SEVENTH REPORT

The Defence Committee has agreed to the following Report:—

DECOMMISSIONING OF NUCLEAR SUBMARINES

Introduction

1. In our 1988 inquiry into the Progress of the *Trident* Programme we considered briefly the decommissioning of nuclear submarines.[1] We learnt that the Ministry of Defence (MoD) expected 10 nuclear powered submarines to be decommissioned by the year 2000,[2] but had formed no clear view of what should be done with them, or, more precisely, with their radioactive reactor compartments, when they came out of service. The Ministry told us that, when the first nuclear submarines had been built, little thought had been given to the problems of decommissioning—

> "The Admiralty decided—God bless it—to go into nuclear propulsion for submarines in the early 1950s . . . There were quite enough problems to contemplate at that time without thinking too much about what on earth we should do with it when we were finished with it."[3]

DREADNOUGHT, the first nuclear submarine to be decommissioned, was berthed at Rosyth apparently waiting for its fate to be decided. In our Report we concluded—

> "We recognise the technical and political difficulties involved. Nevertheless, we hope that there will be progress to report before long, and certainly before our next review of the *Trident* programme."[4]

This progress has not been forthcoming. In March this year the Ministry told us—

> "During the past year, the MoD have continued to consider actively the options for disposing of the reactor compartments from decommissioned nuclear submarines, although the Government have not reached a decision about which option to choose."[5]

We therefore decided to conduct a short inquiry specifically into the decommissioning of nuclear submarines.

2. The aim of this inquiry has been strictly limited. The problem of how to dispose of nuclear submarines after decommissioning is closely tied to the wider issue of radioactive waste management, which is outside our remit. This issue has been the subject of careful examination by the Environment Committee and by a Committee of the House of Lords.[6] We have not taken evidence on the merits, or otherwise, of the various options for disposal of nuclear submarines and for this reason offer no recommendation as to which option should be preferred. The environmental debate is vitally important, but it is outside the scope of this inquiry. **Our intention in this Report has been merely to set out in simple terms the options open to the Ministry of Defence in disposing of nuclear submarines, and the extent of the problem.** To this end we took oral evidence from United Kingdom Nirex Limited (Nirex) and from the Ministry of Defence, and written evidence from MoD, Nirex, the United Kingdom Atomic Energy Authority and Rolls-Royce and Associates Limited. We are grateful to our witnesses for the help that they gave us.

HMS DREADNOUGHT

3. The immediate problem is what to do with DREADNOUGHT. Since decommissioning in 1982, the submarine has been lying at Rosyth Naval Base on the Firth of Forth. Upon decommissioning, the highly radioactive reactor

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[1] See Third Report from the Defence Committee, *The Progress of the Trident Programme*, HC 422 of Session 1987-88, paragraphs 118 and 119, Evidence, pp.33 to 35 and Qq. 89 to 125.
[2] This estimate has now been reduced to 8—see paragraph 19.
[3] HC 422 of Session 1987-88, Q 124.
[4] *ibid.*, paragraph 119.
[5] Evidence, p.1.
[6] See the First Report from the Environment Committee, *Radioactive Waste*, HC 191 of Session 1985-86; and the Nineteenth Report of the House of Lords Select Committee on the European Communities, *Radioactive Waste Management*, HL 99 of Session 1987-88.

core[1] with the uranium fuel was removed and transported to Sellafield.[2] We were told this was a relatively simple procedure, being "half of the routine refuelling operation which takes place in every nuclear submarine's refit."[3] With the reactor core gone, the part of the submarine that remains radioactive is the reactor compartment—that part of the submarine which houses the nuclear steam-raising plant, including the reactor[4]. The reactor compartment weighs approximately 850 tons and forms a cylinder 10 metres in diameter and 8 metres long.[5] It contains a variety of radioactive elements, notably isotopes of cobalt, iron and nickel. A list of the principal radionuclides involved and a graph showing their radioactive decay appear on pages 18 and 19 of our written evidence. For the most part, the radioactivity is the result of activation of metals in the submarine's structure through proximity to the reactor; a small part is the result of products from the fuel cladding being circulated in the cooling water and deposited on the inner surface of the pipework.[6] The remainder of the submarine is not radioactive and may be treated as scrap metal.[7]

