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INTERNAL DOCUMENT 20

I.O.S.

Radio-active Waste Disposal

1. Notes of meeting at IOS 22nd October 1976
2. Bibliography
3. Outline proposals

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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Radio-active Waste Disposal

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Radio-active Waste Disposal

The notes of our meeting last year have been belatedly collated and are here reproduced with the outline proposals we developed at that time. There has been little in the way of development this year.

Miss Bugden has updated the bibliography she prepared for us.

Distribution:

Director,
Dr C E Calvert,
Dr D E Cartwright,
Mr J Crease,
Mr P M David
Dr A S Laughton,
Dr B S McCartney,
Dr I A Rees,
Dr J C Swallow,
Mr M J Tucker

Internal Document No. 20

Institute of Oceanographic Sciences,
Wormley,
Godalming,
Surrey GU8 5UB

October, 1977.

1. Discussion Meeting - 22nd October, 1976

Disposal of Atomic Waste on/under sea floor

Present: Charnock, Crease, Francis, Thorpe, Rees, R. Wilson, Calvert, Elford, Rice, Laughton and Swallow.

Apologies from David, Tucker and McCartney.

The meeting was an opportunity for us to jointly state our preliminary view on the research needed prior to dumping atomic waste. The R.C.E.P. calls for an active research programme by IOS.

Individual staff (particularly Laughton and Swallow) have been involved over several years in discussions relevant to both low and high level wastes. We are also now being drawn into more active discussions with interested Departments of Government.

The Director outlined evidence to RCEP in which we had expressed a preference, if there were to be a disposal programme at sea, for it to be under rather than on the sea floor thereby introducing an additional barrier. He expressed some concern that meetings by IOS staff with Departments intended to be purely at the technical and advisory level sometimes turned to financial and other possible commitments. These latter aspects should aways be for the Director in the first place.

Swallow spoke of aspects of the present storage at Windscale. He serves on a committee of the NII. He and Laughton reported on their visit to a U.S. meeting at WHOI as members of a U.K. team. In the USA and Sandia laboratories manage the disposal research programme for ERDA and produce a substantial annual report. Prior to this the Batelle Institute issued a several volume report on the options available.

Director believes that over the recent years we have built up a group of people eminently qualified to tackle the research required prior to a high level waste disposal programme. He was not keen to go for short term contracts without good scientific basis.

It was agreed that a bibliography would be of value. This might be in two parts a) one containing what members of the group felt to make definitive contributions in their field and those papers would aid other disciplines in appreciating the wider problems; b) a more substantial inventory of specialist papers in the fields. Bibliography a) would indicate whether the papers were available in the library or in an individual's personal papers.

It was expected that specific research proposals would evolve over many months, but Tony Rees believed that it would be helpful to have some further elaboration of the existing ideas (Appendix A) in a shorter time (not more more than one month).

Director said that there was a meeting at Harwell shortly to discuss research aspects of disposal. When the papers come he would enquire who would like to attend. (J.C. and A.S.L. attended this meeting and have the papers).

It was agreed that we would meet again at the end of January.

John Swallow believed that much of the need for the research we might conduct remained, even if the question was only continued dumping of low and medium level activity waste.

Prior to individual disciplinary contribution to the discussion, Tony Rees and H. Charnock explained that we had submitted very rapidly the proposal (Appendix A) outlining the fields in which research to the tune of £500 k/year recommended by the RCEP might be conducted. We believed that they should be additional to the present programme. The point of this and following meetings would be to keep groups into touch with the overall development of the IOS programme in this field.

Comments submitted after meeting:

Geology and Geophysics

When Director asked what programmes MG and G might put up, ASL spoke to the paper that Tony Rees had prepared for NERC.

(a) Selection and evaluation of areas and sites in the N. Atlantic that could be considered suitable for sub-ocean floor disposal.

(b) Long term observation of low level seismic activity to establish a base of data for prediction of site stability.

(c) Sedimentological studies of near surface sediments (0-5 my) to establish geological criteria for prediction of site stability.

(d) Deep sediment sampling (30 metres ?) to obtain material from depths possibly appropriate to buried depths, for studies of ionic exchange capacity (by Harwell ?), pore water migration, geotechnical properties, etc., etc.,

Biological Work bearing on the problem of Radio-active waste disposal

Up to the present time biological work in midwater has been concentrated on the upper layers mainly because this is the region where the largest biomass occurs and where the greatest biological acitivity goes on, but also because the technology of monitoring the sampling has not been sufficiently advanced to extend sampling to greater depths. As this technology has improved so the depth of sampling has increased: whereas 1000m was the goal in the mid sixties 2500m became routine in the early seventies.

It has now become possible to take monitored samples at all normal oceanic depths, and our work in the next few years will be concentrated on the animals between about 2500m and the bottom with particular emphasis on the distribution and trophic relationships of animals close to the bottom, that is in the region between the sea floor and say 500m above it.

At the same time the group of biologists working on deep benthic animals will be looking at the region immediately above the bottom as well as at the normal run of bottom animals. It is our intention to look particularly at the organisms which cause bioturbation of the sediments. We are hoping to find out the extent to which animals are involved in recyling material from the sea floor back up the surface of the sea and much of the work will be alogical extension of the current programme of trophic relationship work in the upper layers.

In the early stages we intend to continue working off the N.W. African Coast where Dr Calvert does his sampling, this is a rich area and the animals are more numerous there: processes should be easier to see than in poorer areas elsewhere.

However, after two years or so we shall consider the merits of working at other sites, for example a site near an actual or potential radio-active waste dump if this seems to be politic.

Although at the outset we shall look primarily at processes in the vertical dimension we should perhaps consider that horizontal processes may also be of importance, and material recycled to the surface by processes occuring along the sea floor and up the continental slopes may be more serious in the context of radio-active waste than material recycled to the surface in a mid ocean gyre. These horizontal processes will however be much more difficult to study.

While it would not be our intention to study directly the accumulation and distribution of radio-active substances in oceanic animals either benthic or planktonic it would seem a pity to miss an opportunity of collecting material for anyone suitably equipped and skilled who needs to look at that particular problem.

Geochemistry

A possible series of research projects in Chemistry which would involve studies of:

(1) The chemical composition of pelagic sediments: Basic information on the chemical and mineralogical makeup of sediments together with their accumulation rates, collected by new techniques which yield minimally disturbed sections some tens of metres in length.

(2) Composition of sediment pore waters: Analysis and modelling of pore waters; estimation of fluxes through pore waters and exchange of bottom water.

(3) Suspended particles: composition and sources of particles in the nepheloid layer; exchange of particles with the bottom sediment, residence times and studies of the adsorptive properties of such particles.

Physics

If it is generally accepted that the highly-active waste has to be buried, either below the sea bed or on land, there may be little support for work in the water itself. The other waste that may need to be dumped in the deep sea (fuel element cladding, medium-active chemical sludge, Pu-contaminated solid wastes) is not expected to amount to as much as ten times the present authorizations for discharges into the Irish Sea. MAFF may see this as negligible and not feel a need to spend money on it. But they may not be able to convince other govenerments, or the IAEA, so some token investigation may be seen to be needed. We need to decide, among ourselves, whether this is good enough, and what could be done to clarify the situation if we think it is not.

While it may be satisfactory in the long term to use single diffusion models or just to regard the deep water as well mixed, the limits on dumping are ultimately related to maximum permissible annual intakes of nuclides by individual people, i.e., we should only be averaging the final results over a year (or maybe a few years) and perhaps over a fairly small region. What will the plume of water passing over a dumping site in a year look like? What extremes can be realized, in a long succession of years?

To look at that problem, is it good enough just to try and guess an extreme advection velocity (e.g., 10 cm/sec persisting in one direction for a year) or should we take up numerical modelling with an eddy-resolving model and try generating trajectories in it? The shape of an actual plume is, of course, going to depend on the small scale diffusion coefficients which are not going to be represented properly in any eddy-resolving general circulation model. What do we do about these? Can plausible values be guessed from internal wave and microstructure studies, or should we be trying to measure them directly, i.e., insitu diffusion experiments?

Advection in some directions is obviously going to be more serious than in others, e.g., advection of deep water towards an upwelling region could be serious. How deep-seated is the upwelling off NW Africa? In the upwelling regions off Peru and S. Arabia there is some evidence for upwelling from depths 2000 m or more, implying advection towards those regions in the upper deep water. Does this occur off NW Africa? Some deep water must get advected northward, i.e., towards some important fishing grounds, in the north Atlantic to become entrained in the overflows. Do we need to look further into the nature and quantity of entrained water, and the paths by which it is supplied?

