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(1) Gibbons, W.S. and Hackney, B.D. - Survey of Piping Failures for the Reactor Coolant Pipe Rupture Study - GEAP-4574(1964).

(2) USAEC Division of Reactor Development and Technology. Requirements for Nuclear Components. (Supplement to ASME Boiler & Pressure Vessel Code, Section III). - RDT E 15-2T (1971).

of the most relevant experience in conventional plant it has been deduced that the frequency of serious in-service pipework failure, including marine boiler failures, has been in the range 10^{-6} - 10^{-7} failures per ft. per year[1]. In a naval PWR there would be of the order of 100ft. of relevant pipework. Hence the estimated frequency of a serious pipe failure is less than 10^{-4} per reactor per year which is consistent with the figure used in the British assessments relating to their own nuclear warships.

14. For the worst case of a full core meltdown which might be associated with a pipe failure of the type discussed above, the AAEC has assumed that a release of the order of 50% of the iodine-131 in the core is credible and has estimated that approximately a thousand curies of this iodine-131 could leak from the containment to the atmosphere over the period of 12 hours or so. This is also comparable with British estimates. Hence, this accident is estimated to lead to a Mean Annual Severity less than $10^{-4} \times 10^{3} = 10^{-1}$ curies of iodine-131 per reactor per year. This must be regarded as an upper limit of risk in view of the higher standards of design and construction of nuclear plant.

The Possibility of Uncontained Accidents

15. The loss of coolant accident described above represents the maximum credible release of fission products from the core. Any release into the atmosphere beyond that associated with this accident must involve either coincidental failure or sub-standard performance of the containment.

16. In accordance with the general conditions of entry, there will be no intentional breach of the reactor containment in Australian ports. Therefore, the only possible cause of an uncontained airborne release of fission products would be from accidents with simultaneous rupture of both the primary circuit and containment. Such an accident could be caused by a high speed ship collision considered in paragraphs 20 to 22 or by certain conceivable reactor accidents which are discussed below.

17. It could be postulated that a gross failure of the pressure vessel might cause fragmentation of sufficient energy to rupture the containment, thus leading to an uncontained release of fission products. This suggestion has been examined by the AAEC, which has concluded (in common with most overseas reactor safety opinion) that its probability is so low that it can be considered incredible. Therefore no account has been taken of this accident for purposes of port assessment or planning emergency procedures. The basic arguments in support of this conclusion are given in paragraphs 23 to 30.

18. A nuclear reactivity excursion generating shock waves or a high release of energy sufficient to damage the containment is not possible under any circumstances, because of the inherent safety characteristics and design features of the pressurised water reactors used for naval propulsion. However, there are various conceivable mechanisms for failure or partial failure of the containment coincidental with a reactor accident as follows:

(Evidence, p. 251)

(a) deterioration of leak-tightness of containment in service;

(b) generation of shock waves other than by nuclear excursions;

(c) formation of missiles other than fragments of the reactor pressure vessel;

(d) uncontrolled overheating of the reactor fuel·

19. In assessing the risk from these accidents, it is necessary to consider both the probability of the events and their consequences.

High Speed Collisions

20. Nuclear powered ships are subjected to marine hazards such as collision, grounding and sinking which might damage the reactor plant. In particular, it is conceivable that the reactor, its protective systems and its containment could all be damaged in a major ship collision in the approaches to a harbour. Ports in densely populated regions and their approaches are the areas where marine accidents are most likely. For example, an analysis of ship collisions from Lloyds' Register, involving ships over 7,000 tons, shows that about 30% occur in rivers and harbours and more than 50% in coastal waters. Only about 10% occur on the high seas over 25 miles from the coast. In spite of improvement in navigational aids, the annual rates of marine accidents of all types remain about the same. In an average of at least 2 collisions per annum there would have been a significant risk of damage to a reactor installation if the struck ship had been nuclear powered. However, collisions of this severity are highly unlikely in a port because ship speeds are low. They are more likely in the port approaches where ships converge and speeds are higher. The probability of such collisions would be lower in Australian port approaches than in crowded European ports because of the smaller volume of sea traffic.

21. A collision of sufficient severity to breach the reactor of a submarine would almost certainly sink the vessel since the hull and reactor compartment would also have to be breached. Fission products would then be released to the sea rather than to the air, with a correspondingly much lower risk to the population. A surface warship on the other hand would be less certain to sink if involved in a high speed collision. A substantial release of fission products to the atmosphere over a short period of time is therefore a possibility posing a serious hazard to any nearby centre of population.

22. Despite the very low probability of high speed collisions, controls must be exercised (even in the case of submarines) to prevent this type of accident in view of the potential severity of the consequences. The movement of nuclear warships into

ports and harbours should only be permitted during daylight hours with good visibility and other favourable weather conditions, and controls on the speed and movement of shipping to prevent high speed collisions in the vicinity of the coastal towns. It is considered that these precautions, which are subject to Australian control, will reduce to an acceptably low level the risk to the population from marine accidents in the harbour and port approaches.

Failure of the Reactor Pressure Vessel

23. The AAEC is not aware of any case of a pressurised water reactor vessel having failed in service in any mode. From published world sources, including both military and civilian reactors, it is estimated that there are about 2×10^3 reactor pressure vessel-years of experience with no record of a loss of coolant accident from failure of either a pressure vessel or pipework. However, at this stage, the available statistics are inadequate to demonstrate unequivocally whether or not the extremely exacting reliability requirements for reactor pressure vessels have been met, although the evidence to date is clearly encouraging.

24. An upper limit to the failure rate for reactor pressure vessels can be inferred from a study of the failure rate of conventional pressure vessels designed and built to Class 1 Standards(3). There are a few recorded instances of gross failure of conventional Class 1 pressure vessels undergoing pre-acceptance tests.

25. According to British and German experience(4)(5) the frequency of gross in-service failures in conventional Class 1 vessels necessitating major repairs has been of the order of 10^{-5} per pressure vessel-year. This figure is representative of the reliability currently being achieved in conventional pressure vessel practice. Because nuclear pressure vessels are subject to more exacting standards of design, fabrication and inspection (for example, the pre-service testing cost for a nuclear vessel is 10%-20% of the total fabrication cost compared with 0.5% for conventional boiler steam drums(6)) their reliability is certainly higher than conventional pressure vessels. On this basis, it is concluded that the failure frequency for reactor pressure vessels is certainly much less than 10^{-5} per pressure vessel-year.

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(3) & (4) Philips, C.A. and Warwick, R.G. A Survey of Defects in Pressure Vessels Built in High Standards of Construction and its Relevance to Nuclear Primary Circuit Envelopes. AHSD(S) R162 (1968).

(5) Kellerman, O. and Seipel, H.G. Analysis of the Improvement in Safety Obtained by a Containment and by Other Safety Devices for Water Cooled Reactors. IAEA SM-89/8 (Vienna 1967).

(6) I. Mech. E. Periodic Inspections of Pressure Vessels. London (1972), pp 24 and 140.

26. The embrittlement of steel by neutron irradiation introduces a factor which is not encountered in conventional practice, but this effect is now well understood as a result of comprehensive research and development work. The precautions against embrittlement incorporated in both the design and operating procedures of reactor pressure vessels are considered adequate to protect against this type of failure. The main safeguard against irradiation effects is the operational requirement defined in all the USNRC's published Standards and Regulations on pressure vessels, viz. that metal temperatures must be maintained at a safe margin (60°F) above the highest nil-dictility transition temperature when the vessel is under stress. The USNRC further states that this margin must be maintained under all possible conditions of stress, such as normal operation, maintenance, testing and postulated accident conditions.

