CHAPTER 7

ASSESSING THE VALIDITY OF THE REFERENCE ACCIDENT

INTRODUCTION

7.1 The concept of the reference accident was explained in chapter 2.[1] It was noted that current planning is based on the premise that the worst accident that needs to be planned for is a contained core meltdown. The design and significance of containment was discussed in chapter 4.[2] In particular it was explained that a 'contained' accident may not be totally contained, but may involve slow leakage to the atmosphere.

7.2 In chapter 3 it was explained that the principal point made by those submissions opposed to the adequacy of current contingency planning was that the reference accident should be an uncontained rather than a contained core meltdown.[3] Some of the technical matters relevant to this and related issues were addressed in chapter 4. The remaining matters are considered in this chapter.

7.3 The Committee did not consider that it had the resources to carry out a full-scale risk assessment of its own. Instead, it critically reviewed the adequacy of the assessment carried out by the Australian Nuclear Science and Technology Organisation (ANSTO)[4] for the Department of Defence in the early 1970's. The

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1. See para. 2.17.
2. See paras. 4.20-4.23 and 4.63-4.78.
3. See paras. 3.16-3.17
4. As already noted, ANSTO is the successor to the Australian Atomic Energy Commission, which provided the original assessment. For simplicity, 'ANSTO' is used throughout.

method ANSTO used to assess the risk and derive the reference accident was outlined in chapter 2.[5] It was described in some detail in ANSTO's submission.[6] This description follows closely the wording of the relevant paragraphs of the 1974 environmental impact report on nuclear powered warship visits.[7]

7.4 The view of ANSTO and the Department of Defence is, as already noted, that an uncontained accident is so unlikely that it is not appropriate for the purposes of contingency planning. This conclusion is entitled to some weight simply because it is the conclusion of those in Australia having the most information and the greatest expertise on the subject and being based on a detailed examination of the issues.[8] But clearly the conclusion acquires greater weight, to the extent that the assessment that led to it is available for critical public examination.[9]

ANSTO'S ASSESSMENT

Need to Revise the Original Assessment?

7.5 Before reviewing the assessment in some detail both as to accident likelihood and accident consequences, it is helpful to deal with the argument that the assessment is out of date. A number of submissions suggested that, even if it was adequate at the time it was done, it is no longer so due to the increased knowledge of reactor accident risks gained in the last 15

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5. See para. 2.17.
6. Submission from ANSTO, Attachment 1, pp. 1-11 (Evidence, pp. 247-57).
7. Department of Defence, The Environmental Impact of Visits by Nuclear Powered Warships to Australia, (July 1974), paras. 35-79.
8. Note that AIRAC has not attempted to assess the likelihood of an accident, but has focused on assessing the consequences were an accident to occur: Evidence, p. 742 (AIRAC).
9. cf. submission from Mr R. Bolt, p. 9 (Evidence, p. 959), where the ANSTO assessment, as presented in the 1976 Environmental Considerations report, is criticised for not disclosing the sources and methods upon which its conclusions rest.

years.[10]

7.6 Little in the way of detailed argument was provided. Rather there seemed to be a general assumption that scientific developments since 1974 had in some unspecified way invalidated the original work. It was suggested that, as a result of the accidents at Three Mile Island and Chernobyl, experts were now more pessimistic about reactor safety than in the early 1970's.[11] It followed on this view that the original ANSTO assessment should be revised to take into account this alleged increase in the perceived risk.

7.7 The Committee put this view to ANSTO. The response was twofold. First, there had been no major scientific developments that would cause the revision of the original assessment. In particular, ANSTO stated that their assessment leading to the adoption of the current reference accident was not invalidated by their study of the 1979 reactor accident at Three Mile Island.[12]

7.8 Second, there had been developments which would allow refinement of some of the calculations that led to the assessment, but these would not invalidate the overall result. Regarding these calculations, Mr Donald McCulloch of ANSTO told the Committee:

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10. e.g. see the submissions from Mr K. G. Blake, p. 4; State School Teachers' Union of WA (Inc.), p. 1.
11. e.g. see the submission from Mr R. Bolt, p. 7 (Evidence, p. 957); and Evidence, p. 582 (Prof W. J. Davis). It should be noted that it is difficult to find evidence that any perception of increased risk that there may have been about civil reactors following the Three Mile Island accident also extended to naval reactor safety: e.g. see para. 4.134 above. Moreover the expert (as opposed to popular) view is by no means unanimous that there has been any major increase in the assessment of risk regarding civil reactors: e.g. see US, Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987), p. ES-6: current risk estimates show no particular trend when compared with those from previous risk analyses, except that the estimates from the 1975 Reactor Safety Study often appear to be near the higher-risk end of the currently accepted range of estimates.
12. Evidence, pp. 433.448, 1268-69 (ANSTO).

> My judgment is that were they now undertaken it might be possible, while still remaining conservative and being certain one's results were remaining conservative, to perhaps make less conservative assumptions regarding some of the parameters which were used in the analysis.[13]

7.9 As a result of ANSTO'S present view, the Committee considered it appropriate to evaluate the assessment made in 1974.

ANSTO's Methodology

7.10 ANSTO's method of assessment was the orthodox one of estimating the likelihood of a range of reactor accidents. The possibility of reactivity accidents, start-up faults, loss of power supplies, and fuel handling accidents were considered and found to be low or non-existent. The maximum credible accident was considered to be a loss of coolant accident. Confidential information available to ANSTO led it to conclude that the containment design catered for this accident, and only slow leakage to the atmosphere would result from it. 'Any release into the atmosphere beyond that associated with this accident must involve either coincidental failure or sub-standard performance of the containment.'[14]

7.11 Ways in which either of these might occur were then examined in some detail. Scenarios considered were ship collision, pressure vessel failure, deterioration of containment in service (including the possibility of violation of operating procedures), shock waves within the containment from sources such as hydrogen explosions, flying debris within the containment, and melt-through by molten fuel. ANSTO explained why it thought each of these was either not possible or was of sufficiently low probability that it could be discounted.

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13. Evidence, p. 371 (ANSTO). See Evidence, pp. 443.48 and 1300.01, where ANSTO note aspects of their assessment on which revision could be done. See also the 'Revised Accident Model' discussed below, para. 7.17.
14. Submission from ANSTO, Attachment 1, p. 4 (Evidence, p. 250).

7.12 In comparing contained to uncontained accidents, ANSTO used the concept of mean annual severity. This is a measure of the amount in Curies per reactor per year of iodine-131 that would be released in a defined accident. It is obtained by multiplying the accident likelihood (measured in accidents per reactor year) by the accident consequences (measured in Curies of iodine-131 that would be released from that accident).

7.13 The mean annual severity of the current reference accident was calculated by ANSTO to be less than 0.1 Curies of iodine-131 per reactor per year.[15] The mean annual severity of one type of uncontained accident, a massive pressure vessel failure leading to simultaneous breach of containment, was calculated as 0.01 Curies of iodine-131 per reactor per year.[16] This is one-tenth the mean annual severity for the reference accident. The greater consequences of the uncontained accident

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15. Submission from ANSTO, Attachment 1, p. 4, (Evidence, p. 250). The result was derived from the amount of iodine-131 expected to be released in the first 12 hours following an accident (1000 Curies), multiplied by the likelihood of a contained accident (1 in 10,000 reactor years). The figures are the same as those used by the British authorities in relation to a contained submarine reactor accident: UK, Parliamentary Debates (Commons), 6th series, vol. 112, Written Answers, 20 March 1987, cols. 634-35 (Evidence, p. 1300.19). ANSTO also supplied figures for the iodine-131 release that are based on more conservative (ie. safety-oriented) assumptions (see Evidence, p. 443.449). On this basis, releases are estimated of 1875 Ci of I-131 in the first 12 hours following the reference accident, and of a similar amount in the following 12 hours. Recalculation of the mean annual severity using this 24-hour total gives likelihood (1 : 10,000) x consequences (3750 Ci) = 0.375 Ci of I-131 per reactor per year.

16. Submission from ANSTO, Attachment 1, p. 8 (Evidence, p. 254). The likelihood is put at 1 : 10,000,000 per reactor year, and the consequences at 100,000 Curies of I-131 released. The figure used by ANSTO for the amount released is the same as that used by the British authorities: see previous footnote. The British authorities, however, put the likelihood of an uncontained accident at 1 in 1,000,000 reactor years. ANSTO did not use this figure as they regarded it as including considerations that are only relevant during visits to homeports/dockyards, where reactor repairs and maintenance may be carried out, containment breached, etc. ANSTO derived the figure of 1 in 10,000,000 from its consideration of what would be required to cause gross containment failure during a visit to an Australian port, when reactor repairs, etc are not permitted: see ibid., especially p. 8 (Evidence, p. 254).

are outweighed by its lesser likelihood, giving a lower overall figure.

7.14 ANSTO did not claim to have quantified the likelihood of all the possible contained or uncontained accidents. Numerical mean annual severity calculations were made for only two uncontained accident scenarios.[17] In other cases quantitative calculations were replaced by qualitative assessments of the unquantified factors. Nonetheless its conclusions were the same for other uncontained accident possibilities: their mean annual severity would always be less that that of the current reference accident.[18]

Conservatism of the Assessment

7.15 Throughout its assessment ANSTO made conservative (ie. pessimistic or risk enlarging) assumptions about safety where it considered reliable estimates could not be made. Overlapping with this were other conservative assumptions. It was assumed that there would be no operator intervention to minimise an accident sequence once it commenced, and that failures would, if they occurred, be total.[19] For example, any serious failure of the coolant circuit was assumed to lead to a core meltdown.[20] Particular points of conservatism identified by ANSTO relating to accident consequences were that the reference accident assumes:

- a much higher fraction of the fission product inventory available for release from the reactor compartment than experience would indicate is probable;
- unfavourably stable atmospheric conditions [ie. minimal wind] for dispersion of the release; and
- impracticably long duration (12 hours) of

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17. See the submission from ANSTO, Attachment 1, p. 8 (pressure vessel failure causing containment breach) and p. 9 (LOCA and violation of containment integrity by operator breach of procedure) (Evidence, pp. 254 and 255).
18. Submission from ANSTO, Addendum, p. 1 (Evidence, p. 379).
19. Evidence, pp. 742-43 (AIRAC).
20. Evidence, p. 1272 (ANSTO).

unchanged wind direction into the most populated sector from commencement time of release.