4. The compartment contains both intermediate level and low level waste[8]. According to evidence submitted by Rolls-Royce and Associates Ltd. (the designers of the steam-raising plant used in British nuclear submarines), after a decontamination process only the reactor pressure vessel and its surrounding shield tank would have to be treated as intermediate level waste; the rest of the reactor compartment could be treated as low level waste.[9] The UK Atomic Energy Authority told us that, while they had not decommissioned a nuclear submarine, "the task is simpler than that of decommissioning an irradiated fuel reprocessing plant".[10] **It is the size of the reactor compartment, not its level of radioactivity, that makes it hard to deal with.**

5. The presence of DREADNOUGHT at Rosyth has caused some concern in the local community which has been reflected in the local and national press. The MoD assured us that the submarine is monitored for radioactivity approximately once every six months,[11] and that the level of radioactivity is steadily reducing.[12] The latest reading taken from outside of the hull over the reactor compartment recorded 5 microSieverts an hour.[13] This level, we were informed, is "much less" than the radioactivity level of an in-service nuclear submarine.[14] For comparison, the average level of natural radioactivity in Britain amounts to 2,500 microSieverts a year or 0.28 microSieverts per hour. A person spending 5 hours by the hull of DREADNOUGHT would therefore accumulate a dose equal to 1 per cent. of the annual natural radioactive dose. The Assistant Under Secretary of State (Fleet Support) could see no reason why the results of the monitoring process should not be made available to Dunfermline District Council. **We recommend that in future this be done on a regular basis.**

6. Some anxiety has been expressed about the risk involved if DREADNOUGHT rusts through. The rate of rust damage appears not to be an immediate problem. The steel of which the submarine is made is thick enough to resist pressures at great depth and its rust resistance is enhanced by protective paint (last applied in 1982)[15] and a cathodic protection system.[16] The Assistant Under Secretary of State (Fleet Support) told us—

[1] Q.104.
[2] Q.93.
[3] Q.105.
[4] See Figure, p.iv.
[5] See HC 422 of Session 1987-88, Evidence, p.34.
[6] Evidence, p.18, paragraph 4.
[7] Q.107.
[8] Low-level waste contains less than 4×10^9 bq per tonne alpha and 1.2×10^{10} bq per tonne beta-gamma. Intermediate-level waste exceeds these levels but generates insufficient heat to be classed as high-level waste. Intermediate-level waste requires remote handling and shielding; low-level waste does not. For details see, for example, Nirex Report, *The Way Forward*, p.5.
[9] Evidence, p.39.
[10] Evidence, p.34, paragraph 15.
[11] Q.100.
[12] Qq.94 to 96.
[13] Q.86.
[14] Q.98; for details of radiation doses received by in-service submarine personnel, see *Official Report*, 20 March 1989, cols. 477 and 478, and 2 May 1989, cols. 61 and 62.
[15] Q.103.
[16] This consists of heavy zinc anodes electrically connected to the steel hull. The zinc corrodes preferentially protecting the hull.

10. The Norwegian State Institute for Radiological Protection has obtained and analysed air and water samples from the area where the submarine sank. Tests on these samples show no evidence of the leakage of radioactivity from the submarine. Further samples are being collected.

NRPB Report

11. This is attached, together with a covering memorandum from the MoD [Annex below].

US Final Environmental Impact Statement

12. This is being forwarded.*

13. The MoD hopes that the information provided to the Committee will be helpful.

26 April 1989

ANNEX

ASSESSMENT OF THE RADIOLOGICAL IMPACT OF DISPOSAL OF SUBMARINE NUCLEAR STEAM RAISING PLANT: REPORT BY THE NATIONAL RADIOLOGICAL PROTECTION BOARD

Covering Memorandum by the Ministry of Defence

1. The MoD commissioned the NRPB to carry out an assessment of the radiological impact of disposing of decommissioned nuclear submarine reactor compartments and their associated steam raising plant early in 1988. The purpose was to obtain an independent scientific assessment which could be drawn upon by the MoD in support of any application to the appropriate department for authorisation to dispose of DREADNOUGHT at sea. The international instrument governing the dumping of radioactive waste at sea is of course the London Dumping Convention, which requires that consideration be given to the practical availability of alternative land based methods of disposal. The NRPB therefore compared sea-disposal with the two other options under consideration, shallow land burial and deep geological disposal. A report was prepared for the NRPB board which it endorsed in May 1988. The paper attached behind this memorandum is an updated version of that report.