27. The foregoing assessment of the reliability of reactor pressure vessels is supported by analyses based on the techniques commonly used in relability engineering for synthesizing the overall failure rate of a system by consideration of the component parts which contribute to this overall failure rate. These analyses use direct statistical evidence or, where this is not available, informed judgements. The technique has been used with marked success by the aerospace industries, and has recently been applied by O'Neil and Jordan of the UKAEA's Safety and Reliability Directorate to estimate the reliability of nuclear pressure vessels[7]. The probability of failure occurring between service inspections was determined from a series of nine factors, each of which had ascribed to it a failure probability. These factors included failure of the pressure test to reveal faults, failure of the non-destructive testing programme to reveal faults, failure of visual examination, failure to "leak before break", failure in design, material and construction. It was concluded from this study that with only modest assumptions on the reliability of the various validation processes a failure rate of less than 8×10^{-7} per vessel-year could be demonstrated. This conclusion is in agreement with an earlier German estimate[8] and with the findings of the US Advisory Committee on Reactor Safeguards and the US Reactor Safety Study[9] that the frequency of failure of nuclear vessels was at least one order of magnitude less than that of conventional vessels, i.e. the frequency of failure of nuclear vessels was of the order of 10^{-6} per vessel-year or less.

28. These estimates of failure frequencies do not apply to the extreme case of catastrophic fragmentation capable of causing a simultaneous breach of the containment and an uncontained release

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(7) I. Mech. E. - Periodic Inspections of Pressure Vessels. London (1972), pp 24 and 140.

(8) Kellerman, O. and Seipel, H.G. - Analysis of the Improvement in Safety Obtained by a Containment and by Other Safety Devices for Water Cooled Reactors. IAEA SM-89/8 (Vienna 1967).

(9) Reactor Safety Study - An Assessment of Accident Risks in US Commercial Nuclear Power Plants. US Nuclear Regulatory Commission - WASH - 1400 (Oct 1975), page V-45.

of fission products. Such failure simply have not occurred either in conventional or in nuclear plant. Taking the failure frequency of reactor pressure vessels as being of the order of 10^{-6} and making the conservative assumption that 10% of all gross failures of vessels will be of this type then the frequency of such accidents would be of the order of 10^{-7} per vessel-year. Such probabilities are so low as to be of no practical significance, and the application of appropriate controls in the design, fabrication, operation and inspection of plant gives acceptable assurance against this type of failure.

29. The AAEC is satisfied that this judgement is applicable to naval reactors. In fact, there is little doubt that the degree of reliability in naval reactor pressure vessels is higher than in civilian reactors, e.g.:

(a) The quality assurance programmes for naval reactor machinery, including pressure vessels, are extremely demanding and of a higher standard than civil power reactors (confirmed by the UKAEA and USNRC).

(b) The design bases for the pressure vessels of the US nuclear warships reveal a design standard more rigorous than the ASME[10]. Code for nuclear pressure vessels (the civilian code).

(c) The United States Naval Materials Research Laboratories in Washington is considered to be the leading research laboratory on nuclear pressure vessel technology. Leading world authorities in the field of fracture mechanics and the effects of neutron irradiation work in this laboratory (e.g. Pellini).

30. Published estimates of the proportion of the total iodine inventory which might be released into the atmosphere as a result of an uncontained accident of the type described are generally of the order of 10% (about 10^{5} curies). With an estimated frequency of the event of the order of 10^{-7} per year the associated Mean Annual Severity is of the order of 10^{-2} curies per year, i.e. less than that from the contained loss of coolant accident. This is considered to be an upper level figure for nuclear warships because the iodine inventory is unlikely to be as high as the full power equilibrium level. Uncontained accidental releases are accordingly discounted and no account is taken of them in planning emergency procedures.

Deterioration of Containment in Service

31. The main guarantee of containment integrity is provided by periodic leak tests given to all compartments within the hulls of all submarines (conventional and nuclear). These tests normally consist in the application of positive and negative pressure differentials, to detect changes in leakage characteristics, accompanied by a vessel inspection for damage, corrosion, deterioration of seals, etc.

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(10) American Society of Mechanical Engineers.

32. A full pressure leak test and strength test is made on the containment during construction. After refuelling, which involves opening and resealing the containment, a further pressure and leak test is carried out.

33. Leakage of radioactivity from the containment bulkheads would be further contained by other compartments within the ship's structure. Any loss of integrity of the hull in normal operation would result in the leakage of sea water and would therefore be noticed and repaired. Furthermore, nuclear submarine hulls are inspected periodically for any indications of physical deterioration.

34. The assumptions made in the analysis of the Reference Accident include an allowance for a 50% deterioration in leak rate over the design specification, although experience has shown that measured leak rates are actually much less than that specified. There is further conservatism introduced into the Reference Accident analysis by the assumption of a constant leak rate over the course of the accident whereas the leak rate will fall by a factor of approximately 10 during the period of the first 24 hours due to the reduction in pressure inside the containment. Since the leakage will be associated with penetrations it will be into the secondary compartments surrounding the containment. As already mentioned, no allowance has been made for the leak tightness of these compartments in the analysis. Hence, overall the conservative assumptions made in the Reference Accident compounded together overestimate the likely leak rate to the atmosphere by a considerable margin.

35. Containment integrity could also be compromised by the unauthorised opening of airlocks through major administrative violation of interlocks and operational controls. During operation of a nuclear warships at sea or in port, violation of containment by action or omission would be contrary to regulations and a breach of discipline. Violation of operational procedures is therefore regarded as improvable in the context of naval operations. Even assuming pessimistically the occurrence of a major violation of containment once a year for a period of an hour, the probability of being in this condition at the time of an unrelated loss of coolant accident is approximately 10^{-4}. It has previously been shown that the frequency of a serious loss of coolant accident can be estimated as less than 10^{-4} per year, and the frequency of this accident with coincidental violation of containment integrity is therefore less than $10^{-4} \times 10^{-4} = 10^{-8}$ per reactor per year. The upper limit of possible release of iodine-131 would be of the order of 10^{5} curies. Hence the Mean Annual Severity of the accident is less than $10^{-8} \times 10^{5} = 10^{-3}$ curies per reactor per year. This compares with 10^{-1} curies per reactor per year for a contained loss of coolant accident and supports the decision to use the latter accident as the Reference Accident representing the greater risk to the community.

Shock Waves

36. The containment of nuclear warships is designed for the pressure generated by the full release of all energy and contents from the primary circuit, with the addition of heat energy from

chemical reactions involving the fuel and structural materials of the reactor core which would reach high temperatures as a result of the accident.

37. If the forces were applied suddenly the structure would be exposed to a shock loading which might exceed its yield strength. Potential sources of shock wave generations must therefore be considered in order to ensure adequate factors of safety in the design of the structure.

38. The only conceivable mechanism of a significant shock wave due to the release of primary circuit coolant would be the gross bittle failure of the reactor pressure vessel or a heat exchanger. Even this could not cause the complete, instantaneous release of all primary coolant. In view of the quality assurance provisions against brittle failure, and other factors discussed elsewhere, this mode of shock wave generation is considered incredible. Failure of pipework would cause only an insignificant shock wave followed by the blow-down of the primary circuit over a period of at least 5 seconds.