Together, these conservative assumptions, which are extremely unlikely in practice all to occur simultaneously and in conjunction with the reactor accident itself, mean that the consequences estimated for this reference accident are in general scale (but not necessarily in detail) likely to be closer to those which might arise from an uncontained, rather than a contained, loss of coolant accident.[21]

A More Realistic Assessment?

7.16 The Australian Ionising Radiation Advisory Council (AIRAC) noted the conservatism of ANSTO's assessment and thought it 'desirable to have a more realistic assessment'.[22] At AIRAC's request ANSTO produced such an assessment. The Committee requested and was provided with a copy of this. ANSTO described the assessment as a 'Revised Accident Model'.[23]

7.17 The main differences between the current reference accident and the revised model are as follows:

- the amount of iodine-131 it is assumed would be released

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21. Submission from ANSTO, Addendum, p. 2 (Evidence, p. 380).
22. Evidence, p. 743 (AIRAC). In this context 'more realistic' meant in effect a less serious accident: Evidence, pp. 1275-76 (ANSTO). In New Zealand, a reference accident was developed in the 1970's which is broadly similar to that devised by the Australian authorities: see NZ, Atomic Energy Committee, New Zealand Code or Nuclear Powered Shipping, (AEC500, 1981 edn.), paras. 5.2 - 5.5. It appears that this has since been reassessed. See A. C. McEwan, 'Health Physics Aspects of Nuclear Issues in New Zealand over the Last Decade', Australasian Physical & Engineering Sciences in Medicine, April-June 1986, vol. 9(2), p. 79:

    A more recent assessment suggests that the AEC500 reference accident is an unlikely outcome for a core meltdown event. It is more probable secondary containment would reduce the airborne release of volatiles to much smaller values.

23. ANSTO, 'Visits by Nuclear Powered Warships: Revised Accident Model' (June 1986). The complete document is reproduced in Evidence, pp. 1300.23-31. It explains the revisions made and documents the reasons for each change.

has been reduced from 25% of the total present in the reactor to 2.5%. This reduction is based on studies done since the 1979 Three Mile Island accident of proportions that would be released following accidents.[24]

- the allowance made for the other radioiodines that would be released is reduced from 2.0 times the iodine-131 dose to 1.4 times. This reduction is based on criteria put forward by the Medical Research Council in the United Kingdom.

- a reduction in the containment leakage rate from 1.5% per day constant to 1% initially, reducing in a linear fashion by a factor of 10 over the 24-hour period. The reduction is based on an assumption that the containment will not leak more rapidly that its design specification permits. Credit is also taken for the reduction over time in containment pressure (ie. the pressure that forces the radioactive material out of the containment).

- a reduction in radiation doses received of 2-3 times due to use of a different airborne dispersion model. A model recommended in 1982 by the United States Nuclear Regulatory Commission has been used instead of the model used in the calculation of the current reference accident.

7.18 The description of the revised accident model included graphs showing the reduction in consequences. ANSTO noted:

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24. As an indication that the revised accident model nonetheless retains very conservative (ie. safety-óriented) assumptions, ANSTO noted that studies indicate that pre-Three Mile Island estimates of the release of iodine-131 are overestimates by a factor of 10 to 1,000: ANSTO, 'Visits by Nuclear Powered Warships: Revised Accident Model', (June 1986), para. 4 (Evidence, p. 1300.24). ANSTO adopted the lowest end of this range in its revised accident model, reducing iodine-131 release by only a factor of 10.

> Individual thyroid doses at the perimeter of Emergency Planning Zone 1 (600m) are reduced by a factor 70 for the revised accident relative to the reference accident, and whole body doses by a factor 7.5. Collective thyroid dose would be reduced by a factor 70 for the revised accident relative to the reference accident.[25]

7.19 The Committee considered what regard it should have to the revised accident model, compared to the current reference accident. The Committee noted that neither AIRAC (who asked for the revised model) nor ANSTO (who produced it) had advised the Committee that current plans should be altered to take into account the revised accident model.[26]

7.20 The revised accident model appeared to the Committee to be based on a combination of two factors: an intention to use less safety-oriented (ie. less conservative) parameters, and the results of improved scientific knowledge since the 1974 assessment was done. At least to the extent that it is based on the latter, it could be argued that the revised accident model should replace the current reference accident.

7.21 The Committee considers that the current reference accident can continue to be used. It saw no need to investigate the revised accident model in order to determine if it should be used instead. The Committee's conclusion rests on two grounds. One related to the use of any reference accident for overall risk assessment and for berth assessment; the other related to its use as a basis for detailed contingency planning.

7.22 First, with regard to overall risk assessment and berth assessment, the Committee took the view that, for the purposes of its inquiry, it did not matter if the reference accident was over-cautious. For example, the effect of this on berth assess-

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25. ANSTO, 'Visits by Nuclear Powered Warships: Revised Accident Model', (June 1986), para. 16 (Evidence, p. 1300.27).
26. cf. Evidence, p. 1276 (ANSTO).

ment is that berths that might be assessed as safe using the revised accident model might not be approved if the current reference accident is used. But this apparently causes no practical difficulties, given the number of berths that are or could be approved under the current reference accident.

7.23 The second of the Committee's reasons relates to the model's possible use as a basis for detailed planning. For this purpose, the choice of an unnecessarily safety-oriented reference accident may have detrimental consequences should an accident occur. It was in this context that AIRAC raised the issue of the appropriateness of the current reference accident.[27]

7.24 The concern is that the detail of planning for the more serious accident (the current reference accident) may lead to incorrect or less than optimal responses should a less serious accident (e.g. the revised accident model) occur. For example, use of the current reference accident results in an emphasis in post-accident monitoring on the detection of radioiodines. The revised accident model gives a far smaller role to radioiodines. Planning based on this model might require a different focus in post-accident monitoring.

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27. Evidence, p. 743 (AIRAC).

7.25 The Committee recognised the validity of the concern.[28] The Committee considered, however, that the concern could be met by ensuring that the detail of planning was sufficiently flexible to cope with both the reference accident and with less serious accidents, such as the revised accident model. In general terms, the current planning is flexible in this regard.[29] Particular aspects are indicated in the discussion of the details of planning.[30]

EVALUATION OF ANSTO'S ASSESSMENT

Logical Probabilities

7.26 As a matter of logic an uncontained reactor core accident has to be considered less likely than a contained one.[31]

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28. The issue extends more widely than a choice between the current reference accident and the revised accident model. With regard to land-based reactors it has been suggested that it is inappropriate to base the detail of accident contingency planning on a single reference accident. See for example, US, Report of the President's Commission on the Accident at Three Mile Island, The Need for Change: The Legacy of TMI, (Washington, 1979), Recommendation F(2)(a):

    No single plan based on a fixed set of distances and a fixed set of responses can be adequate. Planning should involve the identification of several different kinds of accidents with different possible radiation consequences. For each such scenario, there should be clearly identified criteria for the appropriate responses at various distances ... .

    cf. International Atomic Energy Agency, Planning for Off-Site Response to Radiation Accidents in Nuclear Facilities, (Safety Series No. 55, IAEA, Vienna, 1981), para. 2.03:

    emergency planning should be based upon the technical assessment of the potential consequences, time-factors, and release characteristics of various classes of accidents with different possible radiation consequences.
29. Evidence, pp. 1300.47-48 (Department of Defence).
30. See paras. 8.42, 8.127 and 8.136-8.137.
31. Evidence, p. 662 (Dr T. P. Speed); p. 1269-70 (ANSTO). Contrast the submission from People for Nuclear Disarmament, p. 3 (Evidence, p. 1305), where it is claimed that what is in effect an uncontained accident is 'a much more likely scenario'. When a representative of the group appeared before the Committee he did not support the view in the submission: (Evidence, p. 1325).

If the core accident is independent of the containment breach then two independent events have to occur together to produce an uncontained core accident. It is more plausible that the accident and the breach are related. But even so the occurrence of the two events together is less likely. Not all events that might breach the containment (e.g. ship collisions) will invariably cause an accident to the reactor core. Equally, not all accidents that might occur to the core will necessarily cause a breach of containment (e.g. the 1979 Three Mile Island core meltdown accident).

7.27 But this logical point means little unless some indication can be given of how much less likely an uncontained core accident is than a contained one. In paragraph 3.28 it was noted that the British Government has given the relevant figures for its nuclear powered submarine reactors. These indicate that an uncontained accident is one hundred times less likely than the 1 : 10,000 per reactor year chance of a contained accident. The Committee put this ratio of the likelihood of contained versus uncontained accidents to ANSTO. In response, ANSTO said it regarded the British 1 : 100 ratio as a believable figure for naval reactors.[32]

7.28 ANSTO also made clear the fact that it had not independently verified the figure, nor had it seen the British documentation setting out the process which led to the figure. The Committee was no better placed. Therefore the Committee thought it prudent not to place too great a reliance on the British figure as such.

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32. Evidence, pp. 1270-71. The question was put and answered in general terms. In footnote 16 in this chapter it is noted that figures giving a ratio of the liklihood of a contained to an uncontained reactor accident of 1 : 1000 are used by ANSTO in relation to an Australian port visit. Because no reactor repairs necessitating breach of containment are permitted during these visits, ANSTO regards the likelihood of an uncontained accident as lower than during a visit to a homeport/dockyard, where such repairs may occur.

Views in Submissions

7.29 No submission provided detailed justification for regarding an uncontained accident as sufficiently probable to warrant using it as the reference accident. This was no doubt in part due to the limited information in the public domain on the design and operation of naval reactors. In addition, none of the authors of these submissions claimed any expertise in naval reactor design.

7.30 A further handicap was the fact that there has never been a core accident that breached containment in either a commercial power reactor[33] or a western naval reactor. There are no precedents to serve as guides. Because there has never been an accident involving core damage to a western naval reactor, naval reactor containment has never been tested by an accident.

7.31 While all these factors are understandable, the effect of the submissions was to leave the Committee with little more than vague suggestions as to how serious accidents were likely to happen and why containment was likely to prove ineffective. There was no measure of agreement in the submissions opposed to the current reference accident as the basis of planning on what scenario or scenarios would lead to an uncontained accident. One view put in submissions was that those making submissions were entitled to assume lack of effective containment. It was for those who advocated planning based on a contained accident to show that containment existed and would be effective.[34]

7.32 The arguments in submissions relating to the perceived flimsiness of containment on warships and other design features were considered in chapter 4. The conclusions reached were that

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33. The reactor involved in the 1986 accident at Chernobyl lacked a complete containment structure.
34. e.g see supplementary submission from Prof W. J. Davis, p. 2 (Evidence, p. 617.002); submission from the Australian Quaker Peace Committee, p. 2.

there were no technical reasons for regarding the containment for United States and British warship reactors as any less adequate for naval-size reactors than the larger containment is for correspondingly larger land-based reactors.