2. The original report contains classified data which is specific to a single submarine. Since it was issued, data have been derived for a generic submarine, enabling the report to be updated and declassified. It therefore adopts the same approach as the US Final Environmental Impact Statement, which published generic data for US submarines. The period of storage assumed for the reactor compartment before cutting-up for encapsulation and deep geologic disposal is somewhat arbitrary. The dose burden to the operatives in such a process is dominated by the hard gamma emission of 60Co; this isotope has a half-life of $5\frac{1}{4}$ years, so 30 years storage would allow that activity to decay by a factor of 40. The assumed storage period might be increased if the dose burden were considered unacceptable, but decreased if developments in robotics technology in the interim allowed a greater degree of remote and shielded cutting; the availability of the National Radioactive Waste Centre ("the Nirex deep site") has also to be considered. The original detailed work relating to a shallow site included both inland and coastal locations, but the initial report dealt only with inland case. The size and weight of the reactor compartments make a coastal site more appropriate as the base line assumption for this option in the updated report.

3. The NRPB report shows that all three disposal options give dose levels to individual members of the public migration (i.e., the transport of radioactivity away from the disposal site) which are well below the relevant limits set by the International Commission on Radiological Protection (ICRP). The findings are in line with other scientific studies. The US Final Environment Impact Statement concluded that "either land or sea burial of nuclear submarine reactor plants would have no significant radiological effect upon man" (1). In 1986, the Department of the Environment published a study which concluded that sea-disposal could be the preferred option for the intermediate level waste produced as a result of decommissioning (2).

*Not printed.

4. The NRPB report does not contain the input data for a generic submarine. The Committee may therefore find it helpful to have a table showing the principal radionuclides involved and the activity levels one year after shutdown, and a graph showing the rate at which the radioactivity level will decay after the plant has been shut down. These are attached at annexes A and B. Over 99 per cent of the activity results from activation of the solid structural components (various steels etc), but the remainder is present as an adherent film of products ("crud") from the fuel cladding which has been circulated in the cooling water and been deposited on the inner surface of the pipework. It is pessimistically assumed that all this "crud" is instantaneously released on sea disposal. Annex C contains an explanation of the units of radioactivity used in the annexes and in the report itself.

5. Finally, it should be noted that although the NRPB report was originally commissioned with sea-disposal in mind, the Government have made no decisions about which disposal option to select, and the data contained in the report could equally be used to support either shallow land burial or deep geologic disposal.

Notes

1. *"Final Environmental Impact Statement of the disposal of decommissioned, defueled naval submarine reactor plants"* published in May 1984 by the US Department of the Navy, volume I p S-15.

2. *"Assessment of Best Practicable Environmental Options (BPEOs) for management of low and intermediate level solid radioactive wastes"*, published by the Department of the Environment in March 1986, pp 3-4.

Plant Active Inventories (Bq)
(1 year after shutdown)

Radionuclide	*In Solid Components*	*In Primary Circuit Corrosion Products*
^{14}C	4.23×10^{11}	0.58×10^{6}
^{55}Fe	2.26×10^{15}	7.16×10^{10}
^{60}Co	4.71×10^{14}	4.02×10^{12}
^{59}Ni	1.73×10^{12}	5.07×10^{7}
^{63}Ni	1.93×10^{14}	9.64×10^{9}
^{94}Nb	6.97×10^{8}	3.15×10^{4}
^{99}Tc	9.76×10^{8}	8.04×10^{5}
^{125}Sb	6.74×10^{10}	3.42×10^{6}
^{146}Sm	3.32×10^{7}	1.13×10^{2}
^{133}Ba	1.85×10^{8}	0.63×10^{3}
^{152}Eu	3.53×10^{11}	1.20×10^{6}
^{154}Eu	4.71×10^{11}	1.57×10^{6}
^{239}Pu	0	1×10^{6}
TOTAL	2.93×10^{15}	4.10×10^{12}

The left-hand column is self-explanatory. The right-hand column represents a pessimistic assumption of the activity instantaneously released upon sea disposal: it was derived by adding one-half of the total activity in the forward and aft bulkheads and hull of the reactor compartment to that in the "crud", an adherent film of corrosion products from the pressure vessel internals and fuel cladding which builds up on the inner walls of the primary circuit pipework.