39. In the most serious loss of coolant accident the reaction of the metallic cladding of the most highly rated fuel elements with steam would commence within a minute, due to over-heating of the fuel, but would then continue progressively over a period of uncertain duration. The metal-water reaction produces hydrogen which might subsequently react with air already present in the containment. This problem has been examined for civil power reactors by Moore and Gilby of the UKAEA[11]. The actual volumes and quantities relevant to a naval reactor installation are not known for certain. However, from Moore and Gilby's study it appears most unlikely that the composition of the mixture could be within the flammability limit immediately following the accident, and detonation of gases in the free space of the containment is inconceivable. A locally high concentration of hydrogen could only occur in the immediate vicinity of the metal-water reaction, i.e. within the pressure vessel. Engineering tests within the UK naval reactor development programme have shown that shock waves generated by an explosion within the pressure vessel would become attenuated so as not to endanger the containment.

Missiles

40. The primary circuit provides a source of compressible fluid at 2000 p.s.i. If the extreme view were taken that this pressure could be applied to any fragment of the primary circuit or piece of machinery within the containment so as to accelerate it through the distance between its normal location and the containment boundary, then the formation of missiles capable of damaging the containment is conceivable. However, it would not be possible to identify actual physical sequences which could have this effect in a practical reactor installation.

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(11) Moore, J.G. and Gilby, E.V. A review of the Problems due to the Combustion of Hydrogen in a Water Reactor Containment. (AHSB(S) R101 (1966)).

41. The possibility of missile formation is recognised in reactor technology and is prevented by design, layout and quality assurance. Quality assurance provisions have been discussed above, and the techniques of prevention by design and layout can be studied in the documentation of any licensed nuclear power station, e.g. potential missiles associated with the primary circuit are firmly anchored, unrestrained pipe runs are too stiff to move more than a few inchea even in the event of a guillotine failure.

42. It should be noted that primary circuit pumps in a naval reactor are of the canned rotor type with low inertia and would not therefore constitute a significant source of missiles due to rotational energy.

43. It should also be noted that most modes and locations of primary circuit failure would not have the extreme consequence of full core melt down. The Mean Annual Severity of these accidents would therefore be reduced by the low release of radioactivity as well as the remote probability of missile formation.

Breach of Containment by Molten Fuel

44. In a nuclear submarine the containment boundary is formed by the ship's hull. Molten fuel could only reach the inner surface of the hull after melting through the reactor pressure vessel. However, release of gaseous and volatile fission products from the molten fuel would reduce the decay heat power to a level where melt-through appears to be impossible. Even if it is assumed that there is no such reduction in decay heat power in the molten fuel (which is physically impossible) it would require some 3 to 4 hours before the molten fuel would melt through the pressure vessel. At this time the fission product heating is about one-third of a megawatt and it would be readily dissipated through the hull to the sea water. It is therefore concluded that melt-through of the hull will not occur. In a nuclear surface ship the containment may be inside the hull and not in contact with the sea water. However, the hull could be fully sealed in the time available, before any possible melt-through of the containment and would then form an additional barrier to the release of fission products.

The Reference Accident

45. The AAEC's assessments of the suitability of berths and anchorages take into account the detriment to public health that might be incurred, and the feasibility of appropriate emergency procedures to protect the public, in the event of a Reference Accident in a nuclear powered warship during its visit. A Reference Accident is defined as failure of the reactor primary coolant circuit resulting in a full meltdown of the core and the release of gaseous and volatile fission products to the reactor containment. A slow leakage of the fission products to the environment would follow. It is believed that the Reference Accident represents a realistic upper limit of radiological risk to the public.

APPENDIX 2A TO SENATOR DUNN'S DISSENT

(Evidence, p. 658)

SENATE STANDING CTEE ON FOREIGN AFFAIRS & DEFENCE 14 May 1987

ACTING CHAIRMAN - I now invite you to speak on the document circulated to the Committee and at the conclusion of your remarks I shall invite members of the Committee to submit questions to you.

Mr Speed - I wonder whether it would be appropriate for me to give some background to my involvement in this area, because it may be useful to relate some of my answers to it later. I first got involved in this area about 11 years ago, in 1976, when the Fox commission was taking evidence, there was a lot of discussion about the risk of nuclear reactors around the world, and that was being considered in relation to Australia's possible decision to mine and export uranium. Around that time, representatives of the Australian Atomic Energy Commission were publicly citing results from this document, the 'Reactor Safety Study', which I have referred to as reference 1 in my paper. As a statistician, when I heard some of these statements I became sceptical and suspicious. I became interested enough to see what lay behind them. I sought a copy of the 'Reactor Safety Study' and obtained one with the co-operation of the AAEC. Over a period of some months I read it fairly carefully and wrote a critical review of it. I discussed this widely with professional colleagues in Australia and eventually wrote a paper on this, which I will mention later.

In 1978, a couple of years later, I had sabbatical leave and went to Scandinavia, to the United Kingdom and to the United States. During that time I gave a lot of talks and had a lot of discussions about the issue of reactor safety with statisticians or people from the nuclear industry. At around that time the review group of the Rasmussen committee - which I also refer to in my document - was sitting. I submitted my paper to them and I understood that it was considered a worthwhile contribution. I was pleased to find the broad recommendations of the Rasmussen report - which is also the 'Reactor Safety Study' - broadly agreed with my analysis; that is to say that, roughly speaking, the figures themselves were of very limited value for assessing the risks, or as I have stated in my document that they are unable to say whether they were too high or too low but they were sure that any accuracy that was attributed to them was understated.

As I said, I spoke widely on this and visited places like the Nuclear Regulatory Commission in the United States, spoke with statisticians there, got a reasonable background and got what I felt was a lot of support for my views. That, roughly, is where it sat until about three or four years ago and the events leading up to this other document that I have referred to, written by myself, the one relating to the Sizewell inquiry. I was asked to comment on the proposed Sizewell reactor probabilistic safety study. I did that, and the main conclusions there are in a published paper which I have referred to. Since then I have had a bit of experience as an expert witness and as a consultant in the general area of risk analysis. More recently, I was asked to put my views on this topic, and that resulted in my submission.

In summary, I would like to reiterate the opening paragraph of my document. I believe the task of this Committee is to address the following: What could go wrong with a nuclear powered vessel in a port or in a sea around Australia; how likely are any of the things that could go wrong to go wrong; and, finally, if these things go wrong, what are the likely consequences? As I have said in my document, I do not find the advice, the background to the Atomic Energy Commission's recommendations, satisfactory for a number of reasons, which I am sure we will be going into in discussion. In particular I am not impressed by the way in which it has focused on the so-called reference accident. In 1976, in its earlier document, it was called a maximum credible accident, and the same accident in 1986 or 1987 is called the upper limit to the risk. The risk, at this stage, was probability by consequences. It is the same accident, and I feel, that it is unwise to base the entire considerations of this Committee on that accident. I have commented that I feel that the subject of probabilistic risk assessment has come a long way since the 1976 document of the Atomic Energy Commission and I do not believe it has revised its approach to this issue significantly since that time.