Is there a case for a deliberate release of a fairly large quantity of activity and subequent monitoring?

The question was asked: 'Given that waste disposal is achieved by burying containers beneath the sea bed, what physical oceanographic studies should be made to ascertain the longterm safety of the method?' It is assumed that leakage into the sediment will occur in a time scale of about 1000 years and that, at some later time, release into the bottom water will occur.

The time scale of the half life of certain waste components is comparable with that of climatic changes, and so, whilst local observational studies over 10-20 years may be recommended, these should be related to the long term (paleo-) oceanography of the area, based on information from local and wider area data, particularly from the sediments. We have little expertise in paleo physical oceanography at IOS.

The space scales of the study may need to be very broad. It is not yet known whether vertical diffusion in the ocean is in general dominated by mid ocean processes or processes at the edge (e.g. upwelling), but it is possible that wastes released in certain mid ocean locations will find their way to the surface most rapidly, although indirectly, by the latter process. If advection of atomic waste from the disposal site to a region of intense vertical diffusion occurs on a sufficiently short time scale, this may be a much more important process in the transport towards the surface (where radioactive waste may cause significant biological damage) than a local vertical diffusion near the dispersal site. It should also be noticed that regions of intense vertical diffusion (upwelling) are also important fishery areas. Hence advection (and of course its variability) in the bottom 500 m from a proposed site needs to be studied both experimentally and theoretically (understanding causes and variations). The former may need technological development for long term float tracking. Upwelling processes are already being widely studied, but should be examined from this new point of view. Mixing processes on continental slopes requires more general study (the turbulent boundary layer on a slope, effect of breaking internal waves and so on).

On the shorter time and smaller space scales, there are a number of poorly understood phenomena which are relevant. Among these are:

(1) The benthic boundary layer, particularly the importance of bioturbation and other sedimentary processes, heat flux, and the possibility of different exchange rates for different components.

(2) The existence of well-mixed bottom boundary layers, their generation and variability and importance on diffusion rates.

(3) The nepheloid layers and their relation to 2.

(4) Turbidity currents (which may carry wastes far from their site of deposition into an area more subject to vertical diffusion).

(5) The existence of fronts similar to those at the ocean surface and base of the atmosphere. These are important in producing vertical diffusion, but are unknown at the ocean floor (at present ?).

(6) The ray paths for internal waves of tidal period generated by surface tide-topography interaction at the continental shelf break. Is diffusion greater along their path?

In general the 'local' studies would cover vertical scales of perhaps 500m and horizontal scales of 50-100 km, and time scales of a few days, whereas the longer scales may be many years and cover an entire ocean basin. The physical studies should be related and compared with biological studies, in particular the rates at which atomic materials may be vertically transferred by physical and biological processes need careful comparison.

There are engineering and technological problems, especially those concerning navigation and sufficiently precise sampling.

Disposal of high level radioactive waste in the floor of the deep ocean.

Outline cost plan 1976-80 - for IOS

The tables following show in outline how an interdisciplinary project might be developed within IOS. The project would, of course, continue after 1980. The costs quoted here are in addition to existing related studies, many of which are relevant or even essential to the success of the suggested project. Allocation of additional ship time has yet to be considered.

The additional work might be organised to cover the following broad topics:

1. Physics:

   Turbulent transport in the lower boundary layer of the deep ocean.

   The deep mesoscale circulation.

   Vertical fluxes in the water column.

2. Chemistry:

   Chemical composition of the uppermost deep ocean sediments.

   Experimental studies of exchange properties and processes.

   Pre water composition.

3. Biology:

   Assessment of possible chemical fluxes through diffusion by animal movement.

4. Geology and Geophysics:

   Selection and evaluation of areas and sites.

   Longterm observation of low level seismic activity.

   Sedimentological studies.

Illustration of possible additional costs to 1980

£K f.c.c. (extra staff)	1976/77	1977/78	1978/79	1979/80
Physics		100 (7)	136 (9)	150 (10)
Chemistry	10 (1)	45 (3)	70 (5)	70 (5)
Biology	6 (1)	16 (2)	30 (3)	30 (3)
Geology		66 (5)	105 (8)	105 (8)
Special Capital		300	250	50
Total f.c.c.	16	527	586	405

No consideration has yet been given to additional costs for ship time.

2. Bibliography

RADIOACTIVE WASTE DISPOSAL		SELECTED REFERENCES (Key) refs	through numbering
I	GOVERNMENTAL POLICIES		
	(a) International Convention	1-5	1-5
	(b) EEC practice	6	6
	(c) UK policy	7,8	7,8
II	HIGH LEVEL WASTE		
	(i) Management options		
	(a) Individual comment (published papers)	1-3	9-11
	(b) Institution reports	4,5	12,13
	(c) Discussion papers	6	14
	(ii) Research programmes		
	(a) International) ocean disposal	1	15
	(b) US) ocean disposal	2-7	16-21
	(c) UK		
	general and land geological disposal	1-8	22-29
	deep ocean disposal	9-17	30-38
	(iii) Deep ocean/sea bed		
	(a) Disposal feasibility, release pathways, models	1-6	39-44
	(b) Seabed properties	1-5	45-49
III	RADIOACTIVITY IN THE MARINE ENVIRONMENT		
	(i) General compendia	1-5	50-54
	(ii) IAEA international symposia	1-4	55-58
IV	RADIOACTIVE WASTE DISCHARGE TO COASTAL WATERS	1-6	59-64
V	NON-RADIOACTIVE WASTE DISPOSAL IN THE OCEAN		65

Attachment A

UKAEA Symposia on Radioactive Waste Management, Harwell November 1976 and November 1977

List of papers

Attachement B

Oceanus 20 (1) Winter 1977

List of papers

Attachment C

Current awareness and bibliographies

I GOVERNMENTAL POLICIES

(a) International

London Convention and related papers

1. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter

Inter-Governmental Conference on the Dumping of Wastes at Sea, London Oct/Nov 1972.

Articles of Convention

Annex 1 lists prohibited materials of which item 6 is high-level radicactive wastes (etc) defined on public health, biological or other grounds by the competent international body in this field (IAEA) as unsuitable for dumping at sea.

2. Background Information Papers related to the Meetings on the IAEA'S Responsibilities under the London Convention of 1972 on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.
IAEA. Restricted document P1-540.

Compilation of papers, 1973-74 meetings.

3. Report on the Advisory Group on the Development of a Generalized Oceanographic Model Related to the Dumping of Radicactive Wastes at Sea.
IAEA Headquarters Vienna Feb 1975
AG-2 (1975) Draft 5
Revised June 9 1976 Y. NISHIWAKI

(Oceanographic model used as one input in deriving the provisional definition of "high-level radioactive wastes" as unsuitable for dumping at sea, and for assessing hazards.)

4. Convention on the prevention of marine pollution by dumping of wastes and other matter. The Definition required by Annex I para 6 and the Recommendations required by Annex II Section D.
IAEA Information Circular INFCIRC/205/Add 1 10 Jan 1975.

5. The revision of the oceanographic basis of the IAEA provisional definition and recommendations concerning high-level radioactive waste unsuitable for dumping at sea.
Working Paper prepared by Consultants' Meetings at Woods Hole (Dec 1976) and Lowestoft (Feb 1977).

(b) European practice

6. Radioactive waste management practices in Western Europe.
European Nuclear Energy Agency 1972.
OECD

(c) UK policies

7. Royal Commission on Environmental Pollution Sixth Report:
Nuclear Power and the Environment.
HMSO Cmnd 6618 1976.

8. Nuclear power and the environment
The Government's response to the Sixth Report of the Royal
Commission on Environmental Pollution
HMSO Cmnd 6820 May 1977.

II HIGH LEVEL WASTE

(i) WASTE MANAGEMENT OPTIONS

(a) Individual comment (published papers)

9. Managing radioactive wastes
BLOMEKE, J.O. et al
Physics Today 26 (8) Aug 73 pp36-42

(Geological disposal, seabed)

10. Radioactive wastes: some urgent unfinished business
CARTER, L.J.
Science 195 18 Feb 1977 pp 661-666, 704

11. High-level nuclear wastes in the sea bed.
Oceanus 20 (1) Winter 1977

(6 papers, see Appendix B for detailed listing)

(b) Institution reports

12. High-level radioactive waste management alternatives
SCHNEIDER, K.J. and PLATT, A.M. eds
Battelle Pacific Northwest Laboratories
Report BNWL-1900 May 1974 Vols 1-6.