4. Memorandum submitted by Rolls-Royce and Associates Limited

Introduction

Rolls-Royce and Associates Limited, now a wholly-owned subsidiary of Rolls-Royce Limited, was founded in 1959. Its formation met a vital condition for the transfer of American naval nuclear technology to Britain; the US government insisted that a single company of recognized integrity should be responsible for the whole of a submarine's nuclear steam-raising plant.

Rolls-Royce and Associates was soon employed adapting a Westinghouse propulsion system for the Royal Navy's first nuclear submarine, HMS DREADNOUGHT. This role developed through advances in naval engineering and changes in its parent companies' organizations. Over the past thirty years, the Company has designed, procured and supported in service all the British-built nuclear steam-raising plant used in this country's nuclear submarines.

RRA's involvement in the disposal of nuclear submarines, extends as far back as 1972. This involvement has included a number of technical studies and analyses aimed at comparing and evaluating preceived disposal options for assessment of their viability.

The options which have been identified and evaluated are:

1. Deep sea-bed placement of the whole submarine.
2. Shallow land-burial or engineered storage of the reactor compartment.
3. Piecemeal disposal.

The reactor compartment would remain subject to a national security classification until broken down. Some individual components in interim storage would also need to be protected from unauthorized intrusion.

Background

Decommissioning

Decommissioning in the context of this Paper refers to the disposal of a nuclear submarine after it has been taken out of service and its nuclear reactor core removed. All highly active fission products will have been removed with the reactor core. The radioactivity of interest remaining is contained within that section of the submarine which houses the nuclear steam-raising plant systems, including the reactor, i.e. the reactor compartment. The radioactivity arises from activation of the structure of the systems by neutrons during reactor plant operation, and a very small amount of surface contamination on the internals of the pressure-retaining systems.

Sea-bed Disposal

Until 1982, sea-dumping of radioactive waste was carried out annually in accordance with international legislation. In 1983, public pressure led to a decision by the London Dumping Convention to impose a moratorium on sea-dumping. Britain opposed this decision, claiming it was not based on scientific evidence, and declared its intentions to go ahead with the 1983 dumping operation. However, no sea dumps have been carried out since that time.

In November 1984 the Report of the Independent Review of Disposal of Radioactive Waste in the North-east Atlantic (the "Holliday" report) was published. This was a review of the scientific evidence, including environmental implications, relevant to the safety of sea-disposal of radioactive waste. Its two principal recommendations were:

— That sea-dumping should not be resumed until the current international reviews and the comparison of sea-dumping with land-disposal had been completed.

— That an assessment be carried out of the best practicable environmental option, i.e. as called for in the Fifth and Tenth reports of the Royal Commissions on Environmental Pollution.

The report "Assessment of the Best Practicable Environmental Options for the Management of Low and Intermediate Level Solid Radioactive Wastes" was published by the Department of the Environment in March 1986. The report concluded that sea-bed disposal could be the best practicable environmental option for many wastes, including some decommissioning wastes. It stated that sea-bed disposal, used selectively, could be expected to give rise to no detrimental health effects over the next ten thousand years.

Other reviews since 1983 have also been undertaken internationally, notably:

— The North-east Atlantic Site Suitability Review.

— Review of the International Atomic Energy Agency definitions for the London Dumping Convention of high level wastes unsuitable for sea-disposal, and the recommendations to national competent authorities about permitted disposals.

— The ad hoc review of the scientific and technical considerations relevant to sea-disposal, being carried out for the contracting parties to the London Dumping Convention.

have provided comprehensive dose-rate information to the National Radiological Protection Board to enable them to assess isodose contours to ensure that doses to members of the public are minimal.

The basic method of reactor compartment preparation is the same as for the land-burial option. However, because of the need to inspect the stored compartments over a prolonged period, perhaps fifty years, 'blind' bulkheads would not be fitted.

The attraction of engineered storage is that it places the reactor compartment in a defined environment where it can be monitored and retrieved. However, a storage building designed to take complete reactor compartments represents a significant capital investment. There would also be a need for security provisions and for periodic supervision of stored compartments, possibly with some rectification over a prolonged period. It is worth noting that engineered storage does not reduce the volume of the reactor compartment nor is it truly a disposal option; it merely delays the requirement for disposal at a later date when dose-rates are lower.