Finally, at the end of my document I summarise my conclusions, which I will just repeat. The best way to answer the questions 1, 2 and 3 that I have put in my document and to lay contingency plans accordingly would be to seek the full co-operation of the navies whose vessels we are considering and to get access to the maximum amount of information about the reactors in question and about the data on their past histories, and endeavour to do a comprehensive risk analysis of the kind that I have outlined and with the improvements that I have outlined, and on that basis consider the contingency plans. Without that, I would not have a great deal of confidence in the conclusions of the planning accurately reflecting the risks that might arise.

ACTING CHAIRMAN - You have directed yourself predominantly to nuclear-powered vessels. We have, of course, another reference, nuclear-armed vessels. Is it within your competence to comment in that regard?

Mr Speed - I am sorry, it is not. I know nothing about that issue other than what I have read in the papers associated with this hearing. I have no independent knowledge.

ACTING CHAIRMAN - You have mentioned Three Mile Island and the report of the Nuclear Regulation Commission and so on. Did you attempt to bring your knowledge up to date as a result of further modifications done by NRCs and others and also as a result of world interest in Chernobyl? Are you aware of any reassessments in terms of probabilities as the result, shall we say, of Chernobyl?

Mr Speed - No. I am afraid my review of the literature prior to writing this document was necessarily rather cursory because I have a lot of commitments at the moment and I was unable to do exactly what you said, which is something I would have liked very much to do. I have an idea about what went on at Chernobyl and how that relates to the issue today, but I have not been able to spend the time to find out what impact that has had, for example, in the safety activities of the United States.

ACTING CHAIRMAN - Should we all not so much look over our shoulders - indeed you ask us not to, about the Atomic Energy Commission in 1976 - but start by looking at, shall we say, what the International Atomic Energy Agency may be analysing in terms of probabilities at this moment, 1987?

Mr Speed - That would be the ideal, and if my contribution has brought us closer to focusing on that issue, it will have been of some use. I regret that I have not had the time to do that myself.

ACTING CHAIRMAN - You have not sought to get that information?

Mr Speed - I did not because of a couple of logistical factors. I am shortly to leave the country and not to return for some time and even to get this submission done and to appear here was quite an effort.

ACTING CHAIRMAN - That was not a criticism, it was meant to put it in perspective.

Senator HAMER - I would like to start with your suggestion of how we tackle the basic inquiry, that we look at what could go wrong, then how likely it is and what would be the consequences. That is, of course, a somewhat different approach from the one that has been put to us by the Atomic Energy Commission. But something could go wrong and the consequences might be trivial. Is it worth pursuing them if they are lesser consequences than those which might happen? In other words, is the probability of minor incidents happening important to us if we are providing for a more serious accident which would subsume the consequences of a minor one? Do you see the point? We do not want to pursue each minor accident to a probability conclusion if we are satisfied that its consequences would be less than the major ones for which we are prepared.

Mr Speed - I concede that the issue should be about severe accidents.

Senator HAMER - I find a lot of your remarks about the difficulty of risk assessment very persuasive. Is it true that the likelihood of an uncontained meltdown is less probable than that of a contained one?

Mr Speed - Generally speaking, that would be true. To answer that question fully competently, I think you would have to speak to someone who knows the reactor design. But in a simplistic way, to have a meltdown and a breach of containment, you have to have the meltdown first, so the compound is a sub-set of the----

Senator HAMER - As you understand, what we are looking at is the meltdown, or the loss of cooling and a slow leak, not a total disruption. How likely that is, is knowledge we are having very great difficulty in getting. It is: What is the structural strength of the containment in naval warships? Have you any information in that field?

Mr Speed - Certainly that would be part of it.

Senator HAMER - But do you have any information in that field?

Mr Speed - I am afraid I have no independent information about nuclear reactors in warships. None of the literature I have read has related to warships.

Senator HAMER - You were, I think, critical of the AAEC's quantification of accident probabilities. You are critical of them. What are your views of the accident probabilities and the AAEC's quantification of them? Do you think they are out of date?

Mr Speed - Without trying to sound too disrespectful, I did not see a lot of quantification. The only numbers that I saw, unless I have read the document inadequately, related to 100 feet of piping, and a probability that a rupture might occur over this length. There was not any quantification of a comprehensive kind that I normally associate with a thorough risk analysis. There were just figures like the one that I mentioned. There was a lot of discussion with words like 'incredible' and 'highly improbable' and so on, which I do not regard as quantification. In a sense I see those as professional judgments by the people making them, but not in any sense checkable, scientific analyses. So if I am not wrong, the only actual quantifications were relating to these pipe ruptures.

Senator HAMER - Do you know of any studies that have been made of naval reactors? I presume you have to have two stages: One is the type of accident, the meltdown or the loss of coolant or whatever the possibility is of that. The other is the possibility of that occurring in a form that might seriously rupture the containment vessel. Do you know of any studies that have looked at that?

Mr Speed - No.

Senator HAMER - You see what we want it for, do you not? That is fundamental to our inquiry. We are assured up until now that that is, to use your word, incredible.

Mr Speed - My impression is that the Atomic Energy Commission did not have access to that information either and was extrapolating from civilian nuclear reactors. I guess the thrust of my argument is that it did not do that very well either, without worrying about the issue of whether the AAEC had the more relevant information that we would all like.

Senator HAMER - You appear to have rejected this so-called reference accident as being a suitable basis for our contingency plan, or you are not happy with it as a suitable basis.

Mr Speed - 'Not happy with it' would be better.

Senator HAMER - Before you answer that part, could I ask: Is your worry the probability of this reference accident or the consequence of the reference accident?

Mr Speed - It would be both. What I would have liked to see - and if it exists somewhere I think it should be of interest to the Committee - is the basis on which this reference accident was selected. It is said in one place that it was the accident which had the highest combination of probability by consequences. So there would be some that would have worse consequences but lower probability and, in forming this combination, they were regarded as less important. There would be others with higher probability but lower consequences, and they are less important. And it is suggested - it is almost stated categorically - that this reference accident came in at the maximum of this combination. I would have felt that the Committee would want to look at all combinations of probability and consequences rather than take this numerical combination which purports to single out one accident and base everything on that. That would be my view.

Senator HAMER - But if we have picked one case as our reference - assuming we do stick to a reference accident - and its probabilities are of a certain scale, is there any point in pursuing accidents that have less consequences in trying to establish their probability? What is the point of doing that?

Mr Speed - This is just a personal view, but what I would like to see when I am having my safety taken into account, as it were, is consideration of a wide range of possible accidents. Obviously it is going to have cost issues and, if you like, logistical issues. There would be very bad accidents which have enormous consequences and it might be inconceivable that we could seriously plan for them. At the other end of the scale you might have quite trivial accidents which require next to no planning or contingency. My view is that I would like to be reassured that all of these, in the whole spectrum of consequences and probabilities, have been duly considered. I think that is the task of doing a comprehensive risk analysis, not focusing immediately or fairly quickly on to one thing. This does not necessarily help you if that is not the thing that actually happens.

Senator HAMER - Maybe I did not make my question clear. I am using the reference accident - and I do not like the expression but let us keep this so that we know what we are talking about - but if the consequences of the reference accident are an area of contamination which depends on winds and all sorts of other factors, then we accept that if the reference accident happens these would be the consequences. What is the point of pursuing other accidents where the consequences would be less than that? If we are prepared for the greater one are not the lesser ones subsumed by that?