7.33 No submission or witness appearing before the Committee provided information which explicitly challenged any part of ANSTO's assessment in any detail. Nor were any plausible accident scenarios identified that ANSTO had entirely omitted to consider. Instead the Committee was presented with general statements that one or more of the scenarios considered by ANSTO was a likely route to an uncontained accident. For example, Senator Vallentine provided to the Committee a comment made to her by Dr Richard Webb:

> I am very much interested in the official claims (as you stated them) that the core could even suffer melting and still cause no danger to the public. Off hand; I think such claims are mere words, which cannot possibly be supported by experiments, as full scale reactor destructive experiments would be needed to establish just what would really happen in an accident.[35]

7.34 Since full-scale destructive testing is never likely to be done, proof is never going to be available to this standard.[36] Similarly, no amount of expert opinion obtained by the Committee would prove convincing according to this standard.

7.35 Another approach taken in submissions was to give little regard to technical considerations and instead simply say that human error would be the cause of the uncontained accident. Speaking at a sufficient level of generality, it is no doubt true

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35. Letter from Dr R. E. Webb to Senator J. Vallentine, 29 April 1988, p. 2. The wording as read to the Committee by Senator Vallentine and appearing in Evidence at p. 1218 differs in some respects from that of the original letter.

36. cf. 'Sandia puts the pressure on containments', Nuclear Engineering International, March 1987, p. 26, which describes tests using scale models to test containment integrity for commercial reactors.

to say that human error is the cause of many accidents. But no precise suggestions were made on how human error would turn a contained accident into an uncontained one.[37] It is possible to speculate on how human error might lead to a meltdown. But it is far less easy to see how, a meltdown having occurred, human error could then cause the containment to fail, unless the error occurred at the containment design, manufacture or inspection stage.

7.36 A further possibility is that the human error impacts on the accident frequency, not on the containment failure directly. For example, assume containment failure occurs in, say, one in ten core accidents. Assume further that risk assessors do not give due weight to human error as a cause of accidents, and this leads to an under-estimation of core accident likelihood by a factor of ten. On these arbitrarily chosen figures, the result is that the likelihood of the uncontained core accident would be the same as the original (erroneous) estimate for the contained core accident. If it was originally accepted that planning was required for the latter, it follows that, on the corrected estimate, planning should now be required for the uncontained accident.

7.37 This argument was not put explicitly in any submission.[38] Clearly it is equally applicable to any core accident cause that has been under-estimated, not just human error. Equally, its persuasiveness depends on the closeness of the ratio of the likelihood of uncontained to contained accidents. If the ratio is large (say 1 : 1,000) then a large under-estimation of core accidents is necessary to enable the likelihood of the uncontained accident to approach the original assessment for the contained accident. Assuming adequate assessment (a matter considered below), a large under-estimation is less likely than a small one. The naval reactor safety record to date also gives no support to any suggestion that a large (or

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37. cf. Evidence, pp. 392-93 (ANSTO): low probability of operator action having this effect should the reference accident occur.
38. cf. submission from Mr R. Bolt, p. 10 (Evidence, p. 960), where the point was made in a somewhat different context.

indeed any) under-estimation is likely.

Completeness

7.38 The Committee noted the expert view that it is impossible to guarantee absolutely that all relevant factors have been taken into consideration in a reactor risk assessment.[39] The Committee asked ANSTO if it was confident that its assessment was accurate in the sense that all relevant factors had been given appropriate weight. ANSTO responded:

> If we had not been satisfied on the basis of our judgments and experience that this was likely to be the case, we would not have provided this advice to the Department of Defence in the first place.[40]

MATTERS RELATING TO ACCIDENT LIKELIHOOD

Introduction

7.39 It is convenient in considering further points relating to ANSTO's assessment to separate accident likelihood from accident consequences. As a check on the completeness of the factors considered by ANSTO that might lead to a significant accident the Committee compared ANSTO's assessment with the types

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39. e.g. UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987), para. 28.86:

    It was generally agreed that there could be no guarantee that all relevant initiating faults and accident sequences would be identified in an accident probability analysis.

40. Evidence, p. 376 (ANSTO). See also Evidence, p. 391 (ANSTO):

    Any probabilistic assessment of reliability must contain a factor of engineering judgment, which depends on the experience and ability of the people who are making the assessment. That is always true, but ... in general, a large number of factors come into play in arriving at an overall figure for reliability and it is unlikely that an error in any one of them will produce a significant influence on the final result.

of scenarios evaluated in risk assessments relating to commercial reactors.

7.40 The Committee acknowledges that such a comparison can provide no more than a partial check due to the differences between commercial and naval reactors. The object of the comparison was twofold. Primarily it was to determine if what were regarded as plausible accident scenarios for commercial reactors had been considered in the ANSTO assessment. Secondly, these other assessments provided an occasional means of spot-checking the ANSTO assessment on points of detail.

7.41 To take the latter point first, where comparison was possible the ANSTO assessment seemed to be consistent as to method and compatible as to results. For example, the evaluation of the possibility of coolant pipe breaks in the Sizewell B report proceeds on similar lines and comes to broadly similar conclusions to the ANSTO assessment.[41] The assessment by ANSTO of the possibility of pressure vessel failure is compatible with other studies.[42]

7.42 The comparison in order to determine if ANSTO had omitted any plausible scenarios revealed that the depth and sophistication of examination given to particular scenarios varied considerably. This was true not only as between the ANSTO

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41. UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987), paras. 28.29–28.48. cf. submission from ANSTO, Attachment 1, pp. 3–4 (Evidence, pp. 249–50).

42. e.g. 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. 5.3.2.4; NZ, Atomic Energy Committee, New Zealand Code for Nuclear Powered Shipping, (AEC500, 1981 edn.), para. 5.6. See also J. G. Waddington and A. Wright, 'Safety Criteria for a Canadian Nuclear Icebreaker' 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. 360.

assessment and others but also amongst other assessments.[43]

7.43 However, the comparison did not disclose any broad omissions of scenarios which the Committee regarded as having major significance. For example, the Sizewell B report identified four principal ways in which events inside the containment might lead to containment failure.[44] None of these has been omitted from consideration in the ANSTO assessment.[45] The focus by ANSTO on a loss of coolant as the key element conforms with the focus in other studies.[46]

7.44 Without attempting to canvass all the scenarios that ANSTO considered or could have considered, the Committee makes the following selective comments on some of them.

Fire or Weapon Accidents

7.45 The ANSTO assessment did not address the risk of a

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43. The major assessments of land-based reactors used as points of reference were US, Nuclear Regulatory Commission, Reactor Safety Study: An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants, (WASH-1400, NRC, Washington, 1975); US, Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987); and UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987). The 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) was also useful. The safety assessments in relation to nuclear powered merchant ships that are summarised or discussed 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) were also useful.
44. UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987), para. 29.15.
45. Submission from ANSTO, Attachment 1, pp. 4-11 (Evidence, pp. 250-57).
46. e.g. 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. S28:

    the accidents that are expected to lead to the possibility of an appreciable source term (i.e., those in which a substantial amount and wide variety of types of radioactive material are released to the environment) are all postulated to involve a system failure that results in loss of water from the primary system.

reactor accident due to the warship catching fire. However the risk of radioactive release from a warship fire appears to be very low.[47] The ANSTO assessment also did not consider the risk of a reactor accident resulting from a weapon accident. This risk was raised with ANSTO by the Committee. The Committee was told that the presence of weapons would not increase the risk of reactor failure.[48] It appears that this conclusion is based on the assumption that the weapons are in safe storage during visits.[49]

Sabotage and Terrorism

7.46 Other risks not addressed by ANSTO in the material supplied to the Committee were those of sabotage or terrorism.[50] These have been addressed by Australian authorities, but the

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47. See para. 5.38 for references to fires that have occurred on nuclear powered warships. See also Australia, Environmental Considerations of Visits of Nuclear Powered Warships to Australia, (May 1976), para. 37 (Evidence, p. 133):

> Fires could not result in damage to the reactor of sufficient severity to cause release of radioactivity unless they occurred within the reactor compartment. Such damage is not credible because of:
> a. the lack of combustible material in these areas to support a fire of the necessary intensity; and
> b. the elaborate measures, both structural and procedural, taken to prevent the outbreak and spread of fire in warships.

See similarly NZ, Atomic Energy Committee, New Zealand Code for Nuclear Powered Shipping, (AEC500, 1981 edn.), para. 5.8. For nuclear powered merchant ships, see UK, Department of Industry, Second Report on the Nuclear Ship Study, (HMSO, London, 1975), para. 100:

> it is considered that the greatly reduced use of oil fuel in machinery spaces and the nature of reactor containment give confidence that present fire protection and extinguishing systems could ensure an appropriate standard of fire safety.

48. Evidence, pp. 425-27 (ANSTO). See also NZ, Atomic Energy Committee, New Zealand Code for Nuclear Powered Shipping, (AEC500, 1981 edn.), para. 5.9.
49. The safety features relating to weapon storage are discussed in paras. 11.71-11.81.
50. cf. submissions from Mr R. Addison, p. 6; Greenpeace Australia (NSW) Ltd, p. 29; Esperance Nuclear Awareness, p. 1; Milton-Ulladulla People for Peace, p. 3; Assoc Prof P. Jennings, p. 1; Scientists Against Nuclear Arms (Tas), p. 6 (Evidence, p. 825); Medical Association for the Prevention of War (NSW), p. 3.

conclusions remain classified.[51] As far as the Committee was able to discover, there have been no reports of either incidents of significant sabotage[52] or of terrorist actions relating to nuclear powered warships. ANSTO did consider the possibility of a crew member compromising containment integrity by unauthorised opening of airlocks. The possibility was regarded as small,[53] but was evaluated from the point of view of an accident rather than intentional sabotage.