As with the land-burial option, special equipment would be needed for transportation.

Piecemeal Disposal

Piecemeal disposal involves cutting up the nuclear steam-raising plant to allow it to be packaged in standard NIREX containers for disposal. The size of the container design limits the size of the pieces to about three metres in length. Remote cutting and handling equipment for the most radioactive equipment, principally the reactor pressure vessel and its internals, would need to be developed.

This option, also assessed by the National Radiological Protection Board in their report, involves the highest dose burden because of the exposure of personnel during cutting operations which are unnecessary with the other options. Early studies were based on published US Navy information which reflected high estimates of component dose-rates. For this reason, and the large amount of cutting required to break down major vessels, piecemeal disposal looked unattractive.

Early estimates of dose burden to the work-force involved in breaking up the reactor compartment, suggested that it would be comparable to that for a refit. However, more extensive use of remote cutting equipment than originally envisaged, together with whole-plant decontamination, would reduce the dose burden significantly. Nevertheless piecemeal disposal would still present the highest dose burden of the perceived options, as well as the highest cost. On the other hand, the National Radiological Protection Board have assessed the collective dose to the public as being well within the International Commission on Radiological Protection limits.

Despite the disadvantages, piecemeal disposal is consistent with developing UK waste-disposal practice and is therefore the option most likely to win public acceptance. In addition, cutting up the reactor plant does not result in an increase in the volume of waste; indeed the total packaged volume is estimated to be about half that of a reactor compartment volume. Completed waste packages, being grouted, are inherently secure.

Disposal of the Dounreay Submarine Prototype

In 1988 MoD requested RRA to undertake a feasibility study into the future of the original Dounreay Submarine Prototype. This land-based nuclear submarine propulsion plant had been in service for about 25 years and had virtually fulfilled its purpose as a test and development facility for current class nuclear submarines. It has been defuelled and is being used as a Loss-of-Coolant-Accident test facility.

Applicability to Nuclear Submarines

The Dounreay Submarine Prototype feasibility study also considered levels of radioactivity recorded on nuclear submarine plants and concluded that the hybrid disposal process would be equally applicable. Defuelling and decontamination of the plant could be undertaken at the dockyard prior to final disposal.

It is envisaged that the reactor compartment could be separated from the submarine and transported by sea to a facility adjacent to the disposal location. This operation is dependent on the availability of a site to dispose of the low-level waste generated and to store in a secure manner the reactor pressure vessels and shield tanks which are intermediate-level.

Once at the disposal site, the reactor compartment would be broken down by simple manual methods. The pressure vessel and shield tank assembly would be extracted and removed to a suitable shielded bunker. The remainder of the plant would be either packaged as low-level waste or as uncontaminated scrap. A storage facility, 10 metres by 50 metres in plan, would be able to accept the intermediate-level waste from the decommissioning of approximately ten nuclear submarines.

It would be possible to use the Prototype site facilities to break down submarine reactor compartments, with the radioactive waste being stored or disposed of at Dounreay. RRA has demonstrated the transportation of reactor compartment by sea and land to Dounreay, by using a sea-going barge and air-bag rollers. The UKAEA site has the facilities and the skills to handle, package and store the waste after dismantling at the nearby Vulcan site.

Similar waste facilities exist at British Nuclear Fuels Limited, Sellafield. The transport of items as large as a reactor compartment to Sellafield has not actually been demonstrated but there is no intrinsic reason why the techniques used at Dounreay should not be equally successful. The availability of large, secure buildings at Sellafield in which to undertake the break down of the reactor compartment has also not been established.

RRA Capabilities and Experience

Submarine Reactor Plant Design, Procurement and Support

Over the past thirty years, RRA has, of necessity, developed extensive, multi-disciplinary, engineering expertise applicable to pressurized water reactors. No comparable organisation exists in this country, and so RRA is obliged to be self-reliant when subcontractors with applicable skills are not available. It draws on its own personnel and its own facilities to build up teams for its various tasks. Such tasks are concerned not only with the design, procurement, installation and commissioning of nuclear steam-raising plant; they also include through-life support of all the plant's systems and components. Support functions involve the defuelling and refuelling of reactors, the refit, modification, replacement and radioactive decontamination of such components as pumps, valves and steam generating plant, as well as the testing, repair and modification of electrical control and instrumentation systems. Chemical, metallurgical and health physics support needed for these tasks is provided by the Company. All its work is carried out to procedures planned with regard to nuclear safety and to quality assurance.