Mr Speed - That is assuming that we can get a nice, simple quantification of this concept of consequences, but I think different accidents will have different consequences. To answer your question a little more pointedly, I am much more interested in more severe consequences but with apparently lower probabilities that have been disregarded because the combination in general----

Senator HAMER - Do you think we should look more closely at the obvious one, which is the probability of the breach of containment? In an accident we have to look more seriously at that. That, of course, is our fundamental problem; getting the information on which any assessment can be based. When we are looking at these risks, even if you dispute the absolute probability value of assessments that have been made, is there any merit in a sort of mean annual severity, allowing them to rank the things in relative probability?

Mr Speed - In my view, no. If I do not believe the figures in absolute terms, I find myself unable to believe them in relative terms either.

Senator HAMER - It could be the same error in both.

Mr Speed - It is a nice thought, but often if you look in more detail at the objections that I have to the figures, it is not a matter of possible common error. It is things that might be left out entirely. If we talk about modes of accidents that are left out entirely, then the figure is wrong in absolute and relative terms - it is just left out. Quite a common reaction to figures that are a bit rubbery is that maybe they are useful in relative terms, but I am afraid that, as a practising statistician, this does not appeal to me.

Senator HAMER - If, as appears possible, we are unable on security grounds to get really accurate information on the strength of the containment in submarines and surface ships, is there anywhere we can go in your field? Would your approach enable more useful extrapolation from shore-based reactors without special knowledge of what the strength of containment is around a naval reactor?

Mr Speed - I would think so.

Senator HAMER - Maybe you could help me.

Mr Speed - I would think that the sort of thinking that has gone into the Atomic Energy Commission's case, which does not really build on any knowledge of naval reactors, could still be incorporated in a much more comprehensive analysis of the kind that I have described. Of course, it still would not be focusing on naval reactors.

Senator HAMER - They have that problem at the moment in that they just do not know what the strength of that is.

Mr Speed - As I think I alluded to earlier, I am still not happy with the way in which they marshall the material relating to civilian power generating reactors.

ACTING CHAIRMAN - If I may intrude, in considering the law of probabilities you need large samples, do you not? Small samples give you a much greater distortion. Do you regard as a large sample an extent of 30 years, being the history of civil reactors, and a gradual buildup over 30 years to what - some 300 or 400 operative reactors today? I put it to you that that must be a relatively small sample altogether, and therefore, looking at probabilities - even though you may have some thousands of reactor years - is that sample not too small to deal with probabilities?

Mr Speed - In its own right, certainly. I agree that it is a small sample. The 4,000 years sounds like a lot, but when you look at the statistical errors on estimates based on that, they are very broad.

ACTING CHAIRMAN - Probabilities deal with hundreds of thousands, not four thousands, do they not?

Mr Speed - For such small probability events, that is certainly true.

ACTING CHAIRMAN - Without too much whimsy, would we not be better to state the law of probabilities for this Committee, that the probability is that the improbable will happen. I do not say that with too much whimsy. Bear in mind that you are dealing with warships that in ordinary times have to look at every kind of contingency and plan for them. Whilst in port or coming into port and so on, things can happen. Is there too much whimsy in the idea that we should in fact disregard probabilities and just look at each circumstance as it might happen?

Mr Speed - Depending on what you mean by that statement, I would be inclined to agree. In general terms, I am very much against setting a lot of store on these probabilities because I do not believe them. The accident record of nuclear reactors, which is not very extensive, shows that generally the things that happen are things that have been ignored by the calculations and probabilities. Three Mile Island, Chernobyl, Browns Ferry are all things that were left out of the analyses. In that sense you are quite right. Regardless of the size of the sample even, we would be better off thinking what might happen and not letting our thinking be guided by probabilities which may or may not have any value and which I would argue do not have any value. But, of course, what you do next is still a very serious issue, is it not?

ACTING CHAIRMAN - In human life, does not the improbable tend to happen?

Mr Speed - Very much so. In fact everything that happens tends to be improbable.

Senator AULICH - Can we go back to an assumption that you may or may not make, so that I can just clarify where you stand on that. Let us assume that we go into that area of past reactor experience and, as the Chairman said, it is a fact that we do not have a base which we can use for any reasonable probability analysis because of the small experience that we have in that area. Do you assume from that, for example, that there have been improvements to reactor design - both naval and civilian - over the years which lessen the chance of an accident occurring? Or have the parameters of design that have had to be built in through compromise, speed of a naval vessel or even costs and the need to compete in the nuclear industry with other people on a tender basis and so on, maintained the same level of probability of an accident occurring? Or is there in human history always an improvement which, in this particular case, would lessen the probability of the occurrence of an accident of some seriousness?

Mr Speed - The short answer is that I would like to think so. The longer answer is that it is very difficult to see what sort of evidence one can point to to argue that this is in fact happening. If I find that most of the probability figures I see presented are not, in my view, well based, that is not a very good basis for deciding whether there is, in fact, a learning curve or not. On the other hand, if you look at it from the point of view of design or operation, every time something serious happens, such as at Three Mile Island, Brown's Ferry or any number of accidents or incidents that you might mention, one would like to think - I am sure it is happening to some extent - that the experience gained from these incidents or accidents, is fed back into design, into regulatory codes and does make things safer. The problem is whether this is being manifested in probability and that is a much more difficult question, I think. I hope the industry is behaving sensibly; learning as much as it can about accidents; not covering up; not getting cheaper and shoddier and so on, but actually doing what you are suggesting. I am not sure that I could point to much to prove this.

Senator AULICH - So you say there is a hope, but mathematically or in terms of probability the other parameters may well affect the net improvement in terms of safety standards and so on.

Mr Speed - That is the way it works in engineering, generally, and I do not have any reason to believe that things are any different in the nuclear engineering area: You build on experience; design faults become revealed; accidents occur; experience expands, and things get better. I am not trying to sound totally naive but that, roughly speaking, is the way I think things go in building bridges, tall buildings, et cetera. People do not calculate the probability of a very tall building falling over, or a bridge dropping - they build on past experience. Occasionally a new design comes along; they build it and it falls down and they decide that that was not such a good idea. But that was not done on the basis of any probabilistic calculation; this is all just part of what I think is the engineering approach to creating the world we live in.

Senator AULICH - I think that engineering approach dominates the nuclear industry in much the same way as it would dominate other civil engineering approaches.

Mr Speed - Yes. Maybe I could give you a little anecdote which will put that point very clearly. One of the things that has concerned me most about these probability risk analyses that I do not believe, is that somebody else might believe them. If you have a risk analysis which tells you that things are terrifically safe, my concern would be that that might lead you to be rather more lax than you might otherwise be; you might cut corners or decide that you have something that tells you you can use a cheaper component. It was very reassuring to me when I visited the Nuclear Regulatory Commission to talk to the statisticians there. They told me, quite frankly, that they did not think the people in the Commission believed these figures, which were for public relations purposes, but they reassured me that the people actually building reactors and, monitoring and, licensing them, do not give a lot of credence to these figures. That to me is the main worry, that you somehow alter the engineering tradition of improvement and, of learning from experience, by focusing on these figures that I regard, by and large, as anything from misleading to quite bogus, depending on who has done them and how they have been done. If I had any message at the end of the day, it would be that the general principles that are embodied in engineering design remain at the basis of the way in which we view the safety issues associated with the reactors, both civilian and military.