(waste characteristics, safety, costs; geologic, ice sheet, and (vol 6) seabed disposal)

13. Options for the ultimate disposal of high level radioactive waste
GRAY, D. et al

(for presentation at IAEA Internat Conf on Nuclear Power and its Fuel Cycle Salzburg April 1977.)

See also Harwell Information Bulletin (Appendix C) for current awareness

(c) Discussion papers (unpublished)

See Harwell Symposia Nov 1976 and Nov 1977 (Appendix A) particularly:-

14. Management of high level liquid wastes: some options and their time scales
ANON
Radioactive Waste Management Coordinating Cttee D. Environment
(Introductory paper to 1976 Symposium)

and

Sessions on Environmental issues and waste disposal options (1977 Symposium)

(ii) RESEARCH PROGRAMMES (PROPOSALS AND DISCUSSIONS)

(a) International programmes
(sea-bed disposal)

15. Report to the Radioactive Waste Management Committee on the First International Workshop on Seabed disposal of high-level wastes
Woods Hole, Massachusetts Feb 16-20 1976
ANDERSON, D.R. et al eds
Sandia Laboratories Report SAND 76-0224 Apr 1976

(b) US ERDA Programme Reports
(sea-bed disposal)

16. A program on the ocean basin floors and radioactive materials: data bases for assessing preliminary concepts
BISHOPS, W.P. and Hollister, C.D. eds
Sandia Document Sep 1973 SLA-73-0596

17. Seabed disposal program - a first-year report Dec 1974
BISHOP, W.P. ed
Sandia Laboratories Report SAND 74-0410 March 1975.

18. Seabed disposal program
Annual report Jan-Dec 1975
TALBERT, D.M. ed
Sandia Laboratories Report SAND 76-0256 1976

19. Annual report Jan-Dec 1976 SAND 77-1270 Parts I & II 1977

20. Release pathways for deep seabed disposal of radioactive wastes
ANDERSON, D.R. et al
Sandia Laboratories Report SAND 74 -5854 October 1975

21. Disposal of long lived radioactive wastes into the sea bed.
Progress Report
ANDERSON, D.R.
OECD Nuclear Energy Agency
Restricted Report Nov 1976
Steering Cttee for Nuclear Energy Radioactive Waste Management Cttee.

(c) UK Programmes

General

22. Radioactive waste storage and disposal plans
JOHNSON, K.D.B., KEEN, N.J. and LEWIS, J.B.
UKAEA Authority Cttee on Coordination of Nuclear Waste R and D
ACCNW(76)24 1976

(Summary of UKAEA views for use in interdepartmental discussions on responsibilities and budgets, relating to the three basic options of engineered store, geological disposal, and deep ocean disposal)

23. Proposals for research on the environmental aspects of nuclear power
NERC Jan 1977

(New or expanded projects relating to disposal of radioactive wastes, pathways and accumulation of radioactive materials, non-nuclear energy sources)

Land geological disposal

24. Disposal of highly-active, solid radioactive wastes into geological formations - relevant geological criteria for the UK
IGS Report No. 76/12 4pp.
GRAY, D.A. et al.

See also Harwell Symposium papers (unpublished, restricted):-

25. Geological disposal. Progress reports, future programme and general discussion
GRAY, D.A. (IGS),
1976.

26. National Waste Storage Site and conditioning wastes for long term storage.
JOHNSON, K.D.B. (AERE)
1976.

27. Report by Institute of Geological Sciences on disposal of waste underground
MATHER, J. (IGS)
1977.

28. Progress on access to Sites; studies at Harwell Laboratory; and field experiments on heating of rock.
FEATES, F.S. (AERE)
1977.

29. Radiological protection aspects of geological disposal
GRIMWOOD, P., HILL, M.D. and Webb, G.A.M.
1977

Deep ocean disposal

30. Deep sea disposal of high level radioactive wastes
Preliminary report
CLARKE, J.H.
UKAEA unpublished document 1975.

31. Ocean disposal of high level wastes - a UK review
JOHNSON, K.D.B. and LEWIS, J.B.
Process Technology Division AERE Harwell
30 Jan 1976 9pp.

(for presentation at Internat. Workshop on Seabed disposal of high-level waste, Woods Hole Feb 1976).

32. Deep ocean disposal of high level wastes
JOHNSON, K.D.B. and LEWIS, J.B.
UKAEA Authority Cttee on Coordination of Nuclear Waste R and D.
ACCNW(76)7 June 1976.
16pp.

See also Harwell Symposium papers (unpublished, restricted):-

33. A high level waste management scheme for ocean disposal
CORBETT, A.D.W. 1976
(BNFL)

34. A proposal to explore the oceanographic option for dumping HLW
HILL, H.W. 1976
(MAFF, Lowestoft)

35. A national programme for R and D on Deep Ocean Disposal of HLW
JOHNSON, K.D.B. 1976
(AERE)

36. Progress in Waste Disposal Options: Ocean Disposal
PRESTON, A. 1977

37 Progress in exploring the oceanographic option for dumping of high level radioactive wastes on the seabed.
HILL, H.W. 1977

38. Sea disposal of plutonium wastes over the next decade.
LEWIS, J.B. 1977

Deep Ocean Disposal

(a) Feasibility, release pathways, models

39. Seabed disposal - where to look
BISHOP, W.P. and HOLLISTER, C.D.
(Sandia) (Woods Hole)
Nuclear Technology 24 Dec 1974 pp425-441
(Seabed characteristics)

40. Feasibility of sub-seafloor emplacement of nuclear waste
VALENT, P.J. and LEE, H.J.
(Naval Construction Battalion Centre, California)
Marine Geotechnology 1976
(Emplacement technology)

41. Assessment of the radiological protection aspects of disposal of high-level waste on the ocean floor
GRIMWOOD, P.D. and WEBB, G.A.M.
National Radiological Protection Board Report NRPB R48, Oct.1976.

42. A model for the evaluation of the deep ocean disposal of radioactive waste
WEBB, G.A.M. and MORLEY, F.
Nat. Radiological Protection Board Report NRPB R14. June 1973.

43. A revised oceanographic model to calculate the limiting capacity of the ocean to accept radioactive waste
WEBB, G.A.M. and GRIMWOOD, P.D.
Nat. Radiol. Protection Board Report NRPB R58 Dec. 1976.

44. A simple model for the dispersion of radioactive wastes dumped on the deep-sea bed
SHEPHERD, J.G.
Fisheries Research Technical Report No. 29 1976.
MAFF

(b) Properties of the sea bed

45. Engineering Seismic Risk Analysis,
CORNELL, C.A. 1968
Bull. Seism. Soc. Am, 58, 1583-1606.

46. Effect of Earthquakes on Deep-Sea Sediments,
FRANCIS, T.J.G., 1971.
Nature, 233, 98-101.

47. A simplified procedure for evaluating soil liquefaction potential.
SEED, H.B. and IDRISS, I.M. 1971.
Proc. Am. Soc. Civ. Eng., 97, SM9, 1249-1273.

48. Penetration of projectiles into seafloor soils
TRUE, D.G. 1975
Civil Engineering Laboratory, California, R822, 1-47.

49. Deep sea sediment types on the North Atlantic sea floor
KIDD, R.B.
IOS Internal Document No. 15 March 1977

(Prepared as part of initial studies of the option for high level radioactive waste disposal beneath the sea bed).

See also papers by Hollister and Silva in Oceanus 1977
(Appendix B)

III RADIOACTIVITY IN THE MARINE ENVIRONMENT

(i) General Compendia

50. Radioactivity in the marine environment
SEYMOUR, A.H. ed
National Academy of Sciences 1971

51. Health in the oceans
GOLDBERG, E.D.
Unesco 1976

Chap 4 Radioactivity

52. A guide to marine pollution
GOLDBERG, E.D. ed
Gordon and Breach 1972

Chap 7 Radioactivity
PRESTON, A. et al.

53. Environmental toxicity of aquatic radionuclides: models and mechanisms
MILLER, M.W. and STANNARD, J.N. eds
Ann Arbor Scientific Publications Inc. 1976

54. Radioactive nuclides in seawater, marine sediments and marine organisms
BURTON, J.D.
pp425-492 in Chemical Oceanography vol 2
ed J.P. RILEY and G. SKIRROW
Academic Press 1965.

(Naturally-occurring radioactivity)

(ii) IAEA INTERNATIONAL SYMPOSIA

55. Radioactive contamination in the marine environment
Symposium Seattle 1972.
IAEA Proc. 1973.

56. Impacts of nuclear releases into the aquatic environment.
Internat. Symposium Otaniemi July 1975
IAEA Proc. 1975.

56a. Radiological impacts of releases for nuclear facilities into aquatic environments
(Report on Internat. Symposium Otaniemi July 1975)
NISHIWAKI, Y.
Atomic Energy Review 13 (3) 1975 635-641.