7.47 Quantitative risk assessments relating to land-based reactors have not considered the possibility of sabotage in any detail because, as the 1975 Reactor Safety Study noted:

> no convincing way could be found to estimate the probability of acts of sabotage directed at any target. However, the study believes that nuclear power plants would be difficult to sabotage in the sense of creating an

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51. One of the deletions on security grounds from the copy supplied to the Committee of the Department of Defence's, The Environmental Impact of Visits by Nuclear Powered Warships to Australia, (July 1974) is that of paras. 80 and 81 dealing with (it appears) terrorism and sabotage.
52. This is not to say that there have not been incidents relating to the nuclear reactor, but which have not caused or threatened to cause any radiation hazard. See for example 'Ship's Nuclear Plant Forced to Shut Down', Washington Post, 3 March 1986, p. D2: disgruntled sailor stopped cooling pump without permission, forcing the shutdown of one of the two reactors on the USS Bainbridge. The press report notes the incident caused no danger to any equipment and no safety problem. It also implies that this type of incident had occurred previously. See also Rear Admiral E. J. Carroll jr (USN Ret.), 'Nuclear Trojan Horse', New York Times, 8 August 1983, p. A17: 'Sabotage occurs even on United States warships'; Department of Defence, The Environmental Impact of Visits by Nuclear Powered Warships to Australia, (July 1974), para. 34(f): 'One case of minor sabotage in a nuclear warship undergoing maintenance in a US Dockyard has been reported but no cases are known involving an operational warship in a US or foreign port'.
53. Submission from ANSTO, Attachment 1, p. 9 (Evidence, p. 255). cf. US, Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987), p. 1-6, with respect to commercial reactors:

    > Because of the experience gained in U. S. plant operation and existing regulatory requirements and industry practices, it is believed that the likelihood of severe core damage caused by the intentional violation of procedures is small.

accident with large public consequences ...[54]

7.48 In other words, while unlikely, it is conceivable that a saboteur could initiate a reactor accident by, say, causing a ship collision or shutting off the reactor coolant pumps. But the accidents that would result from collisions and coolant pump failures have been taken into account in the general risk assessment.[55] To this limited extent the risk of sabotage is not a separate head of risk.

7.49 The question of a terrorist attack relating to nuclear weapons is considered in chapter 13. The Committee has no reason to consider the risk of terrorist action relating to a naval reactor any greater than that with respect to a nuclear weapon. If anything, reactors are perhaps a less inviting target because they lack the symbolism of nuclear weapons.

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54. US, Nuclear Regulatory Commission, Reactor Safety Study: An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants, (WASH-1400, NRC, Washington, 1975), section 1.9. See also 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. S51; UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987), para. 28.85 ('It was common ground that the probabilities of accidents caused or aggrivated by war or sabotage could not usefully be estimated.'); Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987), p. 2-1:

> The risk of sabotage has not been included in the results of this report. It is the staff's opinion that the likelihood of a specific threat is very dependent on the changing political and social climate. The applicability of historical data pertaining to a threat of sabotage to a nuclear plant in the future is less obvious than for hardware data or information on human error probabilities.

55. cf. 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. S51: '... the accident scenario after initiation [by sabotage] could conceivably (and probably would) resemble some of those which have already been analyzed in PRA's, given the large number of scenarios with multiple system failures that have been investigated'.

Hydrogen or Steam Explosions

7.50 A number of submissions referred to the possibility of hydrogen or steam explosions, either generally or as matters on which the 1974 assessment might have been rendered suspect by later scientific developments.[56] It was not clear to the Committee why submissions took this view: inappropriate comparisons to the Three Mile Island and Chernobyl accidents appear to have been a factor.[57] Nonetheless, the Committee put the possibilities to ANSTO, even though they had been to some extent addressed in ANSTO's original submission.[58] The response was:

> The primary containment design specification allows for internal pressures due ... to the hydrogen which might be generated by metal-water reactions under accident conditions. Specific reference to design allowance for steam explosions has not been located. However, the conditions under which such an explosion might conceivably occur are closely analogous to those necessary for

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56. e.g. submissions from Prof W. J. Davis, pp. 14-15 (Evidence, pp. 461-62; Mr R. Addison, p. 6; Medical Association for the Prevention of War (Vic), p. 2. See also Evidence, p. 617 (Prof W. J. Davis).
57. A summary of experiments on these issues in the commercial reactor context done at Sandia National Laboratories in the US quotes a researcher:

    > We've defined a safety threat that appears to be more likely than the classic China Syndrome scenario of molten core melting through the basement. That threat is the interaction of <u>structural concrete</u> and molten core debris following a LOCA and the subsequent generation of heat and explosive hydrogen.

    'Sandia puts the pressure on containments', <u>Nuclear Engineering International</u>, March 1987, p. 28 (Dr J. Walker, emphasis added). This scenario cannot occur in naval reactors due to the absence of structural concrete. The same source also states:

    > We now believe that steam explosions are more likely to occur than we thought several years ago. However, the conditions required to produce a steam explosion with sufficient energy to fail containment may be more difficult to achieve than was originally thought.

    See similarly APS Study Group, 'Report to the American Physical Society of the study group on radionuclide release from severe accidents at nuclear power plants', <u>Reviews of Modern Physics</u>, July 1985, vol. 53(3)(part II), p. S98: likelihood of steam explosion large enough to fail containment considered by most investigators to be much smaller than assumed in 1975 <u>Reactor Safety Study</u> and regarded as impossible by a few. Again the context is commercial, not naval, reactors.
58. Submission from ANSTO, Attachment 1, p. 10 (Evidence, p. 256).

> hydrogen/air/steam explosions [considered in the original submission] ... It is reasonable to expect that, as for the hydrogen/air/steam explosion, any steam explosion could only occur within the reactor vessel. Similar attenuation mechanisms for the resulting shockwaves would therefore apply, and provide the same measure of protection for the integrity of the primary containment.[59]

7.51 The Committee acknowledges that a degree of scientific uncertainty exists with respect to hydrogen and steam explosions in reactors following core accidents. The Committee regards ANSTO's assessment of the likelihood of these types of explosions breaching containment as being consistent with what it understands to be the predominant scientific view.[60]

Melt Through to the Sea

7.52 A number of submissions put to the Committee the possibility that, following an accident leading to core meltdown, the molten core would melt its way through the bottom of the

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59. Evidence, p. 443.462 (ANSTO).
60. cf. US, H of R, Committee on Science and Technology, Subcommittee on Energy Research and Production, Nuclear Powerplant Safety Systems - Hearings, 24 May 1979, p. 1071 (Admiral H. G. Rickover): a hydrogen explosion was not a credible threat in the Three Mile Island context. Note also the following exchange (pp. 1071-72):

> Mr Anthony: Going back to your own personal operation [ie. the US Naval Nuclear Propulsion Program], what has been the naval experience with a hydrogen bubble that would create the possibility of a hydrogen gas explosion?
> Admiral Rickover: We have never had anything like it. The next question would be what if we did? That is a good question. I can anticipate that but our system is such that the hydrogen would not have formed. That is the way we operate.
> Mr Anthony: You feel that your safety and your training would have been such that you would not have had the water contamination that apparently is existing at Three Mile Island?
> Admiral Rickover: Yes, sir; I do firmly feel that. ...

The Admiral then elaborates on the basis for his confidence.

pressure vessel and the containment into the sea.[61] One concern is the contamination that this would cause.[62] Another is that when the molten core comes into contact with the sea water a large steam explosion might result.[63]

7.53 Senator Vallentine told the Committee that, according to a 1973 United States Navy reactor disaster control plan, the 'Navy found that the melt-down could go right down through the ship spilling hot radioactive materials to the bottom of the harbour ...'.[64] When the Committee tried to obtain a copy of the plan, it became clear that Senator Vallentine had not seen the plan she purported to quote from. She in fact was quoting from a booklet authored by a New York peace activist.[65] It would seem that this author had not seen the plan either but was relying on an account in a Honolulu newspaper.[66] The journalist who wrote this account did not purport to have seen the plan, but had interviewed one of its authors. The statement about the melt through is not presented in this account as part of the plan, but as the view of the interviewee, a former shift supervisor in the radiological controls section at Pearl Harbour naval base. The knowledge of reactor design possessed by the interviewee is not stated. The Committee did not regard it as prudent to rely on this source.

7.54 ANSTO informed the Committee that they had examined the

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61. Submission from People for Nuclear Disarmament, p. 3 (Evidence, p. p. 1305). See also Evidence, p. 1330 (People for Nuclear Disarmament). Dr R. Webb raised the possibility of melt-through in a letter to Senator J. Vallentine (Evidence, p. 1362), although, as he stated that he did not know if US naval reactors had containment (Evidence, p. 1361), he is presumably not in a position to reach worthwhile conclusions on the possibility.
62. Submission from Mr R. Addison, p. 6.
63. Submissions from Albany Peace Group, p. 3; Senator J. Vallentine, p. 6 (Evidence, p. 1049). See also Evidence, pp. 1219-20 (Senator J. Vallentine).
64. Evidence, p. 1217 (Senator J. Vallentine).
65. S. A. Sahaydachny, Nuclear Trojan Horse: The Navy's Plan to Base Nuclear Weapons in New York Harbor, (Riverside Church Disarmament Program, New York, 1985), p. 46 (Evidence, p. 1185).
66. Honolulu Star-Bulletin, 18 June 1979, p. A2, 'Pearl Harbor's Nuclear Sub Risks Discussed'.

possibility of a breach of containment by molten fuel. On the basis that there would be insufficient decay heat available in a submarine's reactor, it had 'concluded that melt-through of the hull will not occur'.[67]

7.55 The Committee notes that ANSTO's conclusion with respect to submarines is consistent with the position for nuclear powered merchant ships.[68] However, for surface ship reactors, where the containment is not in direct contact with the sea, the hull forms an additional barrier.[69] The analysis leading to ANSTO's conclusion is conservative in that it makes no allowance for counter-measures (e.g. flooding the reactor compartment) during the time it would take the molten core to melt through.

7.56 The Committee did not understand ANSTO to be claiming that melt-through was physically impossible. Determination of this would require detailed knowledge of, among other things, the structure of the pressure vessel and the hull, and whatever else lay between the hull and the bottom of the pressure vessel.

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67. Submission from ANSTO, Attachment 1, p. 11 (Evidence, p. 257).