Senator AULICH - So we have three main themes: The mathematical probability theme, the engineering experience approach, and the public relations theme, which you say, are all combined, to some extent, in the one syndrome somewhere along the line. Say you were in this Committee's position of having to, first of all, tease out the main issues and then look at probabilities and at what we can do about them. Where would you start if you were going to cut your way through the enormous amount of technical jargon put in front of us, the occasional public relations statements made by people who probably ought to stick to science rather than public relations, and so on down the line? If you were in our position, where would you be going?

Mr Speed - There is the rather unfortunate problem that you want to tie both my hands behind my back and tell me that I am not allowed to have any information relating to the object of our discussion, namely, a nuclear reactor on a ship. It is a rather unfortunate matter which I hope you do not put aside lightly, because it seems to me that someone, somewhere, must have some information that they are prepared to share with this Committee about the design of reactors in ships and submarines. Putting that aside, I would seek the analyses associated with the risks of civilian reactors that are believed to be most similar to the ones about which we have no information - the military reactors. You have to start looking at the accidents that might occur. I have no real quarrel with the general approach of these probabilistic risk analyses, except that I do not believe the bottom line figures.

The main value of these analyses, and the reason why they are being pursued so vociferously around the United States, is that they ask you to take your reactor apart, do the very best you can to think of ways in which it might go wrong, look at all possible things that could initiate accidents, all possible sequences of accidents. Honest people do not believe that is going to exhaust everything, but that is the way a thorough engineer would go about trying to improve the safety of a complex system - essentially, taking it apart, thinking of what could go wrong, and at the end having to look at the relative importance of these accident sequences.

I do not mind a bit of seat-of-the-pants probabilistic calculation to try to rank these because you obviously have to ask 'Is it more likely that this is going to happen than that one?', if you want to start talking about what you are going to do to protect yourself from it. Again, you do not believe the figures; you just do the best you can and preferably use all the data available. To date I am not convinced that that sort of thinking has been adopted by the Atomic Energy Commission. There is a lot of data available. It is not what I call end event data. If you add up the data on actual major accidents and ask 'How many meltdowns are there? How many years are there?', there are, depending on how you like to count, zero or one or two meltdowns in a lot of years, but there is an awful lot of relevant data that refers to events along the sequence leading to a meltdown, giving you an idea of the relative importances of the difference sequences and hence the relative likelihood, as far as you can get it, of these end events.

Look at all that, do some sort of ranking, and then, of course, you have to look at the consequences. As I have said, there is a lot of uncertainty there, but again you just do the best you can. My view would be that after you have done all this you have an awful lot of information in front of you and then you have to start talking about contingency plans, and what sorts of precautions can be taken. What I dislike intensely is somehow quantifying the consequences in a way that is bound to be plagued with uncertainty, quantifying the probabilities in a way that most statisticians and a lot of other people would not believe, multiplying the two together and saying: 'This is the risk'. I would much rather have the floor of my room covered with all sorts of possible accident scenarios and think of the sort of precautions that one could take and try to come up with something which is a compromise with what is feasible financially in terms of where people are. I suppose if it is necessary to have nuclear vessels visiting and they can only stay in a port at a given spot, then you are inevitably going to say that we have to accept that a particular accident, say, of a significant magnitude, might put some civilians within a certain distance at risk. They are part of the political decisions that are made in building the environment around your reactor or around your port. Rather than trying to quantify it in a way that is potentially quite misleading, just mix in the information, which is the best you have, with these political, safety and other considerations. I cannot see any other way than that. If it sounds a bit vague, forgive me, but I have not really tried to do one of these things in practice.

Senator AULICH - Why is the AAEC going in that particular direction? Is that the bent of scientists or is it a general tendency amongst certain types of institutions and organisations to try to want to quantify everything, even if total quantification and policies based upon that total quantification may in fact not be the whole story or the right way to go, as you have already indicated?

Mr Speed - I am not sure. I could speculate on a whole range of reasons. One, which is not all that insulting but is certainly likely to be part of it, is that they probably set a lot more credence in these figures than I do. One of the ironic things is that statisticians, people who work with figures like this all the time, believe them far less than the people who use them only occasionally, and we know just how ropey they can be.

You get people walking around with figures that are hardly better than something that was made up and then telling somebody else a little bit later that this is a hard figure. I have lots of documentation that suggests that. People do not look into where the figures came from and how well based they are. They are happy to have a figure because it makes life so much simpler. That is certainly an error that people like the Atomic Energy Commission scientists fall into, I think.

ACTING CHAIRMAN - It seems to me to ignore the fact that the AAEC has been closely associated with the studies of both Three Mile Island and Chernobyl and has in fact had representatives at international discussions. If indeed it is obsessed with figures, you are suggesting that it has not allowed its mind to be flexible enough to take in all the new consequences that have flowed from those two accidents. That seems to me to be a long bow. Basically a lot of your document is prior to or at the time of Three Mile Island and, as you yourself have indicated this, it has not the knowledge that has flowed from the re-opening of the minds of scientists as a result of those two accidents. I would have thought one should have given tribute to the AAEC that it might learn from the international discussiohs that are still going on and that the International Atomic Energy Commission would be doing its sums, too, and not be so rigid. How would you react to that?

Mr Speed - Firstly, my comments in the paper were based on the material that the AAEC submitted to this Committee. There is nothing that is post-1976 in those documents, much less Three Mile Island. So if it is a matter of timeliness, I am way ahead of them.

ACTING CHAIRMAN - I know, but you must have known that the AAEC would have been associated with international discussions and information post-1976.

Mr Speed - Of course. I assume----

ACTING CHAIRMAN - Therefore, the AAEC would have applied that to the conclusions it reached. I am not saying anything in defence of the AAEC, I am trying to get the environment in which you reached your conclusion.

Mr Speed - Let me go on to the second point then. What would undoubtedly be true is that the AAEC would have learnt a lot scientifically, such as possible accident sequences, and ways in which things might happen that people had not otherwise thought of. That is part of the general knowledge that I was alluding to earlier, that one hopes engineers, and nuclear engineers in particular, are constantly soaking up and implementing in their day to day work. What I do not believe has occurred is any fundamental reappraisal post-Three Mile Island or post-Chernobyl in the AAEC's thinking about risk analysis. I do not believe that a single event like that has had any impact on the thinking that goes on.

ACTING CHAIRMAN - Help me here. The whole of the rest of the world would have been looking at revising its theory of risk analysis as a result of those two accidents, surely. That would be the key to it. We have some new experience - Three Mile Island and Chernobyl. How does that affect our earlier risk analysis? Are you suggesting that the whole world has not caught up to date, or that the AAEC is out of step?

Mr Speed - I would like to emphasise that I have read the risk analysis literature post-Three Mile Island, just not post-Chernobyl. My paper and a lot of the references there are all recent. Three Mile Island did not force a reappraisal of the method of risk analysis, the methodology, the approach, the attitude. All it did, which might sound like not very much, was inject a little more accident experience into it. But this has had surprisingly little effect on the figures that this process produces. It tells them that yet again something occurred which was not in their calculation. I could have told them that was very likely. What happened at Three Mile Island was a pressure-operated relief valve closed when it should have been open and a signal was sent that said it should have done something and they saw the light. That sort of thing is not included in these risk analyses as an initiating event. The difference between a signal indicating that a thing is closed and it closing had not been thought about. So that is an accident which just at the very simplest was left out of previous considerations. Obviously that would be included in subsequent considerations as far as they can, but it does not alter the actual methodology - the approach of risk analysis. This document that I have, dated 1983, certainly uses risk analyses done by Westinghouse in the United States well after Three Mile Island. They have built the technical conclusions of the Three Mile Island accident into their analyses but it has not changed the way they do it. It has not made the figures substantially more believable, in my view.