57. Transuranium nuclides in the environment
Internat. Symposium San Francisco Nov. 1975
IAEA Proc. 1976.

58. Nuclear power and its fuel cycle
Internat. Symposium Salzburg April 1977
IAEA (to be published)

IV RADIOACTIVE WASTE DISCHARGE TO COASTAL WATERS
UK PAPERS

59. Artificial radioactivity in freshwater and estuarine systems
PRESTON, A.
Proc. Roy Soo Lond B180 421-436 1972

60. Contamination of the seas and oceans by artificial radioactivity
PRESTON, A.
Underwater Journal 49058 Apr 1972.

61. Radioactivity in surface and coastal waters of the British Isles 1975
MITCHELL, N.T.
(MAFF) Fisheries Technical Report FRL 12 1977.
(Annual Report)

62. Radioactivity in surface and coastal waters of the British Isles 1976
Part I: The Irish Sea and its Environs
MITCHELL, N.T.
(MAFF) Fisheries Technical Report FRL 13 1977

63. The distribution of some fission product radionuclides in sea and estuarine sediments
HETHERINGTON, J.A. and JEFFERIES, D.F.
Netherlands J. Sea Research 8 (4) 319-338 1974.

64. Caesium-137 as a water movement tracer in the St. George's Channel
WILSON, T.R.S.
Nature 248 (5444) 125-127 1974.

See also some papers in IAEA Symposia

V NON-RADIOACTIVE WASTE DISPOSAL IN THE OCEAN

65. Disposal in the Marine Environment: an oceanographic assessment
Washington: National Academy of Sciences 1976.

(Report of the Ocean Disposal Study Steering Committee prepared under the auspices of the Ocean Affairs Boards Ocean Science Committee in the Commission on Natural Resources of the National Research Council)

ATTACHMENT A

SYMPOSIUM ON R AND D IN RADIOACTIVE WASTE MANAGEMENT
Harwell, November 1976

Discussion papers (unpublished, restricted)

1. The management of high level waste: some options and their timescales
UKAEA Information paper

Deep ocean disposal of high level waste

2. A high level waste management scheme for ocean disposal.
CORBET, A.D.W. (BNFL)

3. A proposal to explore the oceanographic option for dumping HLW.
HILL, H. (MAFF, Lowestoft)

4. A national programme for R and D on deep ocean disposal of HLW.
JOHNSON, K.D.B. (AERE)

Geological Disposal and National Waste Storage

5,6 Geological disposal. Progress reports, future programme and general discussion.
GRAY, D. and FEATES, F.S. (IGS) and AERE)

7,8 National Waste Storage Site and conditioning wastes for long term storage.
Papers No. 7 and 8.
JOHNSON, K.D.B. (AERE)

9. Criteria for the design of short term stores.
CHARLESWORTH, F. (NII)

10. Application of risk analysis of RWM and disposal.
KINCHIN, G.H. (ASRD)

11. Review of European high level waste solidification technology.
CLELLAND, D.W. (BNFL).

12. A development programme for the reduction and treatment of plutonium contaminated materials.
BOYLE, J. (BNFL).

13. The status of developments of instruments for measurement of plutonium in solid waste.
LEAKE, J. (AERE)

SYMPOSIUM ON R & D IN RADIOACTIVE WASTE MANAGEMENT
Harwell, November 1977

Discussion papers (unpublished, restricted)

1. Review of the World Progress in 1977
JOHNSON, K.D.B. (AERE)

Waste Arisings

2. A comparison of PWR, AGR and FBR from the waste production view point (Reactor wastes)
SOLARI, P. (NPC)

3. The activity of arisings from PWR, AGR, FBRs.
BURTON, W. and BARTON, H. (UKAEA)

Environmental Issues and Assessment of Risk

4. A review of the scientific problems raised by radioactive waste.
LIDIARD, A.B. (AERE)

5. Separation and recycling of the actinides. Is it necessary?
A review of the state of knowledge.
McKAY, H.A.C. (AERE)

6. Radiological protection aspects of geological disposal.
GRIMWOOD, P., HILL, M.D. and WEBB, G.A.M. (NRPB)

7. Hazards arising from failure of a long term disposal facility for high level waste from thermal reactors.
BELL, G.D. and FRYER, L.S. (SRD)

Progress in Waste Treatment

8. Strategy for plutonium contaminated waste.
TAYLOR, H.A. (BNFL)

9. Report on progress in vitrification of HALW (concerning BNFL and AEA work)
CORBET, A. (BNFL)

10. Report on progress in treatment of magnox cladding and fuel element hulls (covering BNFL and AEA work).
PLUMB, G. (BNFL)

Decommissioning

11. The decommissioning of WAGR - A feasibility study.
SADDINGTON, K. (UKAEA Windscale)

12. Decommissioning of a plutonium facility.
HUNTER, S., WILSON, E. and KEELING, F. (AWRE)

13. The decommissioning for reconstruction at DNE of various fuel facilities.
BARRETT, T.R. and BAILEY, G. (UKAEA)

Waste Storage Problems

14. Dounreay solid waste management
BLUMFIELD, C.W. (Dounreay)

15. Problems of long term storage of spent fuel.
FLOWERS, R.H. (AERE)

16. An NII view of some waste storage problems.
THACKRAH, D. (NII)

17. A systems approach to waste management.
JAMES, R. (AWRE)

Progress in Waste Disposal Options

18. Ocean disposal
PRESTON, A. (MAFF)

19. Progress in exploring the oceanographic option for dumping of high level radioactive wastes on the seabed
HILL, H.W. (MAFF, Lowestoft)

20. Sea disposal of plutonium wastes over the next decade.
LEWIS, J.B.

Disposal of Waste Underground

21. Report by Institute of Geological Sciences.
MATHER, J. (IGS)

22. Progress on access to sites; studies at Harwell Laboratory; and field experiments on heating of rock.
FEATES, F.S. (AERE)

23. National programme on storage and disposal: costs and timescale.
JOHNSON, K.D.B. (UKAEA)

ATTACHMENT B

High level nuclear wastes in the seabed
Oceanus 20 (1) Winter 1977

1. MACLEISH, W.H.
   Burying Faust

2. FROSCH, R.A.
   Disposing of high-level radioactive waste

3. HOLLISTER, C.D.
   The seabed option

4. HEATH, G.R.
   Barriers to radioactive waste migration

5. SILVA, A.J.
   Physical processes in deep-sea clays

6. HESSLER, R.R. and JUMARS, P.A.
   Abyssal communities and radioactive waste disposal

7. DEESE, D.A.
   Seabed emplacement and political reality

8. Glossary

ATTACHMENT C

ABSTRACTS BULLETIN

1. Information Bulletin on radioactive wastes and fuel reprocessing.
   Harwell Information Services for Radioactive Waste Project

   (issued monthly)

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Disposal on the sea bed

Five papers have been prepared describing work that might be undertaken by IOS in connexion with possible disposal of high level waste on the floor of the deep ocean. A further twelve describe work in connexion with disposal beneath the sea bed.

They describe a substantial body of research only part of which could be carried out by present IOS staff. If the whole were undertaken there would be substantial effects, not yet fully explored, on the Institute's capability to undertake science budget and other commissioned work.

The papers are to be regarded, therefore, as illustrating the sort of work that should be undertaken and, for each individual project, the scale that would be appropriate.

It is hoped that these descriptions will make it possible to decide in general what is needed, who will be the customer and how the requirement is to be treated in relation to others. Proposals for research to be carried out can then be prepared. The project descriptions are summarized below.

	Total cost £K		
Project title	1977-78	1978-79	1979-80
Investigation of currents of the deep N.E. Atlantic IOS 10/16		108	127
Autonomous tracking stations IOS 10/17	82	223	244
Dispersion of tracers in deep water IOS 10/77	60	87	105
Microplankton and micronekton near the ocean floor IOS 30/201	91	119	119
Suspended particles from the deep ocean IOS 10/974	20	31	31

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Disposal beneath the sea bed

Twelve papers have been prepared describing work that might be undertaken by IOS in connexion with the proposed disposal of high level waste beneath the floor of the deep ocean. A further five describe work on the related problems associated with disposal on the sea bed.

They describe a substantial body of research only part of which could be carried out by present IOS staff. If the whole were undertaken there would be substantial effects, not yet fully explored, on the Institute's capability to undertake science budget and other commissioned work.