68. e.g. W. Vinck and others, 'Technical Safety Problems in Nuclear Naval Propulsion as Related to Port Entry Conditions' in International Atomic Energy Agency and others, Proceedings of the Symposium on Nuclear Ships, Hamburg, 10-15 May 1971, (GKSS, Hamburg, 1971), p. 145, with reference to marine reactors up to 100 Mw(t) in power:

> the after heat in the molten masses of fuel and cladding would probably not be such as to jeopardize integrity of the pressure vessel and subsequently of the containment.

Direct comparisons between naval and land-based reactors on this point are not valid. But it is worth noting that concern about melt-thorough on the latter (the 'China syndrome') only became a major concern as reactor size increased. e.g. 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. 26-27:

> In early power reactors the power level was about one tenth that of today's large reactors. It was thought that core melting in those low power reactors would not lead to melt-through of the containment. Further, since the decay heat was low enough to be readily transferred through the steel containment walls to the outside atmosphere, it could not overpressurize and fail the containment. ... However, as reactors grew larger, ... it became likely that a molten core could melt through the thick concrete containment base into the ground.

69. Submission from ANSTO, Attachment 1, p. 11 (Evidence, p. 257).

Variables such as the recent operating history of the reactor and the time since it was shut down would also have to be considered. If worst-case assumptions are made on all points on which firm information is lacking, the possibility of melt-through cannot be shown to be impossible under all conceivable circumstances.

7.57 It is important, however, to keep this conclusion in perspective. First, the conclusion that the scenario cannot be shown to be impossible is based on the limited information available. If more comprehensive information was available the conclusion might alter. Therefore, it should not be taken for granted that melt-through is physically possible.

7.58 Secondly, the scenario is based on a series of unlikely events.[70] There must be a melt down. No effective countermeasures against melt-through are taken either at the design stage or following the accident. The vessel has been running at or near full power for some time immediately prior to, or at the time of, the accident. The likelihood of these events coming together is logically less likely that of a melt down alone. It is because of this that ANSTO concludes that, for practical purposes, the overall scenario can be discounted.

7.59 The Committee finds no reason to differ from this conclusion. The Committee explained in paragraph 3.14 that it does not accept that planning is required for all physically possible accidents, irrespective of their likelihood.

Human Error

7.60 The fact that a number of submissions relied partly or wholly on human error as an accident cause has already been noted. The Committee asked ANSTO the extent to which it had considered the possibilities of human error in making its

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70. See the submission from ANSTO, Attachment 1, p. 11 (Evidence, p. 257) where some of the improbabilities are noted.

assessment. ANSTO told the Committee that it lacked relevant information on the detailed design and operating procedures of naval reactors. It had made a judgment that the incidence of errors with naval reactors was unlikely to be higher than that with commercial reactors.[71]

7.61 In evaluating this judgment, the Committee had regard to the attention paid in the United States Naval Nuclear Propulsion Program to training of reactor operators, to development of safe operating procedures, and to designing reactors so as to minimise the scope for operator error.[72] In the light of this attention, the Committee considered ANSTO's judgment to be reasonable.[73]

7.62 On the basis of its judgment, ANSTO considers that 'a reasonable allowance has been made for human operating errors' in arriving at its reference accident.[74] The Committee did not understand ANSTO to be claiming to have done more than this. Overseas reactor risk assessments relating to land-based reactors have not made allowance for human error with any precision, and

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71. Evidence, p. 375 (ANSTO).

72. On these see paras. 4.115-4.120 and 4.138-4.140. See also UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987), para. 47.44:

> I considered two main indicators of the adequacy of the CEGB's [the electricity board's] case on human factors: first, the Board's managerial arrangements for recruiting, training and providing instructions for operators, and second, whether human factors had been properly integrated with the engineering design.

73. cf. Evidence, p. 834 (Scientists Against Nuclear Arms): three factors identified as contributing to human error are ignorance, apathy, and institutional blindness. It would seem from the material referred to in chapter 4 on the training, etc of US naval reactor operators and the regard for safety that each of these three factors would have minimal effect on Navy reactor safety, compared to, say, civil reactors.

74. Evidence, p. 391 (ANSTO).

probably cannot do so.[75]

7.63 Human error may lead to marine risks such as collision, which in turn lead to reactor risks. One study identified 14 causes of error in merchant marine safety. The majority related to factors such as fatigue, excessive alcohol use, boredom, and a high level of calculated risk.[76] It seems reasonable to assume that these factors would be present to a lesser degree on a warship than the average merchant ship. The fact that alcohol is not permitted on United States warships supports this assumption.[77]

Collisions

7.64 The ANSTO assessment included the possibility of a reactor accident resulting from a collision involving the warship.[78] It was considered that a collision of sufficient

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75. e.g. see J. N. O'Brien and C. M. Spettell, Uses of Human Reliability Analysis Probabilistic Risk Assessment Results to Resolve Personnel Performance Issues that Could Affect Safety, (NUREG/CR-4103, Brookhaven National Laboratory for the Nuclear Regulatory Commission, October 1985), p. 5: 'To date, the human risk component in safety system reliability has been analyzed in only a peripheral manner in PRAs, even though 40 to 50% of all system failures are reported to involve human error'. See also UK, Department of Energy, Sizewell B Public Inquiry: Report of Sir Frank Layfield, (HMSO, London, 1987), para. 47.43: it was common ground during the inquiry that human error is difficult to model adequately in accident probability analysis.
76. US, National Research Council, Human Error in Merchant Marine Safety, (June 1976) discussed in J. Deck, 'Application of Risk Assessment to Nuclear Merchant Ship Safety' 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. 67.
77. Contrast Evidence, p. 1201 (Senator J. Vallentine): concern regarding intoxicated crew members returning from shore leave.
78. Submission from ANSTO, Attachment 1, pp. 5-6 (Evidence, pp. 251-52); Evidence, pp. 396-97 (ANSTO). cf. D. J. Morris and R. Strong, 'A Role for Probabilistic Methods in Nuclear Ship Safety' 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. 195: a sample calculation 'indicates that, without collision protection, a release of fission products due to collision is 10 times more likely than a release caused by a major spontaneous primary circuit leak. Similar probabilities arise for grounding ...'. The calculations relate to merchant ships.

severity to damage a reactor was unlikely in ports, where speed limits are low.[79] The Australian Department of Defence described as a 'virtual impossibility' the likelihood of reactor damage following a low-speed collision.[80] The Committee, noting that the Department lacked detailed design information on nuclear powered warships, asked it to explain the basis of its view.

7.65 The Department replied:

> The judgement about the consequences of a ship collision involving an NPW is based on the Defence Department's very considerable expertise in warship design and construction, and ship engineering in general. Further, it has long been known that marine reactor compartments for the US Navy are designed and constructed to particularly high standards of strength and integrity. ... the reactor plant containment and shielding required to minimize radiation outside of the reactor also provide strong protection for the reactor plant from external impact. We can be confident of that fact without having access to NPW design specifications.[81]

The Committee noted that the absence of reactor damage in the numerous collisions involving nuclear powered warships tends to confirm that reactors are robust enough to survive substantial collision impacts without damage.[82]

7.66 ANSTO regarded the risk from collision as higher in port approaches, where speeds are greater than in ports. Its assessment considered that this risk could be reduced to an acceptable level by the imposition of navigational controls. The adequacy of

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79. Contrast the submission from Mr R. Bolt, p. 8 (Evidence, p. 958), where collision with a wharf while docking is given as a possible cause of a reactor accident.
80. Second supplementary submission from the Department of Defence, p. 19 (Evidence, p. 238.274).
81. Evidence, p. 1300.52 (Department of Defence). The Department noted that ANSTO, in making its original assessment of the effect of collisions, 'possessed significant information on the design of NPWs from confidential sources': ibid.
82. See the references to collisions in para. 5.38.

the controls currently imposed[83] is discussed in paragraphs 8.16-8.21.

7.67 The assessment noted that a collision of sufficient severity to breach a submarine's reactor would almost certainly sink the submarine. A similar conclusion is also made in the context of British plans.[84] The sinking would release radionuclides from the damaged reactor core to the sea rather than the atmosphere. This form of release presents a much lower risk to population.[85]

7.68 The Committee noted that sophisticated attempts have been made to assess the risk of reactor damage from a collision involving a nuclear powered merchant ship.[86] The Committee found it beyond its resources to attempt any detailed quantitative assessment of the collision risk for nuclear powered warships visiting Australia.

7.69 The basic data on vessel collisions in Australian ports are not centrally held and are not in uniform format. Collisions involving small vessels would need to be excluded from the data base, as these would not be relevant to the severity of impact needed to damage a reactor. Judgments would have to be made as to

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83. OPSMAN 1 (2nd edn.), para. 201(c)-(d), (Evidence, p. 49).
84. UK, Ministry of Defence, Liverpool Special Safety Scheme for Visits to Liverpool by Nuclear Powered Submarines, (April 1986), para. 13.
85. Submission from ANSTO, Attachment 1, p. 5 (Evidence, p. 251). See also J. B. Montgomery and C. R. Jordan, 'Impact of Nuclear-Related Safety Requirements on the Design of Merchant Ships' in Organization 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. 377: 'If a nuclear vessel sinks, the immediate danger from radiation is eliminated. Water is a good shielding material'.
86. e.g. see V. U. Minorsky and others, 'Ship Accident Studies' 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. 95-101. The Safety Assessment for the NS Savannah concluded conservatively that the risk of collision with enough energy to breach both containment and the primary circuit was 7 in 100,000 during one year of continuous operation: cited in D. W. Crancher, 'Problems Faced by Host Nations in Accepting Visits by Nuclear Powered Merchant Ships' in ibid., p. 497.

which collisions were serious enough to warrant inclusion in the data base. Allowance would have to be made for the navigational controls imposed during nuclear powered warship visits, and for differing traffic volumes and geography at different ports. Additionally, the higher levels on warships of manning, training, equipment (such as radar), and manoeuvrability compared to most merchant ships would have to be taken into account.

7.70 Despite the absence of any quantitative assessment of the collision risk, the Committee could see no reason to regard the ANSTO assessment of this risk as inappropriate.

Grounding

7.71 The ANSTO assessment did not address the possibility of a ship running aground, although other studies have.[87] In the extreme case, grounding may lead to the total wreck of the ship. Short of this the main hazard is the loss of condenser cooling water supply if the tide ebbs and leaves the intake above sea level. Not all ports visited have a sufficient tidal range to make this probable. If it occurs, cooling water can be provided from a pump aboard another vessel without difficulty.[88]

Assessment Applicable to All Visiting Warship Types?