ACTING CHAIRMAN - Whilst I acknowledge you would not have the technical background of the discussions post-Chernobyl, one could reasonably hope that it having been looked at by something like 40 or 50 nations very closely, that scientists would have modified their risk analysis if the evidence from Chernobyl supported that. Is that not a reasonable assumption?

Mr Speed - One would hope so, but again, I do not think it is the nature of the beast that a single accident revises the whole thinking.

ACTING CHAIRMAN - Chernobyl is not a single accident though, is it? Chernobyl is an international threat and poses an entirely different situation. In itself a great drama, surely it would have forced a reappraisal.

Mr Speed - You think that more goes into these risk analyses than in fact does. There is very little use of the detailed information relating to accidents that have occurred in these analyses. They have a list of initiating events which, of course, gets larger as time goes on because more things happen. They start off with things like 'loss of off-site power' or 'turbine trip' or 'pipe break', but as other things happen this list gets larger. But that does not change the fundamental thinking. Then there are lists of event sequences through the course of the accident and there is the consequence analyses. But the whole way it hangs together and the general approach really does not change - no matter how significant the accident. You just add some possible new events or event sequences that had not been thought of or had been rejected as incredible. Of course, what went on at Chernobyl had previously been rejected because it was people disobeying the rules. There was not a pipe failing, according to something which can be statistically determined, it was a man-made intervention which is impossible to quantify as an initiating event. So in that sense, the main lesson for the probabilistic risk analysis of Chernobyl is: 'Here is another example of something we have left out happening, and causing a very serious accident'.

Senator AULICH - To get back to the question of the AAEC and its presumed reluctance to look at things in the way that you are looking at them, you say that, first of all, there is no evidence in any of the papers that you have seen of late that have taken into account, or could take into account - you will have to make a judgment there for me - the Chernobyl and Three Mile Island accidents. Are you saying that they could not, or they have not?

Mr Speed - I am talking in the context of quantifying probabilities. There are certainly remarks made about Chernobyl. They say: 'An accident like Chernobyl could not happen because that was uncontained and these naval reactors are all supposed to have very strong containments'. There are some remarks, but that is a different thing from changing their fundamental approach to the issue which, as I said, was ultimately assessing the risks by multiplying the probabilities by the consequences. What went into these probabilities and what went into the consequences has not been revealed and there is no evidence that that has been revised. There are just these remarks. Essentially there is very little quantification in that AAEC document. There are remarks that things are incredible, that things will not happen because the designs are different and so on. But that is not what I call a reappraisal of the way you are doing things. It is just a few more caveats, a few qualifications.

Senator AULICH - Let us go on from that to assume, first of all, that there are a lot of factors that cannot be quantified and that you cannot do a type of sum which inevitably gives you almost the total basis on which you make a decision about contingency planning or whatever. What about the question of, say, the movement of naval vessels in a particular harbour? Just for my own information, can you tell me how that can be quantified as increasing the probabilities of certain types of accident occurring - for example, a breach of containment and so on. How do you put those types of factors into a probability exercise? What are the mathematics and the methodology of doing that in the first place? Are all the known methodologies that you know likely to be satisfactory at the end of the day? Are they likely to be able to give us a better picture on which we could base advice, take advice or accept the advice that has been given to us?

Mr Speed - Let us deal with the last question first: I think any analysis that you have, no matter how doubtful or how suspect, is bound to be useful if it is the best possible way of dealing with the problem honestly and competently, admitting that there are inadequacies in data and inadequacies in methodology. Of course, there are a lot of analyses about the movements of ships in contained areas. For example, after the bridge went down in Hobart, statisticians were called in to look at movements of ships and how likely it was that a drifting ship would run into the bridge or something else. There are such calculations for very busy harbours. They are nothing like the hard statistical calculations that one is used to where there is a lot of data, because although you have lots of data on the movement of ships, you do not have a lot of data on things like near misses - how often they come close. This would be much the same as looking at aeroplanes coming in and out of busy airports. The sort of statistical analyses that get done there are not wholly satisfactory but they occasionally give insight into weak points in, say, the management of the operation. You can perhaps simulate and find that if you obey the rules, you might find yourself with half a dozen ships in an area where there should be only three or four. There are ways of getting insight into the situation. I do not think what you will get out of it, though, are the probabilities that tell you that the risk is vanishingly small, negligible, that sort of thing, which is often what people are looking for at the end of these calculations. My view of the value of these calculations is that they give you greater insight into the situation you are dealing with. The bottom line figures are the things that are very, very suspect. It can be done and it is done from time to time. It is obviously very specific to what you are talking about. You do not get bottom line figures, but I think it is worth doing.

Senator AULICH - In other words, from a management viewpoint, the probability of an accident occurring if everyone follows the rules can be worked out. You can say that if everyone is doing the right thing in a particular harbour, the chances are that if these rules are put into operation and people follow them, there is hardly a chance of an accident occurring, particularly one in which there might be a breach of containment. You can put that aside and say that that is a good management tool and it has been very useful; it may give us an idea of probabilities and it will certainly enable us to take management action which could reduce the probability of an accident occurring. I am trained in the humanities, so I have a certain view about science. One of those views is that human stupidity at some time or another will raise its ugly head at times, and has done throughout history, no matter how often we train ourselves to avoid it.

Senator BOSWELL - That is Murphy's law.

Senator AULICH - What do you do about that in your probability calculations? Let us say you just talk in terms of management planning for a particular harbour in Australia which will enable you to reduce firstly, the possibility of an accident and secondly, the possibility of an accident bad enough to have a breach of containment.

Mr Speed - I think you have answered it. What can you do about things you have not thought of - new, inspired pieces of human stupidity that have been left out and have never appeared before? There is obviously nothing you can do. You may get some insight into that by looking at statistical data world-wide and averaging over differences that are going to occur between your harbour, New York harbour, San Francisco harbour or London port. Ignore these for the moment and try to separate the extent of the human stupidity from, say, a loss of power or loss of steering - things that are a little more predictable. Let me say, just as a side comment, that most of the serious accidents in the nuclear business are caused by human stupidity, not by pipes failing and things like that. So you can build up a picture of how frequent those are, as opposed to what you might call the random sort that are occuring because of machine failure, failure of hardware items and so on.

Senator AULICH - You will not get a probability analysis but, from looking at past history of nuclear reactors, for example, you get a picture of when or how often human stupidity raises its head. Of course, you leave aside terrorism, deliberate sabotage, temporary insanity on the part of those who may well be in control of particular important functions in an operation, and so on. You cannot include any of those in the total risk management operation. You may reduce it by having certain rules. Am I correct in thinking that that is part of any calculation you do, that by having certain rules which would tend to push people in the right behavioural direction and you may reduce risks?

Mr Speed - That is all that anybody can do, running. You train people. You hope to have procedures which are safe. Even assuming they are, these odd things still happen, do they not, because things occur for which the procedures have not been laid down in the manual? So the operator does something. He takes a candle, goes and looks behind the switchboard and sets fire to it, and out go the cooling system and the emergency cooling system. That is a genuine accident started by a bloke with a candle. At the time, analyses did not involve fire-initiated accidents; so, from now on they do. You learn from this sort of thing but you cannot rule it out and you cannot quantify the chance that it will happen in the future.