The papers are to be regarded, therefore, as illustrating the sort of work that should be undertaken and, for each individual project, the scale that would be appropriate.

It is hoped that these descriptions will make it possible to decide in general what is needed, who will be the customer and how the requirement is to be treated in relation to others. Proposals for research to be carried out can then be prepared. The project descriptions are summarized below.

Project title	Total cost £K 1976-77	1977-78	1978-79	1979-80 and after
Dynamics of the benthic boundary layer IOS 10/84		78	133	152
Models of oceanic circulation IOS 10/18		142	142	142
Benthic Biology IOS 30/301		229	229	204
Selection of areas for disposal IOS 20/283		33	98	98
Site stability Studies IOS 20/284		12	91	125
In situ seismics IOS 20/285		12	72	72
Seismic hazard assessment IOS 20/286		86	86	96
Downhole resistivity IOS 20/287		48	19	19
Buoyant programmed pinger IOS 20/288		31	16	16
Chemistry of ocean sediments IOS 10/971	4	66	66	66

Project title	Total cost £K 1976-77	1977-78	1978-79	1979-80 and after
Exchange properties and processes IOS 10/972		60	70	45
Pore water composition IOS 10/973	7	28	41	41

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Alternative Energy Strategies

Much of the IOS work already commissioned is in connexion with conventional sources of energy. This work may be summarized as follows:

	Total cost £K		
	1976-77	1977-78	1978-79
Research commissioned by Department of Energy in connexion with hydrocarbon exploitation	498	201	157
Research commissioned by UK Offshore Operators Association	118		
Research to be commissioned by Department of Energy in connexion with the generation of electricity from waves - approximately	10	40	40
	626	241	197

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Investigation of currents of the deep North East Atlantic Ocean IOS 10/16

Description of the proposed research. The objective of the project will be to describe the main features of the currents of the deep eastern North Atlantic, including their variability on time scales up to several years. This will provide a basis for improved models of the disposal of waste.

The work will, at first, use established techniques of mooring emplacement to deploy current meters through the water column in a geographically extended array. This will be supplemented by local studies of spatial variations using neutrally buoyant floats tracked from ships. When an autonomous tracking system (IOS 10/17) becomes available a more extensive mapping will be possible.

This proposal is for extra observational work at sea. Supervisory effort can be made available from the present staff.

Relevant institute experience and research The Institute of Oceanographic Sciences has over the past 20 years played a pioneering role in the study of deep ocean currents. This has been so both on the interpretive side and in the development of instrumentation.

Present work on the science vote aims at a modest programme of maintenance of current meters at 6 sites in the N.E. Atlantic in collaboration with colleagues from the University of Kiel, Germany and from Fisheries Laboratory Lowestoft. Shorter term experiments designed to reveal topographic effects on the meso-scale circulation (variability in scales of several hundred kilometers) are also part of the IOS programme. The work complements a much larger USA/USSR programme in the western North Atlantic.

Annex 2

NCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title: Extended investigations of currents of the deep N.E. Atlantic Ocean IOS 10/16

Institute(s): Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: 5-10 years

	Year 1976/77	1977/78	1978/79	1979/80	1980-81 1987-88 inclusive
Manpower - Scientists			$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{3}{4}$
- Support					
Full Economic Costs					
- Staff and other recurrent £K	[431]*	-	32	45	75
- Capital Equipment					
- Major Operational Costs Cruise costs	[449]	-	60	60	60
- Other					
- Overheads	[237]	-	16	22	37
- Total	117	-	108	127	172

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 1, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Development and emplacement of autonomous tracking stations in the eastern North Atlantic IOS 10/17

Description of the proposed research The long term aim is to instal a system of acoustic receivers at permanent deep-water stations in the eastern North Atlantic which will permit tracking of neutrally buoyant floats over the greater part of the area and of the depth.

The work will be in three stages

(a) Two parallel pilot projects - to determine the optimum siting of listening stations for maximum coverage, and to set out the basis of the design of the stations themselves.

(b) A test phase in which 3 stations are constructed and placed in deep offshore locations and a small number of long range floats are tracked. Much of the technology for the floats will be available from colleagues in the USA. The specific location might most appropriately be chosen in relation to the biological and geochemical components of the overall programme.

(c) An implementation phase to be described in a proposal for later years.

This is a proposal for the development, and assessment at sea, of a specialized instrument system. About half the total staff effort involved can be provided by present IOS staff.

Relevant institute experience and research IOS pioneered the use of acoustically tracked neutrally buoyant floats and deep water mooring techniques. The institute is expert in short range tracking of floats at various depths in the ocean from shipboard. IOS has long experience both of deep water current meter moorings and in the development and management of the larger more permanent UK data buoy.

Annex 2

NCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title: Development and emplacement of autonomous tracking stations in the eastern N. Atlantic IOS 10/17

Institute(s): Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: 5-10 years

	Year 1976/77	1977/78	1978/79	1979/80 – 1986/87 inclusive
Manpower - Scientists		2¼	5	6
- Support				
Full Economic Costs				
- Staff and other recurrent £K	[431]*	55	112	126
- Capital Equipment				
- Major Operational Costs (ship time)	[449]		55	55
- Other				
- Overheads	[237]	27	56	63
- Total	117	82	223	244

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 1, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Dispersion of a tracer in deep water IOS 10/77

Description of the proposed research Experiments will be performed with radioactive or dye tracers to estimate the vertical mixing in mid-water in a variety of oceanographic regimes. This will provide a basis for estimating the possible displacement of pollutants by transient advection and the potential for climatic changes in local conditions. The experiments will be conducted in regions of low vertical stability, in upwelling areas and in overflow regions as well as in areas selected for possible waste disposal.

The project will require a number of developments

(1) Development of methods of dispersal at depth so that tracer is neutrally buoyant.

(2) Selection of tracer (radioactive or dye) and the instrumentation to detect it at great depths.

(3) Design of carrier for the detectors. This will be initially a paper study to decide whether a complex deep towed controlled vehicle would be appropriate.

(4) A series of diffusion experiments in varying oceanographic regimes.

It is envisaged that this project will be a joint one between IOS, AERE and MAFF.

Relevant institute expertise and research IOS has over the last 20 years had a continuing role in the study of variability of deep currents and the parallel investigations of the physical properties of the ocean.

Annex 2

NCDP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Dispersion of a tracer in deep water IOS 10/77

Institute(s) Institute of Oceanographic Sciences.

Subcontracts Joint with AERE/MAFF. IOS costs only shown here.

Duration of proposed research: Up to 5 years

	Year 1976/77	1977/78	1978/79	1979/80 1981/82 inclusive
Manpower - Scientists		1¼	3¼	3¼
- Support				

Full Economic Costs

- Staff and other recurrent £K	[431] *	40	58	70
- Capital Equipment				
- Major Operational Costs	[449]			
- Other				
- Overheads	[237]	20	29	35
- Total	[1117]	60	87	105

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 1, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Distribution and trophic relationships of the macroplankton and micronekton occurring near the ocean floor IOS 30/201

Description of the proposed research The work will be based on the institutes existing programme of research on oceanic ecology. It will concentrate on the organisms in the layer from the sea floor to about 100 m above the bottom. It is probable that these organisms would be the ones most involved in any upward flux of material, which could be transported to and recycled in the uppermost layers of the ocean.

Preliminary experiments at sea have been encouraging. Although modifications of both the gear and the methods of use will be needed the project is known to be, feasible, though difficult. It can begin as a field study without delay.

For the layers between about 2 m from the sea floor upward to 100 m or more the monitored rectangular midwater trawl will be used with modification of the control system. Modifications will be made to the epibenthic sledge to sample the layer between the sea floor and 2 m.

In the initial stages the work will be done in a rich area so that, particularly in the mid depths (where organisms are very few), large samples can be collected and signs of any processes moving material from the bottom to the surface will be most likely to be seen. When such processes have been recognised the sampling will move to areas where dumping is already carried out.

This work will be done mainly by redeployment of existing staff of the IOS Biology Group. It will be necessary to fill at least one vacancy at SO/HSO level so that a necessary expertise on copepods can be developed. Outside assistance will be needed in the later stages to deal with the analysis of radioactive material.

Relevant institute expertise and research IOS has been carrying out for some years a programme of research on the trophic relationships, distribution, migration and ecology of the macroplankton and micronekton of the top 2000 m of the ocean. This programme depends upon advanced unambiguous sampling techniques developed at IOS and on a fairly wide 'in house' taxonomic capability. The staff employed are highly experienced both in seagoing activities such as the operation of collecting gear at considerable depths and in

the processing and analysis of the data collected.