7.72 The Committee noted that much of the recent work on reactor risk assessment has pointed out the need to focus on specific designs. In other words, it is not satisfactory to evaluate one or two designs within the same generic type and then

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87. e.g. see V. U. Minorsky and others, 'Ship Accident Studies' and H. A. Agena, 'Effects of Ship Casualties on Reactor Safety and Marine Reactor Design' both 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), pp. 92-95 and 133 respectively. The studies relate to merchant ships.
88. See UK, Ministry of Defence, Liverpool Special Safety Scheme for the Visits to Liverpool by Nuclear Powered Submarines, (April 1986), Annex 2B, para. 3.

apply the results across all reactors of the type.[89]

7.73 The Committee put this point to ANSTO with respect to its assessment. ANSTO responded by saying that its assessment had been conservatively derived to cover the generic class of naval reactors: 'It is not likely that any ship visiting an Australian port would not be covered by that assessment'.[90]

7.74 The Committee lacked the detailed design information necessary to confirm this. However, it notes both the relatively high degree of similarity between the reactors aboard visiting warships,[91] and the degree to which conservatism has been built into the ANSTO assessment.[92] ANSTO's view appeared reasonable in the light of these factors.

Conclusions on Accident Likelihood

7.75 The Committee accepts ANSTO's view that the likelihood of a contained accident is remote. The Committee is not able to attach any precise figure to the likelihood. This is both because all the necessary information is not available to it and because it does not consider precise calculations to be possible in assessing the likelihood of such rare and complex events. The Committee, however, has not identified any basis for considering the British figure of no greater than 1 : 10,000 reactor years to

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89. This is a theme of US, Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987). See also 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. S11-12: in the 1975 Reactor Safety Study, the risk of the chain of events that occurred in the 1979 Three Mile Island accident was calculated by reference to a Westinghouse PWR reactor at the Surry power station to have a probability of 1 in 100,000 years. Had the same assessment methodology been applied to the Babcock and Wilcox PWR reactor at Three Mile Island it would have predicted a frequency of occurrence of once in 300 years.
90. Evidence, p. 1274 (ANSTO).
91. See para. 4.137 on the higher degree of standardisation amongst naval reactors compared to civil reactors.
92. See above, para. 7.15.

be anything other than a conservative estimate.

7.76 For reasons discussed earlier in this chapter, an uncontained accident is logically less likely than a contained accident. Again the Committee is not in a position to quantify how much less likely. But all the information available to it relating to naval reactor containment and possible scenarios by which that containment might be breached to permit a large airborne release of radioactivity suggests that an uncontained accident is much less likely again than an already unlikely contained accident.

MATTERS RELATING TO ACCIDENT CONSEQUENCES

Introduction

7.77 As already indicated, ANSTO accepted that uncontained accidents would have greater consequences than the current reference accident. However, it considered that the difference would not be as great as one might suspect, due to the very conservative assumptions it had made on the consequences of the reference accident. Moreover, the likelihood of uncontained accidents was much less than the already remote likelihood of contained accidents. Taking both these factors into account, the overall risk (the mean annual severity[93]) of an uncontained accident was less in ANSTO's view than that of the contained accident currently used as the reference accident.[94]

7.78 In the previous section the Committee accepted as reasonable ANSTO's evaluation of factors relating to accident likelihood. In view of this, the Committee did not consider it necessary to examine accident consequences in great detail.

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93. See para. 7.12.
94. Submission from ANSTO, Addendum, p. 1 (Evidence, p. 379).

Rather, what the Committee looked for were indications that ANSTO's assessment was incorrect with regard to consequences to the degree necessary to make the overall risk of the uncontained accident exceed that currently estimated for the reference accident.

7.79 ANSTO did not provide a detailed tabulation of the consequences of an uncontained accident in such a way as to enable a simple comparison with the consequences of the current reference accident. A simple comparison may not be all that realistic. Most submissions treated contained and uncontained accidents as distinct, easily-defined categories. Apart from noting that 'contained' does not mean totally contained, the Committee has to this stage of its report adopted a similar approach.

7.80 More realistically, there is a continuous spectrum of possible containment failures in terms of both time and quantity. The containment may fail instantly or only hours after the onset of the accident. The failure may range from a slow leak to a large hole. The method and timing of containment failure is regarded for land-based reactors as critical for the size of accident consequences.[95] For example, late failure or slow leakage allows time for radioactive decay and for deposition of aerosols within the containment and, for a marine reactor, towing the vessel to a remote anchorage. If there is failure with a large hole, the gases would leave in a puff and release much, if not all, of the aerosols suspended in the containment atmosphere.[96]

7.81 In short, it would be necessary to define what is meant

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95. 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. S92-95.

96. ibid., p. S95, which notes that 'large' in this context for commercial land-based reactors means over 10 square metres.

by an uncontained accident before its consequences could be rigorously compared to those of the contained accident defined for the purposes of the current reference accident. For example, Professor Jackson Davis provided the Committee with a sophisticated analysis of accident consequences. This was based on methodology accepted in the United States,[97] and on the assumption that there was no reactor containment.[98] He calculated that 1% of the non-volatiles would be released, compared to ANSTO's assumption of nil release of non-volatiles following its (contained) reference accident.[99]

7.82 ANSTO regarded the 1% figure as credible only if there were to be a complete and instantaneous loss of containment. If this is correct,[100] Professor Davis's figure is not consistent with his own assumptions. He assumes that there is no containment as such but then treats the 'reactor vessel' as 'containment'. As a result, he assumes a slow leakage (4 hours duration) from this reactor vessel/containment to the atmosphere, rather than an instantaneous release.[101]

7.83 This underlines the point that there can be various types of uncontained accidents. Within the category of uncontained accidents, it is very much a conservative or 'worst case' assumption to postulate the absence of even weak containment. It assumes in effect that the reactor is floating on a raft, rather than contained in a warship's hull. Nonetheless,

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97. See the submission from Prof W. J. Davis, pp. 93-122 (Evidence, pp. 540-69) where the methodology used by him is defined in detail.
98. Evidence, pp. 604 and 617.002 (Prof W. J. Davis).
99. Submission from Prof W. J. Davis, p. 60 (Evidence, p. 507); Evidence, p. 443.454 (ANSTO).
100. See para. 7.99, where it is noted that Prof Davis did not seem to challenge ANSTO's view.
101. Submission from Prof W. J. Davis, p. 59 (Evidence, p. 506). The reference to 'reactor vessel' would appear to mean the pressure vessel surrounding the core. But it is conceivable that 'vessel' means 'hull'. If so, some allowance is being made for the fact that the warship's hull would be in some accident scenarios a barrier of sorts to the instantaneous release to the atmosphere from the reactor even if the hull is not designed to be 'containment' in the technical sense.

ANSTO used this conservative assumption as the basis for what comparative data it supplied.

The Source Term

7.84 In order to assess the consequences of an accident involving release to the atmosphere it is necessary to establish the inventory of radioactive materials available to be released. These materials are the fission products formed either by fission, or by the subsequent radioactive decay of the materials formed by fission. The radioactive isotopes so formed are broadly classified into one of three groups: gaseous, volatile, or non-volatile.[102]

7.85 The quantity of each isotope present depends on factors such as the reactor size, fuel used, length of time since refuelling, and the reactor operating conditions. Further factors requiring consideration govern what quantities of which fission products will remain in the fuel elements or the reactor pressure vessel following an accident.

7.86 The quantity of radionuclides available for release to the atmosphere is referred to as the source term. This is obtained by multiplying the fission product inventory by the proportion released. As the United States Nuclear Regulatory Commission has observed:

> The determination of the radioactive source term that would be released following severe accidents is perhaps the most difficult and

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102. e.g. 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. S4. For a more sophisticated method of classification see ibid., p. S15.

uncertain area of risk analysis.[103]

7.87 In evaluating accident consequences it is important to distinguish two possible grounds of criticism. One relates to the degree to which containment would be breached. The other accepts the reference accident leakage rate but argues that the ANSTO assessment of the types of radionuclides released is nonetheless incorrect in some respect. Almost all the arguments made in submissions focused on the first of these grounds: that is they rejected the current reference accident. Because the Committee has accepted the degree of integrity of reactor containment underlying the adoption of the reference accident, it is necessary to deal only with the second ground.

7.88 While simplifying assumptions had to be made about many factors in estimating the source term,[104] ANSTO's assumptions appear conservative. It assumed a substantially greater release from the fuel elements via the pressure vessel than Professor Davis, for example.[105] ANSTO's assessment of the release from the core as far as the containment was in effect a worst case one. For this reason it is not surprising that it was not criticised in those submissions expressing opposition to ANSTO's overall conclusions. There seemed to be only one point of disagreement with ANSTO's assumptions on this matter. This related to the passing from the reactor core to the reactor compartment of non-

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103. US, Nuclear Regulatory Commission, Reactor Risk Reference Document, (NUREG-1150 (draft), NRC, Washington, 1987), p. ES-14. For a survey of the uncertainties involved in assessing source terms and other aspects of land-based reactor accident consequences, together with the assumptions commonly made, see Organisation for Economic Cooperation and Development, Nuclear Energy Agency, International Comparison Study on Reactor Accident Consequence Modeling, (OECD, Paris, 1984).

104. See Evidence, pp. 381-83, 398-400, 443.449, 443.453-54, 443.458-60 for some of the assumptions made by ANSTO. cf. submission from Prof W. J. Davis, 55-61 (Evidence, pp. 502-08) for some of the simplifying assumptions made by him.

105. Evidence, p. 601 (Prof W. J. Davis); p. 443.454 (ANSTO).

volatiles,[106] and is discussed later in this chapter.

Focus on Iodine

7.89 Rather than deal in detail with all the possible types of radionuclides that might be released, ANSTO made simplifying assumptions.[107] It focused principally though not exclusively on the release of radioiodine.[108] In focusing on radioiodine, ANSTO followed accepted regulatory practice, as Professor Davis

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106. The ability of different species of radioactive substances to escape from damaged fuel rods via the pressure vessel and containment to the atmosphere largely depends on their volatility: see for example, 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. S112. See ibid., p. S62 for a description of the ways in which various species of radionuclides are retained within the core and pressure vessel, and thus never reach the containment.