Senator AULICH - It would be very dangerous for us as a committee, for example, to look at the mathematical probability side of things almost totally and assume that that covers all known contingencies which may affect the nature of the accident, the possibility of accidents or the frequency of such accidents. Is that what you are saying?

Mr Speed - Certainly, but I might add that nobody is asking me to do that. That is clearly not the thrust of the Atomic Energy Commission's submission and I hope it is not apparent that it is the thrust of mine. There is a big difference between going through a process of taking your reactor apart, conceptually, and looking at all the sorts of things that might happen, trying to assign some sort of likelihood to them and learning a lot in the process, and doing it all, getting some figures at the end and basing your conclusions on the figures. I think it is the process that is the important thing, not the quantification at the end. That would apply equally to ship movements in ports, possibilities of collisions and so on.

ACTING CHAIRMAN - You are aware that some years ago there was a major explosion of an ammunition ship in Halifax harbour, carrying high explosives, and it took up half the town and so on. You also are aware that in most ports of the world there are, of course, high explosive ammunition warships in port. What conclusions do you draw from the Halifax situation, which was of major consequence? Should all ammunition ships be banned from harbours or is this an extreme case? From then on, of course, I have no doubt magazines were much safer and much more secure. Here is a classic case for you, one that would have been of a magnitude of destructibility that you could conceive in a nuclear reactor type of situation, since you are not going to get a nuclear explosion but you are going to get radiation problems.

Mr Speed - I have views as a private individual about these sorts of things. I do not know that a statistician does have views on those things. Obviously we are in a position to advise, say, planners if there are reasonable bodies of data about the frequency of accidents of different kinds, and we might relate that to the distance between where the accident occurs and where the population is located. As far as transforming that into, say, planning or safety considerations is concerned, that is essentially a political exercise which trades off certain obvious things. All I would urge is that it is not done with some sort of spurious quantification at the beginning but that all the information that is available has been honestly and openly used.

Obviously we have factories, explosives, magazines, and so on situated nearer people than we might like. I think the Army is moving from St Marys now. That has been regarded as a problem and I have actually been asked to help calculate the probability of that doing something - it is almost impossible. Nothing has happened so far, but it is obviously better to have that sort of thing a long way away from people than close to them. Transforming the best and most well-intentioned technical device into planning and safety is essentially a political exercise, I think. It is not something that I have any special expertise on.

ACTING CHAIRMAN - We should look at all the possible accidents that can happen with a nuclear reactor, examine them, and----

Mr Speed - I would think so. Rather than rule out this uncontained one, I would think you ought to ask what might happen if it occurs in the likely spot that the vessels might be berthed. If that is something you can live with once----

ACTING CHAIRMAN - What you are saying is that we should look at the worst possible situation, which would be a major meltdown and fracture of the containment vessel.

Mr Speed - I am reluctant to go down this worst possible route. I think you need to know as many of the possibilities that seem reasonable, because most of the time the worst possible is so awful that you will not do anything. It is not a more sensible basis, I believe, than say, this maximum credible idea, because at some stage there will be tradeoffs. If the worst possible is so disastrous that we are never going to live in buildings more than three feet tall or something then it has not helped us much in planning has it?

ACTING CHAIRMAN - Are you saying then that we take some kind of a mean between the reference accident that we have now and the worst possible and move in that direction?

Mr Speed - I am reluctant to summarise. I think you should have the information available to you and know that if you make such and such contingency plans the worst possible will tax your plans to the utmost. On the other hand just planning for this so-called reference accident, and there is something which might be slightly less probable - bearing in mind that the calculation for its probability is probably very, very rough - but it is considerably worse. It may be that you ought to know about that.

ACTING CHAIRMAN - What is the significance of the observed frequency of reactor accidents when compared to the calculated probabilities from probabilistic risk assessments? That is, what is the degree of difference between the observed and the calculated probabilities? Does the high quality control of material used in naval reactors have any significance, particularly when taking an approach using statistics from land-based reactors to assess the safety of the naval ones? Does the history of reactor operations suggest the main problem with PRAs is that they lead to an unrealistic estimate of probabilities, that the approach used has not anticipated the accidents that have taken place, or that they lead to uncertainties about the consequences of accidents? I am sorry, that is a very long question.

Mr Speed - Fortunately I have a copy of it somewhere here. Otherwise I would have to ask you to repeat it. I think the first matter you mention about relating the calculated risks to observed risks is one of the serious problems. There is not enough data to confirm or deny, if you like, these calculated risks, so that one has to look at the basis of them and say 'Do I believe them or not? Are they credible, well-intentioned, accurate, plausible calculations?' because, it might sound crazy, but you can come up with a small figure like one in 10,000. Then there is Chernobyl; surely that will revise your one in 10,000, but it does not revise it very much. One in 10,000 means you could wait 10,000 years for one; if they are occurring randomly, the horrifying fact is that they are just as likely to occur tomorrow as in 10,000 years. It has happened, so we do not suddenly double everything or multiply by some enormous number. The fact that the Chernobyl accident occurred about three months after the Minister for Power in the Ukraine said that it had a probability of one in 10,000 of melting down, made me suspect their calculations. When it occurs so early in the lifetime, as it were, you do wonder.

ACTING CHAIRMAN - Was he wrong?

Mr Speed - That is one of the imponderables. I would think that that is clear evidence that the Russians are barking up the same wrong tree as we are, that they have fallen for this trick of thinking that they can quantify things. Of course, what actually happened in Chernobyl was left out of their calculation. It is not a question that anybody can answer in any definitive way. I think you have to go back and say that one criticised the calculated risks on internal grounds, not on the grounds that they are incompatible with observed risks because we are talking about such a low probability that it would take eons to get enough data to distinguish. The second part of your question was about the high quality of material in naval reactors. Of course, I see that as part of the general push for safety. By the way, one hopes that high quality materials are used in civilian reactors because I know some people who live close by them.

I just put that in the category of general engineering activity - you hope that people are using the best materials and are not taking short cuts, that they are making decisions consciously or unconsciously about the need for quality in certain areas that they are not cost-cutting, that they are not deliberately falsifying, and so on. Obviously, that is probably more likely to occur in the Navy but I have no real evidence to back that up. One would like to think, I suppose, that somehow military expenditure, apart from the one per cent cut which has just occurred, is somewhat less constrained than, say, the private enterprise expenditure. I would like to think that the military has more stringent requirements for safety, but that is still only saying that they are operating in the mode that one would like to think all engineers operate.

ACTING CHAIRMAN - Except that you are dealing with something slightly different from a land reactor, are you not? In the Navy the primary aim is to keep that vessel intact under virtually any kind of circumstance you can think about, so surely one would predicate from that that safety rules are continuously infinitely greater in their minds than would be the case for a land reactor.

Mr Speed - One would hope so.

ACTING CHAIRMAN - That would be the essence of planning, would it not?

Mr Speed - Am I being unreasonably reluctant in just saying that I would hope so? I do not have any evidence to the contrary.

ACTING CHAIRMAN - We know, for example, that a Leopard tank is built with tracks on it and we know why that is so. Similarly, we know that a naval vessel is built to survive particular categories. It is not just a hope - one knows that steps are obviously taken. Could we say that it would be a reasonable assumption?

Mr Speed - Yes. Certainly reactors are sitting on fault lines in America so one hopes that they are built to withstand seven or eight on the Richter Scale. We are told they have been