The programme has had the backing and advice of the engineering, applied physics, physics and chemistry sections of IOS for many of years.

The present programme of research on oceanic ecology is concerned with the distribution and migration, mainly in the vertical dimension, of the larger organisms found in the upper 2000 m of the open ocean water column, and with the food, feeding, breeding, swarming and ontogeny of those organisms. A great deal of progress has been made and the investigations are in an active and productive phase.

NCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Distribution and trophic relationships of macroplankton and micronekton near the ocean floor IOS 30/201

Institute(s) Institute of Oceanographic Sciences.

Subcontracts

Duration of proposed research: 5-10 years

	Year 1976/77	1977/78	1978/79	1979/80 1986/87 inclusive
Manpower - Scientists		$2\frac{3}{4}$	$4\frac{3}{4}$	$4\frac{3}{4}$
- Support				
Full Economic Costs				
- Staff and other recurrent £K	[86] *	24	43	43
- Capital Equipment				
- Major Operational Costs	[130]	55	55	55
- Other				
- Overheads	[42]	12	21	21
- Total		91	119	119

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 8, IOS programme review October 1976 for details of work

November 1976

PROVISIONAL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Suspended particles from the deep ocean
IOS 10/974

Description of the proposed research Studies of the composition and sources of particles in the nepheloid layer, exchange of particles with the bottom sediment, residence times and absorbtive properties.

This is a laboratory study using material collected from the ocean.

Only supervisory effort is at present available for this work. Its timing and staffing depend on the decisions that are made for other projects in this series. The most practicable arrangement is to appoint one extra support staff member, preferably early in 1978-79.

Relevant institute expertise and research Relevant IOS research is concentrated in Primary Activity 3 "Chemical Sources, Cycles and Sinks" which aims to understand the processes which transport chemical substances (including hydrocarbons and trace metals) in the marine environment, their effect on physical processes and biological populations and their ultimate fate. The equivalent of $4\frac{1}{2}$ chemists are engaged on this work covering all aspects of marine chemistry.

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Suspended particles from the deep ocean IOS 10/974

Institute(s) Institute of Oceanographic Sciences.

Subcontracts

Duration of proposed research: 5-10 years

	Year 1976/77	1977/78	1978/79	1979/80 – 1986/87 inclusive
Manpower - Scientists		$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
- Support			1	1
Full Economic Costs				
- Staff and other recurrent £K	[91] *	3	10	10
- Capital Equipment				
- Major Operational Costs (ship time)	[71]	16	16	16
- Other				
- Overheads	[51]	1	5	5
- Total		20	31	31

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 3., IOS programme review October 1976 for details of the work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Dynamics of the benthic boundary layer of the deep sea IOS 10/84

Description of the proposed research

Measurements will be made of the internal structure of the well-mixed benthic boundary layers that extend up to 200 m from the bottom in many areas of deep water. The principal objective will be to identify dynamical processes and establish possible mechanisms for the dispersal of heat, matter and momentum.

Most of the necessary instrument development is already underway in other IOS programmes. The principal tools for this study of the boundary layer will be sensors of great sensitivity for temperature, current and possibly conductivity measurement mounted on rigid bottom structures in arrays appropriate to the boundary layer scale under investigation.

This proposal is for measurements at sea and their subsequent interpretation, backed by a substantial engineering development. Present IOS staff will provide the necessary theoretical expertise and will supervise the project.

Relevant institute expertise and research IOS has a continuing programme of observation of the physical structure of the deep sea using modern techniques and long experience of measurement methods. Development of electromagnetic sensors and evaluation of acoustic methods of current measurement are part of the present programme. Studies of turbulence in stratified shear flow in the laboratory and in the field are actively pursued.

NCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title: Dynamics of the Benthic Boundary Layer of the Deep Sea
IOS 10/84

Institute(s): Institute of Oceanographic Sciences

Subcontracts:

Duration of proposed research: Long term - 10 year minimum

	Year 1976/77	1977/78	1978/79	1979/80 – 1986/87 inclusive
Manpower - Scientists		$1\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{3}{4}$
- Support				
Full Economic Costs				
- Staff and other recurrent £K	[431]*	30	52	65
- Capital Equipment				
- Major Operational Costs (shiptime)	[449]	33	55	55
- Other				
- Overheads	[237]	15	26	32
- Total	[1117]	78	133	152

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 1, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project IOS 10/18 Development of models of oceanic circulation

Description of the proposed research Theoretical studies will be made of the possible dispersion of waste material. Models of the ocean circulation, based on the best present understanding of physical processes and observational data, will be developed and exploited.

The work will be carried out jointly by staff at present employed at the Department of Applied Mathematics and Theoretical Physics of the University of Cambridge and staff of IOS with wide experience of field observations and knowledge of the global circulation. IOS will also support the numerical development of the models.

The mechanism of establishing the project has not yet been established. Costs are given on the assumption that it is entirely within IOS.

Relevant institute expertise and research IOS has long experience both of work at sea on the general circulation of the ocean and of the development of theoretical models.

DAMTP staff have developed a special expertise in the numerical techniques associated with circulation models and are in close contact with groups in the USA working on models of circulation and climate.

Annex 2

NCMP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Development of models of oceanic circulation IOS 10/18

Institute(s) Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: Long term - 10 year minimum

	Year 1976/77	1977/78	1978/79	1979/80
				1986/87 inclusive
Manpower - Scientists		4	4	4
- Support				
Full Economic Costs				
- Staff and other recurrent £K		95	95	95
- Capital Equipment				
- Major Operational Costs	Present NERC DAMTP contract			
- Other				
- Overheads		47	47	47
- Total		142	142	142

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Benthic biology IOS 30/301

Description of the proposed research The present IOS programme on benthic biology will be reoriented to emphasise the possible effects of radioactive waste on benthic ecology and of benthic fauna on the dispersal of the waste material.

It will be necessary to take on one additional young scientist to be trained to work on Echinoderms - the Holothuria are one of the most abundant groups of the deep sea benthos and, since they feed by swallowing sediment, may have profound effects on the reworking of the uppermost sedimentary layers - and to employ two part time assistants. The existing contract with University of Wales for study of benthic foraminifera will be continued.

Modifications will be needed to the main winch on Discovery. A larger barrel will be needed to accommodate 12-14,000 m of tapered wire. Two such wires would also be needed as well as a shore-side reeling system for changing wires in harbour under tension.

Relevant institute expertise and research Although benthic work began at IOS in 1968 the effort at that time was minimal and more intensive work only began in 1973/74. A satisfactory system of sampling the macrobenthos has been developed and a commercial single warp bottom trawl which has been used in deep water caught good samples of the larger benthic and epibenthic animals. A box corer built at IOS will supply samples of the fauna living within the sediments. Methods of processing the samples are being improved and taxonomic expertise acquired though, since it would probably be impossible and almost certainly undesirable to build up a large enough team of taxonomists to deal with the very varied benthic fauna, only a very small number of groups of animals can be completely analysed 'in house'. Arrangements have been made for the wide taxonomic abilities available throughout Europe to be used on benthic collections made by those European nations currently engaged in deep-sea research; since IOS was largely responsible for initiating the scheme the institute will be in a good position to benefit from it.

IOS benthic work (Project B3) is concerned with the effects of animals on the chemistry and physics of the Benthic Boundary Layer. Five scientists are engaged on the project at present.

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Benthic Biology IOS 30/301

Institute(s) Institute of Oceanographic Sciences

Subcontracts University College of Wales

Duration of proposed research: long term - at least ten years

	Year 1976/77	1977/78	1978/79	1979/80 1985/86 inclusive
Manpower - Scientists	5	6	6	6
- Support				
Full Economic Costs				
- Staff and other recurrent £K	[70]*	82	82	82
- Capital Equipment		25	25	
- Major Operational Costs	[129]	82	82	82
- Other				
- Overheads	[32]	40	40	40
- Total		229	229	204

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

See Primary Activity 9, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Selection and evaluation of areas and sites for disposal of high level radioactive waste below the ocean floor IOS 20/283

Description of the proposed research A number of areas will be selected in the North Atlantic where criteria for the disposal of high level radioactive waste below the ocean floor might be met. Surveys will be carried out to evaluate the choices.

Initially the project will require a synthesis and analysis of all available morphological, geological and geophysical data, especially seismic reflection data, to locate possible sediment basins where sedimentation has proceeded undisturbed during the Quaternary. Selected candidate sites will require precise morphological and stratigraphical mapping using a variety of geophysical techniques, including long range side scan sonar (GLORIA Mk II) and high resolution seismic reflection profiling.