The Company has operated and maintained the Dounreay Submarine Prototype on behalf of MoD since 1962. The plant has been used for the operation of three different designs of reactor core for their full lifetimes, necessitating three refuellings and two major refits. The progressive modification of the plant required by the overall development programme has brought about the accumulation of many skills. The main components have been removed and replaced. Such tasks have required the cutting of radioactive pipework, including the large-bore primary circuit, carried out to detailed procedures. Sections of the hull have also been removed to assist access, and replaced to a standard which preserves the integrity of the containment boundary.

Similar activities have been undertaken at Royal Dockyards, Naval Bases and the build-yard where full inspection, testing and quality assurance methods have been implemented to maintain the high standards required of the task. This has required RRA to develop novel techniques and equipment, validated on full-scale replicas.

All activities from overseeing the build of the nuclear plant, operating, maintenance, refuelling, refitting and decommissioning augment the technical and design skills of RRA to provide a comprehensive, competent service to the MoD.

Decommissioning of Chatham Dockyard

Following the closure of the Chatham Royal Navy Dockyard in 1981, the various operational facilities were dismantled to prepare the dockyard site for alternative usage. Amongst the facilities to be dismantled were those previously used for refit and service of the nuclear submarine fleet, parts of which were radioactively-contaminated buildings, plant and equipments.

RRA planned and project-managed the dismantling and decontamination of the active buildings. The cleaned-up site was accepted by the Department of the Environment and handed back to the owners in 1985.

The Development of Decontamination Techniques for Nuclear Submarine Steam-Raising Plant

The decontamination process for nuclear steam-raising plant systems was developed from individual component decontamination techniques in the mid-sixties. A two-stage high concentration process compatible with plant materials of the plant was chosen and achieved effective decontamination. A decontamination barge was built and the process was applied to several submarines between 1974 and 1985. The achievements were:

- Large radiation dose reduction for key tradesmen during refit.
- Production of cemented and drummed active waste for sea disposal.
- No deleterious effects to the nuclear steam-raising plant.

To reduce the time taken for decontamination, to take account of the closure of the sea-dumping waste disposal route, and to comply with the ALARP principle a low-concentration process was developed between 1980 and 1984. This was tested on the Dounreay Submarine Prototype in 1985 and has now been applied to four submarines in refit. The improvements realized have been:

- Decontamination earlier in refit, reduced fit-up time and lower dose burden.
- Compact active waste form.
- Lower corrosion rates on plant materials, which means decontamination can be repeated if necessary at future refits.

Further developments in decontamination technology are now in progress with two main objectives:

- To achieve further reductions in active waste arisings from the decontamination process.
- To establish a new process which will be compatible with the materials used in the HMS VANGUARD nuclear steam-raising plant and will be capable of being applied even earlier in the refit.

The Refit and Maintenance Role

RRA has a Resident Engineer and multi-disciplinary team, acting on behalf of MoD, at all nuclear submarine operating Naval Bases and Dockyards and at the Build Yard. This arrangment was made at the very beginning of the UK nuclear submarine programme and has therefore existed since the build of HMS DREADNOUGHT.

All repair work, maintenance, modification and refuelling is carried out to detailed procedures, cleared for use by Authorization Groups made up of specifically nuclear qualified personnel, of which the Resident Engineer, as the representative of the reactor plant design authority, is a full member. Similarly, pre-refit testing, re-commissioning and post-refit acceptance of the nuclear steam-raising plant is performed to authorized procedures also approved by the Resident Engineer.

The outcome of this total through-life involvement with the nuclear steam-raising plant, including decommissioning, is that the Company has accumulated a vast store of expertise in all the practical aspects of nuclear plant maintenance and operation to complement their theoretical and design capabilities.

Conclusions

- A number of safe routes for the disposal and storage of the reactor systems of nuclear submarines are available, including:

  (1)Sea-bed disposal.

  (2)Land-burial or storage.

  (3)Piecemeal disposal.

- It appears unlikely that public fears about sea-disposal will be allayed by technical studies and debates, therefore other more expensive routes need to be employed.

- Land-burial or storage does not address the main problem but only delays eventual disposal.