107. Although many hundreds of nuclides are produced in a reactor, many are regarded as not significant in assessing off-site accident consequences because of their relatively small inventory, short half-life, or low radio-biological hazard. See D. J. Alpert and others, 'Relative Importance of Individual Elements to LWR Accident Consequence Estimates Assuming Equal Release Fractions', Nuclear Safety, January 1987, vol. 28(1), p. 78. This article notes that the 1975 Reactor Safety Study considered only 54 radio-nuclides to be of significance. Other studies cited have considered 60. All these studies relate to land-based commercial reactors. cf. ANSTO, Radiation Monitoring Handbook for Visits by Nuclear Powered Warships to Australian Ports, (ANSTO, Lucas Hights, NSW, 1985), para. 6.3 (Evidence, p. 340), which lists 45 radionuclides as being of importance; submission from Prof W. J. Davis, pp. 58-59 (Evidence, pp. 505-06), who lists 52 radionuclides, but then makes the further simplifying assumption that during a port visit radionuclides with half-lives of less than one day can be eliminated from consideration. By further selecting only those radionuclides making the major contribution to health detriment, Professor Davis arrives at a total of 15: ibid., pp. 60-61 (Evidence, pp. 507-08).

108. Evidence, pp. 381-87. See also ANSTO, Radiation Monitoring Handbook for Visits by Nuclear Powered Warships to Australian Ports, (ANSTO, Lucas Heights, NSW, 1985), p. 5 (Evidence, p. 299); para. 7.12 above on the calculation of the mean annual severity.

agreed.[109] Any radioactive iodine released is particularly significant because it is readily retained by the body if inhaled or ingested and concentrates in the thyroid gland.[110]

7.90 The treatment of iodine in ANSTO's assessment can be criticised as being too conservative in the light of present scientific knowledge. ANSTO in 1974 made what were then conservative assumptions about the amounts of iodine-131 available for release to the environment in the event of an accident. In particular, it was assumed that iodine would be released from the fuel and transported as a gas without change of chemical form.

7.91 Following the 1979 accident at Three Mile Island it became apparent that this assumption could lead to a considerable overestimate of iodine release. In contrast to the 0.1%[111] of the total iodine inventory assumed to be released in the reference accident, it is estimated that only 0.00003% of the radioiodine inventory escaped during the Three Mile Island accident.[112]

7.92 It is now widely accepted that pre-Three Mile Island assessments of radioiodine release from accidents at commercial

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109. Evidence, p. 614. See also the submission from the Medical Association for the Prevention of War (Vic), p. 1: of the material in a reactor, 'the most important biologically is radioactive iodine'. cf. 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. S17-18:

> The current studies of the source term have tended to concentrate their attention on iodine, cesium, and to a modest extent tellurium. ...it is apparent that, if released in sufficiently large quantities, some of the relatively low volatility or nonvolatile fission products and actinides might also contribute to consequences.

110. OPSMAN 1 (2nd edn.), para. 120(b) (Evidence, p. 48). See also ANSTO, Radiation Monitoring Handbook for Visits by Nuclear Powered Warships to Australian Ports, (ANSTO, Lucas Heights, NSW, 1985), p. 5 (Evidence, p. 299); Evidence, p. 1018 (ARL/NHMRC).

111. Submission from ANSTO, Addendum, p. 4 (Evidence, p. 382). Note that the figure relates to the leakage to the atmosphere from the containment, not to the release from the core to the containment.

112. Evidence, p. 443.465 (ANSTO).

reactors were greatly over-estimated.[113] ANSTO considers it reasonable to assume that the physico-chemical factors that led to the much lower than predicted iodine-131 release at Three Mile Island would also generally apply in a naval reactor accident.[114] The amount of the iodine release in ANSTO's revised accident model reflects this view, being only one-tenth of the amount allowed for in the current reference accident.[115]

7.93 It seems clear that, by adhering to its 1974 assumptions regarding the release of radioiodine, ANSTO's assessment has become very conservative indeed in this respect. The Committee took into account the need, noted in paragraph 7.25, to make a more realistic assessment for evaluation of some aspects of detailed planning.

Omission of Other Radionuclides

7.94 A few submissions questioned the appropriateness of ignoring some other radionuclides in focusing on iodine.[116]

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113. e.g. see C. Norman, 'Assessing the Effects of a Nuclear Accident', Science, 5 April 1985, vol. 228, p. 31. See ibid., p. 33, where it is noted that the factors that led to a lower than predicted release of radioiodine also apply to fission products such as cesium and tellurium. See also 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. S127.

114. Evidence, p. 433.466 (ANSTO). cf. 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. S127, where three factors are identified as responsible for the lowering of source term estimates since the 1975 Reactor Safety Study: the recognition that containments are stronger than was assumed; the inclusion in the modeling of previously neglected physical and chemical phenomena that lead to the retention of fission products; and allowance for additional mechanisms such as ice beds, suppression pools, and auxiliary buildings. The second of these is by and large applicable to naval reactors. The degree of applicability of the first and third is not clear, in the absence of detailed design information on naval reactors. The only factor identified which might operate to raise source term estimates is the release of radionuclides due to core-concrete interaction: ibid., p. S127. This factor is not present for naval reactors.

115. See para. 7.17 on the revised accident model. In providing this model ANSTO documented the reason for the reduction.

116. e.g. submission from the Albany Peace Group, pp. 1-2.

Professor Davis told the Committee that by ignoring some other radionuclides in the way that it did ANSTO's assessment understated the effect of its reference accident 'by perhaps an order of magnitude or two'.[117]

7.95 The Committee asked ANSTO to comment on this. The response pointed to a number of what ANSTO regarded as defects and errors in the calculations made by Professor Davis.[118] In particular, it said that he had seriously overstated the extent to which non-volatiles would be released following the reference accident.

7.96 In its 1974 assessment ANSTO allowed for the release of 1% of the solid fission products.[119] Professor Davis defined certain types of radionuclides that would be released in much the same way as ANSTO. He then allowed for the release of 1% of 'all other radionuclides' - presumably most or all of which are the non-volatiles.[120]

7.97 ANSTO, however, criticised this assumption by Professor Davis: 'without an instantaneous and complete loss of containment the 1% value assumed by Davis for non-volatiles is too high ...'.[121] The Committee sought clarification from ANSTO on what appeared to be a change in its view since 1974. ANSTO responded by saying that it had in fact changed its view, and that its current view was correct. The basis of the change stemmed from

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117. Evidence, p. 614. See also p. 615.
118. Evidence, pp. 443.457-59, 743, 1277, 1280, 1282.
119. Department of Defence, The Environmental Impact of Visits by Nuclear Powered Warships to Australia, (July 1974), para. 127.
120. Submission from Prof W. J. Davis, pp. 60 and 96 (Evidence, pp. 507 and 543.
121. Evidence, p. 443.454 (ANSTO).

work done as long ago as 1967 in the United States.[122]

7.98 The Committee notes that, even if the original ANSTO assessment was incorrect, it leads to an over-estimation of accident consequences, and therefore does not affect the orientation towards safety built into the calculations leading to the adoption of the reference accident.[123]

7.99 In his response to ANSTO's criticism, Professor Davis apparently abandoned his own criticism of ANSTO premised on the validity of the current reference accident in favour of what had always been his primary argument, viz. that an uncontained accident should be the basis of planning.[124] Accordingly, the Committee did not pursue the point.

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122. Letter from ANSTO, 15 July 1988 (Evidence, p. 1300.01). This letter referred the Committee to F. G. May, Source Term & Behavioural Parameters for the HIFAR Loss of Coolant Accident, (ANSTO, Lucas Heights, NSW, 1987). This paper and the US data underpinning it, however, are based on molten fuel consisting of uranium and aluminium. The fuel cladding in naval reactors is almost certainly an alloy of zirconium, not aluminium. The melting point of zircalloy used in civil reactors is nearly three times that of uranium-aluminium. For this reason the relevance of the paper and data to naval reactors is unclear.

123. On the uncertainty, with respect to land-based reactors, in estimating the size of the release of non-volatiles, see Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Nuclear Accident Source Terms: Report by an NEA Group of Experts, (OECD, Paris, 1986), p. 19:

> The non-volatile fission and activation products are believed to be nearly totally retained in the melt, at least till the time of vessel failure. The experimental release data for these elements are rather limited, so that determination of escape fractions is relatively uncertain but these values are all quite low.

See also Organisation for Economic Cooperation and Development, Nuclear Energy Agency, International Comparison Study on Reactor Accident Consequence Modeling: Summary Report to CSNI by an NEA Group of Experts, (OECD, Paris, 1984), p. 29: in a 'benchmark accident release' developed to reflect the largest releases postulated in accident assessments relating to land-based light water reactors, figures of 0.03% and 0.003% are used for the release fractions of groups of non-volatiles.

124. Evidence, pp. 617.001-04. See especially p. 617.002, where the assumption about the fraction of non-volatiles that would be released is justified by reference to the Chernobyl reactor accident. This was of course an uncontained accident. ANSTO apparently took the view that Prof Davis had abandoned his argument premised on a contained accident: Evidence, p. 1282 (ANSTO).

7.100 The Committee notes that at least one study has cautioned that the effects of some radionuclides have been neglected in assessing possible accident consequences.[125] The Committee put this view to ANSTO. The Committee took the response to mean that ANSTO was using conservative values (in pre-Three Mile Island terms) for radioiodine as an alternative to using realistic values for radioiodine and at the same time including the effect of other significant radionuclides.[126]

7.101 Moreover, some of these radionuclides are of more significance if exposure occurs over a relatively long period of time than to brief exposure. The focus on those whose effects arise from brief exposure is more appropriate in the context of planning the initial post-accident response.[127] The response for other radionuclides, whose significant effects occur only if exposure is over a long period, can be postponed until accurate monitoring has provided guidance on appropriate remedial measures.[128]

7.102 Both these points seem as applicable to an uncontained accident as to a contained one. On this basis, the fact that

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125. 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. S18 and S19.

126. Evidence, pp. 398-99 (ANSTO).

127. Evidence, pp. 400-01 (ANSTO).

128. Evidence, pp. 443.459-60 and 1300.01 (ANSTO). It is important to note that effective countermeasures may avoid the health effects that arise due to long-term exposure. In the submission from Prof W. J. Davis, pp. 74 and 77 (Evidence, pp. 521 and 524) casualties from a reactor accident are calculated using assumptions that there would be no evacuation (or other countermeasures such as vessel removal) during the first day, the first week or the first year after the accident. Also the assumptions for the longest period appear to make no allowance for the effect of weathering on deposited radionuclides, or for the effect of any clean-up operations. The realism of these assumptions, and hence the results obtained by using them, are open to serious question. This would be true even in the context of a health/environmental assessment of the overall effects of an accident. In the context considered by the Committee, the adequacy of contingency planning to respond to an accident, the focus on immediate and short-term effects and necessary countermeasures is appropriate.