Separate proposals deal with proposed studies of sediments. This is a laboratory/office study based on existing records to begin with. Emphasis will move towards measurements at sea in the later stages.

Relevant institute expertise and research The institute has 25 years of experience in studying the morphology, structure, tectonics, sedimentation and evolution of the ocean floor in both the Atlantic and Indian oceans. This has been achieved by research cruises at sea using geophysical surveying and geological sampling techniques and the subsequent data analyses and interpretation. In recent years the institute has been closely involved with and taken part in the Deep Sea Drilling Project now in its International Phase of ocean drilling.

Current research on relevant topics includes:

1. Preparation of bathymetric charts of the NE Atlantic at scales of 1:1 million, 1:2.4 million and 1:10 million based on international, national and institute sounding data. The preparation of the series at 1:2.4 million is paid for by the Departments of Industry and Energy.

2. Data on sediment distribution and processes in the NE Atlantic have been collected over many years and are being interpreted in relation to environmental and geological history. Mapping of geophysical parameters (magnetic anomalies, gravity anomalies, seismicity, crustal structure etc) is also undertaken as part of general studies of the structure and evolution of the oceanic crust. These projects are supported by Science Vote funds.

3. Programmes of geological and geophysical work at sea which include studies of the axial regions of the Mid-Atlantic Ridge, anomalous mid plate regions such as King's Trough and the continental margins of western Europe.

17.5 direct staff equivalent (p.a.b.) work on the two Primary Activities "Ocean Floor Studies" and "Global Tectonics". 5.5 of them are at present committed to work for the Department of Industry and Energy; the number required is expected to increase. Supervisory staff can be made available for this project. One extra prime mover and one supporting scientist should be appointed as soon as possible with the possibility of one more supporting staff in the next year.

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Selection and evaluation of sites IOS 20/283

Institute(s) Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: Probably 5 years or more depending on the success of the initial search and evaluation.

	Year 1976/77	1977/78	1978/79	1979/80 1981/82 inclusive
Manpower - Scientists		1½	1½	1½
- Support		1	2	2
Full Economic Costs				
- Staff and other recurrent £K	[236]* (60)	22	29	29
- Capital Equipment				
- Major Operational Costs	[185] (98)		55	55
- Other				
- Overheads	[126] (24)	11	14	14
- Total		33	98	98

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activities 5 and 6; IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Site stability studies from the Quaternary sedimentary record IOS 20/284

Description of the proposed research An assessment of site stability during the next few hundreds of thousands of years can be made by studying the nature of sedimentation during the last few million years (e.g. 2my for the Quaternary). At typical N. Atlantic sedimentation rates of 2-10 cm/1000 years, sediments will have to be sampled to depths of 40-200 metres below the sea floor.

The proposal is (a) to study all available relevant core and drill data from possible N. Atlantic sites to achieve an understanding of regional sedimentation patterns and processes, (b) to develop techniques for the recovery of sediment from depths up to several tens of metres below the sea floor (c) to obtain samples from suitable depths in possible disposal sites (d) to analyse sediments to give detailed geological history at the site with special emphasis on the influence of glacial/interglacial environmental changes.

The analysis of the cores will require detailed faunal and statistical analysis of Quaternary planktonic foraminifera, along the lines of the CLIMAP project, which should be carried out within IOS. Use of NERC C14 and isotope facilities will be required. Micro-palaeontological work may be done by external contractors.

The material obtained from this project can also be used for physical and chemical studies, under other projects, of sediments at crucial depths.

Relevant institute expertise and research The institute has experience in deep ocean coring and has the necessary design and mechanical engineering facilities to develop deep penetration coring. Experience in sediment analysis and interpretation in terms of palaeoenvironment have come from close association with and participation in the Deep Sea Drilling Project.

A research programme, funded by Science Vote, has recently been started on the collection and interpretation of ocean sediments in relation to the environmental and geological history of the NE Atlantic and to the processes operating. Effort on this programme might be available for redeployment ($\frac{1}{2}$ man). The necessary supervision can be provided.

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Site stability studies from the Quaternary Sedimentary record IOS 20/284

Institute(s) Institute of Oceanographic Sciences

Subcontracts To be determined

Duration of proposed research: At least 5 years depending on site selection

	Year				
	1976/77	1977/78	1978/79	1979/80	1980/81 1982/83 inclusive
Manpower - Scientists	-	$\frac{3}{4}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$
- Support	-	-	1	2	2

Full Economic Costs

- Staff and other recurrent	[236] (60)*	8	32	48	48
Special Capital Equipment			10	20	20
- Major Operational Costs (shiptime)	[185] (98)		33	33	33
- Other					
- Overheads	[126] (24)	4	16	24	24
- Total		12	91	125	125

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activities 5 and 6, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project In situ seismic studies of the physical properties of the upper layers of deep sea sediments IOS 20/285

Description of the proposed research The objective is to determine in situ geotechnical properties of deep sea sediments, especially porosity, with a view eventually to studying possible sites for the disposal of high level radioactive wastes. This will be achieved by a short range seismic refraction technique using both sound sources and receivers on the ocean floor over line lengths of the order of a few kilometres, giving a measurement of the sediment properties up to a few hundred metres depth. Existing sea bed recorders (PUBS) will be used (being modified where necessary). An ocean bottom sound source with suitable power and frequency characteristics will be developed to generate Stoneley surface waves on the sediment-water interface. The dispersion of these waves can be interpreted in terms of a shear velocity/depth model for the top few tens of metres of sediment. Compressional waves generated simultaneously will give time distance curves that can be inverted to give a P-wave velocity/depth model. Measurement of the amplitude of vertical incidence reflections from below the seabed can give acoustic impedance contrasts. All these data can be combined to give estimates of density (and hence porosity if particle density is known) and the elastic constants of the upper sediments.

The project is basically field research, involving some prior instrumental development, to be followed by mathematical modelling of sediment parameters.

An IOS senior scientist expert in ocean floor seismic research will supervise the project. IOS can provide engineering support. A younger scientist and a man to support him will be required.

Relevant Institute expertise and research IOS has 10 years of experience in the development of pop-up bottom seismic recorders and was a pioneer in this field, and also with development of sound sources. Seismic refraction measurements of the oceanic crust have been made over a wide variety of ocean floor environments using surface explosion or airgun sound sources. Interpretational methods have been developed including the use of synthetic seismograms.

Recent studies at IOS using the seismic refraction method include an assessment of the crustal structure of King's Trough, the crests of the Mid-Atlantic Ridge SW of the Azores and of the Sheba Ridge (Gulf of Aden) and the Arabian margin. Longer range work on the lithospheric structure of the Mid-Atlantic Ridge North of the Azores has also been carried out. The seismic recorders are being developed to include geophones to enable shear waves to be observed.

These projects are entirely funded by Science Vote.

Annex 2

NCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title In situ seismic studies IOS 20/285

Institute(s) Institute of Oceanographic Sciences.

Subcontracts

Duration of proposed research: Work on development of sound sources should start as soon as possible. Duration of the observational work will depend on how long it takes to find suitable sites. Year 1976/77 1977/78 1978/79 1979/80 ~~1984/85~~ inclusive

	1977/78	1978/79	1979/80
Manpower - Scientists	$\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$
- Support	$\frac{1}{2}$	1	1

Full Economic Costs

- Staff and other recurrent £K	[236] (60)*	8	26	26
- Capital Equipment				
- Major Operational Costs (ship time)	[185] (98)		33	33
- Other				
- Overheads	[126] (24)	4	13	13
- Total		12	72	72

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activities 5 and 6, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Seismic Hazard Assessment on the Ocean Floor
IOS 20/286

Description of the proposed research An array of ocean bottom seismographs will be deployed in the North Atlantic so as to detect and locate all seismic events with $M_b \geq 2$. The initial deployment of up to ten instruments will cover an area about equal to that of Great Britain.

Later phases of the work will concentrate on longer term observation of more limited areas so as to build up knowledge of the statistics of smaller seismic events, undetectable by the present world wide network but still possibly capable of damaging ocean floor installations. Present IOS staff will supervise the carrying out and interpretation of the research. Two additional junior scientists will be needed. This is a proposal for work at sea but with substantial preparatory work and interpretation ashore.

Relevant Expertise and Research IOS has been observing earthquakes in seismically active regions of the ocean floor with Ocean Bottom Seismographs (OBS) since 1972. At present there are 5 operational OBS, each capable of recording for up to nine days. Plans are in hand to extend this recording period to about a month. In addition to having the equipment and experience relevant to the long term operation of OBS on the sea floor, IOS has the expertise needed in the assessment of seismic hazard

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Seismic Hazard assessment IOS 20/286

Institute(s) Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: Long term: necessary to build up statistics of seismicity

			Year		
	1976/77	1977/78	1978/79	1979/80	1986/87 inclusive
Manpower - Scientists		3	3	3	
- Support					

Full Economic Costs

- Staff and other recurrent £K	[236]	(60)*	24	24	24
- Capital Equipment			50	50	
- Major Operational Costs	[185]	(98)			60
- Other					
- Overheads	[126]	(24)	12	12	12
- Total			86	86	96

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activities 5 and 6, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Resistivity measurements down IPOD holes
IOS 20/287

Description of the proposed research Electrical resistivity measurements will be made in IPOD drill holes using wide electrode separation so as to ensure deep penetration of the surrounding rock. The measurements will make it possible to assess the gross porosity of oceanic basalts and underlying sediments and the exchange of salt water with the ocean and thus the degree to which fragmentation may make them unsuitable to receive waste.

This is a proposal for work at sea.

Present IOS staff will be able to supervise the project. Two extra scientists will be needed in the first year, reducing to one in succeeding years.

Relevant institute expertise and research. IOS staff have carried out large scale electrical resistivity work at sea. The experience gained will contribute to the work proposed.

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Resistivity measurements down IPOD boreholes 10S 20/287

Institute(s) Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: Duration linked with the IPOD programme

		Year 1977/78	1978/79	1979/80
Manpower - Scientists		1¼	1¼	1¼
- Support		1	-	-
Full Economic Costs				
- Staff and other recurrent £K	[236] (60)*	19	13	13
- Capital Equipment		40	-	-
- Major Operational Costs	[185] (98)			
- Other				
- Overheads	[126] (24)	9	6	6
- Total		48	19	19

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activities 5 and 6, IOS programme review, October 1976 for details of work.

November 1976

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Buoyant Programmed Pinger IOS 20/288

Description of the proposed research A pattern of buoyant programmed pingers will be deployed in the Blanco Fracture Zone, off the coast of Oregon. This area has been selected as suitable for first trials of the system which will detect whether a dense object placed on the sea floor will sink into the sediment as it is fluidised by seismic shocks. Sinking of the pinger anchor weights will be monitored by ships of opportunity which will check the distance of pingers above the sea floor.

This is a programme of research at sea using ships of opportunity and existing equipment. It can be carried out by present IOS staff.

Relevant institute expertise and research IOS staff have several years experience in studying earthquakes on the ocean floor. A long life buoyant pinger has been developed and several constructed. The deployment can commence in 1978.

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Buoyant programmed pinger IOS 20/288

Institute(s) Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: 5-10 years

	Year 1976/77	1977/78	1978/79	1979/80 1986/87 inclusive
Manpower - Scientists		$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
- Support				
Full Economic Costs				
- Staff and other recurrent £K	236 (60)*	16	4	4
- Capital Equipment				
- Major Operational Costs	185 (98)			
- Other (US $		10	10	10
- Overheads	126 (24)	5	2	2
- Total		31	16	16

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activities 5 and 6 IOS programme review, October 1976 for details of work.

November 1976

PROVISIONAL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project: Chemical composition of uppermost deep ocean sediments IOS 10/971

Description of the proposed research Determination of the chemical composition of pelagic sediments in order to obtain basic information on chemical and mineralogical composition and accumulation rates.

Development of new collecting techniques which will yield minimally disturbed sections some tens of metres in length*

This is a laboratory study using material collected from the deep ocean floor.

Only supervisory effort is at present available for this work. Its timing depends on the speed with which appropriate staff can be appointed. The figures given here assume that one support man can be appointed immediately to begin, under supervision, to set up appropriate procedures and facilities and that a SSO prime mover can be appointed next year.

Relevant institute expertise and research Relevant IOS research is concentrated in Primary Activity 3 "Chemical Sources, Cycles and Sinks" which aims to understand the processes which transport chemical substances (including hydrocarbons and trace metals) in the marine environment, their effect on physical processes and biological polulations and their ultimate fate. The equivalent of $4\frac{1}{2}$ chemists are engaged on this work covering all aspects of marine chemistry. These staff are, fortunately, well qualified to provide the supervision needed by projects related to radioactive waste disposal though their number does not permit the redeployment of any usbstantial effort. The group is well provided with the basic laboratory equipment required for project 10/971.

* See project IOS/10/184 for costs of development of sampling equipment

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Chemical composition of uppermost deep ocean sediments IOS 10/971

Institute(s) Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: 5-10 years

	Year 1976/77	1977/78	1978/79	1979/80 1985/86 inclusive
Manpower - Scientists	¼	1¼	1¼	1¼
- Support	1	1	1	1
Full Economic Costs				
- Staff and other recurrent £K	3 [91]*	23	23	23
- Capital Equipment (special)	-			
- Major Operational Costs (ship time)	- [71]	22	22	22
- Other				
- Overheads	1 [51]	11	11	11
- Total	4	66	66	66

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 3, IOS programme review, October 1976 for details of work.

November 1976

PROVISIONAL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project: Experimental studies of exchange properties and processes IOS 10/972

Description of the proposed research Studies of adsorbtion and exchange of major and minor elements and some low level radionuclides onto various sediment compcnents

This is a laboratory study

Only general supervisory effort is at present available for this work. Its success depends on the early appointment of an experienced man able to lead the project and so provide a necessary complement to project IOS 10/971. The figures given here assume that a leader can be appointed early next year and that he will be supported by one man from the beginning of 1978-79. Capital expenditure will be needed to provide and additional facilities.

Relevant institute expertise and research Relevant IOS research is concentrated in Primary Activity 3 "Chemical Sources, Cycles and Sinks" which aims to understand the processes which transport chemical substances (including hydrocarbons and trace metals) in the marine environment, their effect on physical processes and biological populations and their ultimate fate. The equivalent of $4\frac{1}{2}$ chemists are engaged on this work covering all aspects of marine chemistry.

There is at present no IOS experimental project though senior members of staff have experience in the general subject area.

Annex 2

NCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Experimental studies of exchange properties and processes IOS/10/972

Institute(s) Institute of Oceanographic Sciences

Subcontracts

Duration of proposed research: Long term

	Year 1976/77	1977/78	1978/79	1979/80 1986/87 inclusive
Manpower - Scientists		1¼	1¼	1¼
- Support			1	1

Full Economic Costs

- Staff and other recurrent £K	[91]*	16	23	23
- Capital Equipment (special)		25	25	
- Major Operational Costs	[71]	11	11	11
- Other				
- Overheads	[51]	8	11	11
- Total	[213]	60	70	45

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 3, IOS programme review, October 1976 for details of work

November 1976

PROVISIONAL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Programme on disposal of high level radioactive waste in the ocean

Project Pore water composition IOS 10/973

Description of the proposed research Studies of the composition of sediment pore waters. Analysis and modelling of pore waters, estimation of fluxes through pore waters and exchange with bottom water.

This is a laboratory study using material collected from the deep ocean floor.

This work will be best catered for by the appointment of a younger scientist to work under the supervision of a senior member of the present staff. The appointment should be made in about a years time.

Relevant institute expertise and research Relevant IOS research is concentrated in Primary Activity 3 "Chemical Sources, Cycles and Sinks" which aims to understand the processes which transport chemical substances (including hydrocarbons and trace metals) in the marine environment, their effect on physical processes and biological populations and their ultimate fate. The equivalent of $4\frac{1}{2}$ chemists are engaged on this work covering all aspects of marine chemistry.

IOS has developed equipment for taking pore water samples of sediments in situ. The one senior member of staff with directly relevant expertise will devote a substantial fraction of his time to this work.

Annex 2

RCEP VI REPORT: MANPOWER AND COSTS OF PROPOSED RESEARCH

Title Pore water composition IOS 10/973

Institute(s) Institute of Oceanographic Sciences.

Subcontracts one

Duration of proposed research: 5-10 years

	Year 1976/77	1977/78	1978/79	1979/80 – 1985/86 inclusive
Manpower - Scientists				
- Support	¼	¼	1¼	1¼
Full Economic Costs				
- Staff and other recurrent £K	1 [91] *	4	13	13
- Capital Equipment				
- Major Operational Costs (ship time)	5 [71]	22	22	22
- Other				
- Overheads	1 51	2	6	6
- Total	7	28	41	41

Note: Figures in brackets refer to manpower and costs of ongoing relevant research on commission ( ) or Science Vote [ ]

* See Primary Activity 3, IOS programme review, October 1976 for details of work

November 1976