Professor Davis considered a wider range of radionuclides than ANSTO[129] loses much of its apparent significance.

Reactor Size Used in ANSTO's Assessment

7.103 The Committee noted that where ANSTO's original assessment relied on specific input figures, the figures often related to British nuclear powered submarines. The reactor on these submarines has a power output of about 40 Mw(t).[130] Yet the ANSTO assessment is used as the basis for allowing port entry to vessels having a reactor size up to 100 Mw(t). The Committee was concerned that any conclusions based on data relating to a 40 Mw(t) reactor might not be valid for reactors up to 100 Mw(t).

7.104 The main impact of the different reactor sizes would be on calculating the size of their respective source terms following an accident. In fact there is no indication that ANSTO's use, in some parts of its assessment, of the smaller reactor size has led to any overall underestimation of the source term. As already noted, a number of factors has to be considered in calculation of a source term, of which reactor size is only one. Assumptions made with respect to other factors, primarily that relating to the operating level at the time of the accident, operate to overstate the source term. The net effect is to give a larger source term than that, for example, calculated by Professor Davis using a 100 Mw(t) reactor as a starting point.[131]

Conclusions on Source Terms

7.105 It was clear to the Committee that any attempt to

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129. Evidence, p. 613 (Prof W. J. Davis).
130. e.g. see Department of Defence, The Environmental Impact of Visits by Nuclear Powered Warships to Australia, (July 1974), para. 21: 'attention in this document has been directed mainly to' 40 Mw(t) reactors; submission from ANSTO, Addendum, p. 3 (Evidence, p. 381): release calculations based on the inventory of 40 Mw(t) reactor. ANSTO made separate calculations for reactors over 100 Mw(t), ie. for Nimitz-class aircraft carrier visits.
131. Evidence, p. 443.453 (ANSTO).

calculate with precision the consequences of a reactor accident involves considerable uncertainties. Highly complex calculations are required and many simplifying assumptions have to be made. ANSTO acknowledged that its 1974 estimates contain elements that are either not logical or could usefully be revised.[132]

7.106 But as far as the Committee can determine, re-estimation using different assumptions or treating particular radionuclides in different ways would not lead to any more pessimistic view of consequences. The ultra-conservative (with respect to present scientific knowledge) assumptions on radioiodine would appear to negate any over-optimistic (ie. risk understating) assumptions that might inadvertently be part of the overall estimation.

Atmospheric Dispersion and Population Exposure

7.107 Once source terms have been calculated the atmospheric dispersion, ground deposition, inhalation by humans, and so forth all have to be calculated in order to determine the ultimate effects of the accident. These calculations are, like source term calculations, complex and require many simplifying assumptions to be made. Submissions did not raise any issues with respect to ANSTO's assessment on these matters.[133] The Committee is aware of no evidence suggesting that this assessment is insufficiently safety-oriented. There is some evidence, however, in the form of the revised accident model to suggest that it is overly safety-oriented.[134]

Allowance for Countermeasures

7.108 The comparison by ANSTO between the consequences of a

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132. e.g. see Evidence, pp. 443.458 and 1300.01 (ANSTO) for the treatment of tellurium; para. 7.17 above for the 'Revised Accident Model'.
133. e.g. see Evidence, p. 613, where Prof Davis agrees that many of the ANSTO assumptions on dispersion are similar to his.
134. See para. 7.17 for the difference in airborne dispersal models used in the current reference accident and the revised accident model.

contained and an uncontained accident made no allowance for countermeasures. In both cases, once the accident occurred the differing estimated amounts of iodine-131 were treated as being free to cause harm. In the view of the Committee, the effect of this is to introduce an extra element of conservatism into the assessment of the reference accident when comparing it with an uncontained accident.

7.109 The occurrence of the contained accident would allow time for the warship to be towed away. Alternatively, or additionally, people could be evacuated or take shelter in the time available. In contrast, a sudden and catastrophic failure of containment immediately following a core meltdown would not permit mitigating actions to be taken in time.[135] On this point a conservatively-assessed reference accident is being compared by ANSTO to a realistically-assessed uncontained accident.

EFFECTS OF POPULATION EXPOSURE.

Introduction

7.110 The international radiological community and national governments set reference levels below which exposure of people to radiation should be kept. Three sets of levels are used: a low level for general population exposure, a higher level for occupational exposure, and, in some countries, a still higher level for exposure during an emergency or accident.[136] While

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135. cf. UK, Ministry of Defence, Liverpool Special Safety Scheme for Visits to Liverpool by Nuclear Powered Submarines, (April 1986), para. 24(c): sheltering is an inappropriate countermeasure following the rapid release of short duration which would follow the postulated uncontained accident. ANSTO pointed out to the Committee (Evidence, p. 1296) that it is unlikely that an uncontained accident would result in a short-duration release, and where it did not, countermeasures would be worthwhile. See also para. 7.80 on the differing types of uncontained accident.

136. Australia, Environmental Considerations of Visits of Nuclear Powered Warships to Australia, (May 1976), pp. 21-22 (Evidence, pp. 138-39).

there is now reasonable agreement on the expected consequences to people of exposure to doses above 10 rad (0.1 Gray), there is substantial uncertainty for very low doses.[137] As a result, internationally or nationally set reference levels are open to revision.

7.111 A potential revision is not relevant to the choice between a contained and uncontained accident. Whatever levels are chosen apply equally to both types of accident and are used to translate the consequences of whatever measure of exposure results into health effects. Revision would, however, be relevant to aspects of current planning. Distances at which particular response measures may be required, and the time within which any response should be taken, are determined in part on the basis of the emergency reference levels.

International Changes to Reference Levels

7.112 The International Commission on Radiological Protection (ICRP) is considered the authoritative international body for recommending reference levels for exposure to radiation. The most recent comprehensive set of ICRP-recommended levels dates from 1977. A process of revision is now underway within the ICRP and the United Nations Scientific Committee on the Effects of Atomic Radiation. This is based on a reassessment of the effect of the 1945 atomic bombings of Hiroshima and Nagasaki.[138] It appears that there will be a reduction in some aspects of the levels. Any new levels recommended by the ICRP are not expected to be issued until 1990.[139] Some national radiation standards have been altered as an interim measure in anticipation of expected ICRP

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137. 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. S15.
138. Evidence, p. 1019 (ARL/NHMRC).
139. Evidence, pp. 1019-20 (ARL/NHMRC).

changes.[140]

7.113 The emergency reference levels used in conjunction with the reference accident were those recommended for general radiation protection purposes in 1973 by the National Health and Medical Research Council (NHMRC).[141] The Committee inquired if there was any need to alter these levels. Dr Keith Lokan of the NHMRC told the Committee that the 1973 levels did deserve to be looked at again and the NHMRC had formed a working party to do this.[142] However, there would be a long process of consultation with the States and others before any changes were recommended.

7.114 The Committee considered if there was any need to alter planning now, in anticipation of any changes that might be made.[143] Mr Donald McCulloch of ANSTO told the Committee that he considered it would be 'a bit presumptuous' to make alterations now, in advance of the expert bodies' conclusions.[144] It was not, in his view, an inevitable conclusion that plans would need to be altered.[145] The Committee agrees with this view.

Exposure As Low As Reasonably Achievable (ALARA)

7.115 An argument was put to the Committee based on the assumption, generally accepted in the interests of being conservative, that there is no threshold dose below which

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140. e.g. for the UK see 'NRPB ups radiation risk estimates', Nuclear Engineering International, January 1988, p. 2. See also Evidence, pp. 1022-23 (ARL/NHMRC) for the position in the Federal Republic of Germany and the United States.

141. Evidence, p. 1017 (ARL/NHMRC). Extracts from the NHMRC's 1973 Recommendations are set out in Evidence, pp. 149-55. The 1977 ICRP recommendations were adopted by the NHMRC in 1980: Evidence, p. 1021 (ARL/NHMRC). But no changes to the reference levels used for planning purposes resulted.

142. Evidence, pp. 1017 and 1018. (ARL/NHMRC).

143. See Evidence, pp. 1023-24 (ARL/NHMRC) for the way in which changes would affect the current contingency plans.

144. Evidence, p. 1294 (ANSTO).

145. The anticipatory changes made in the UK affect general and occupational exposure levels, but not it seems emergency levels.

exposure to radiation is harmless. On this view it is incorrect to say that persons further away from the accident, and thus receiving less than the reference level dose, suffer no harm.[146]

7.116 The ICRP has derived three principles from the assumption that there is no threshold dose. These can be summarised as:

- the need for justification of the practice creating the risk of exposure, that is, no practice involving radiation hazards should be adopted unless it produces a positive net benefit;
- the optimisation of radiation protection, that is, all exposures should be kept as low as reasonably achievable, with economic and social factors being taken into account (the ALARA principle); and
- the limitation of exposure of individuals, that is, taking steps to ensure that doses received do not exceed recommended limits.[147]

7.117 At the risk of over-simplification, the argument is that the focus in current planning has been on the third of these principles. Little regard has been had to the ALARA principle,[148] except perhaps in the indirect sense that there has been a good deal of conservatism (ie. exaggeration of risk) in the analysis leading up to the application of the recommended limits. No formal regard, it is argued, has been paid to the first principle.

7.118 In effect, application of the first principle would

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146. See for example the submission from Scientists Against Nuclear Arms (WA) and Medical Association for the Prevention of War (WA), p. 3 (Evidence, p. 789).
147. See for example Organisation for Economic Cooperation and Development, Nuclear Energy Agency, Implications of Nuclear Safety Requirements for the Protection of Workers in Nuclear Facilities, (OECD, Paris, 1988), p. 10.
148. cf. Evidence, pp. 1021-22 (ARL/NHMRC).

require the Committee to conduct a risk-benefit assessment of the value of the ship visits. The Committee considers that its terms of reference preclude it from doing this.

CONCLUSIONS

7.119 The Committee accepts the overall conclusions of ANSTO's assessment as to both accident likelihood and accident consequences. The Committee has been unable to find any reason to justify the substitution of an uncontained accident for the current contained accident as a reference accident.