SN

PRIME MINISTER

Although outdated in some respects, this is a useful summary of work going on. MJS

4

SECRETARY OF STATE FOR THE ENVIRONMENT

2 MARSHAM STREET
LONDON SW1P 3EB

My ref:

Your ref:

17 SEP 79

Dear Mike

REVIEW OF RESEARCH ON RADIOACTIVE WASTE MANAGEMENT AND RADIOACTIVITY IN THE ENVIRONMENT

Because of the Prime Minister's interest in the whole area of nuclear power, my Secretary of State has asked me to let you know about a forthcoming Department of Environment Research Report on Research on Radioactive Waste Management and Radioactivity in the Environment. This Report was promised (as "a review by DOE, in collaboration with the other bodies concerned, of the adequacy of the present research programme") in the former Government's White Paper 'Nuclear Power and the Environment'.

The Report has been revised to ensure that it does not prejudge decisions about the desirable level and nature of future research or discuss matters of policy on which the present Government will require to take its own decisions.

Because of the subject matter the Report will attract interest and comments. Its main value (apart from indicating publicly that the action promised in the White Paper has been carried out) is as an account of the main problems of radioactive waste management and the research which the relevant Government Departments are undertaking to deal with them.

A number of conclusions are drawn in Chapter 6 and these will be reviewed during the coming months as part of my Secretary of State's general review of Departmental priorities, and his specific intention to scrutinize the research programme.

Yours sincerely

Paul Bristow

P N BRISTOW
Private Secretary

Mike Pattison Esq

Departments of
the Environment
and Transport

Research Report 32

Review of Research on Radioactive Waste Management and Radioactivity in the Environment

£2.55

Review of Research on Radio-active Waste Management and Radioactivity in the Environment

A review carried out by the Directorate General of Research on behalf of the Department of the Environment

Department of the Environment
2 Marsham Street
London SW1P 3EB

DOE/DTp Research Reports contain the results of research (and sometimes related development or application), initiated within the Departments' HQ Divisions and carried out either by Departmental staff or under extra-mural contract.

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Building (brown)	Resources (purple)
Highways (green)	Transportation (yellow)
Local Government (orange)	Water (light blue)

Reports spanning more than one subject area have black printed covers.

CONTENTS

ABBREVIATIONS AND ACRONYMS

ACPM	Advisory Committee on Programme Management (of EEC)
AERE	Atomic Energy Research Establishment (Harwell)
AGR	Advanced Gas-cooled Reactor
ARC	Agricultural Research Council
BNFL	British Nuclear Fuels Ltd
CEA	Commissariat de L'Energie Atomique (France)
CEGB	Central Electricity Generating Board
CEN	Centre D'Etudes de L'Energie Nucleaire (Belgium)
CERL	Central Electricity Research Laboratories
CNEN	Comitato Nationale per L'Energie Nucleare (Italy)
DNPDE	Dounreay Nuclear Power Development Establishment
DOE	Department of the Environment
ECN	Energieonderzoek Centrum Nederland (Netherlands Energy Centre)
EC	The term used in this report to include some or all of the European Economic, Atomic Energy, and Coal and Steel Communities
EEC	European Economic Community
FBA	Freshwater Biological Association (supported by NERC)
FINGAL	Fission products INto GLAss
FRL	Fisheries Radiobiological Laboratory (MAFF)
GFK	Gesellschaft fur Kernforschung (Germany)
HARVEST	Highly Active Residues Vitrification Engineering STudies
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IGS	Institute of Geological Sciences (NERC)
IMER	Institute for Marine Environmental Research (NERC)
IOS	Institute of Oceanographic Sciences (NERC)
ITE	Institute of Terrestrial Ecology (NERC)
JRC	Joint Research Centre (of EC)
MAFF	Ministry of Agriculture Fisheries and Food
MRC	Medical Research Council
NEA	Nuclear Energy Agency (of OECD)
NERC	Natural Environment Research Council
NII	Nuclear Installations Inspectorate
NRPB	National Radiological Protection Board
OECD	Organisation for Economic Cooperation and Development
PCM	Plutonium Contaminated Materials
RWMAC	Radioactive Waste Management Advisory Committee
SSEB	South of Scotland Electricity Board
THORP	THermal Oxide Reprocessing Plant
UKAEA	United Kingdom Atomic Energy Authority

PREFACE

1 This Review of Research was put in hand by the Department of the Environment in response to the White Paper 'Nuclear Power and the Environment' (Cmnd 6820, May 1977). It was planned to provide a picture of the situation in the early part of 1978, as a basis for considering research requirements. It does not, therefore, include proposals for future research, although some requirements are identified. Instead it deals with state of research in this general field, the agencies involved in it, the programmes they have developed, and the related expenditures. The report has benefited from advice given by many bodies referred to in the text. It is published to provide a background of information about research for those interested in this important field.

2 The Department is continuing to assess the need for research on all aspects of radioactive waste management in the light of this review and in consultation with Radioactive Waste Management Advisory Committee under Sir Denys Wilkinson FRS. Further developments will be described in the annual report of the Advisory Committee and in the Department's annual report on research.

M W HOLDGATE

March 1979

REVIEW OF RESEARCH ON RADIO-ACTIVE WASTE MANAGEMENT AND RADIOACTIVITY IN THE ENVIRONMENT

CHAPTER ONE: INTRODUCTION

1.1 The White Paper 'Nuclear Power and the Environment' (Cmnd 6820, May 1977), the then Government's response to the sixth report of the Royal Commission on Environmental Pollution (Cmnd 6618, September 1976), announced that the Secretaries of State for the Environment, Scotland and Wales [the 'Environment Ministers'] would, as part of their new responsibility for policy on the management of civil nuclear waste, review the adequacy of the research effort on waste disposal and on radioactivity in the environment, including research relevant to the current review of existing arrangements (Cmnd 884, November 1959) for the control of radioactive waste. The present paper prepared by the Environmental Protection Research Division of the Department of the Environment, in association with the Department's Waste Management Division, attempts to lay the foundations for this review of research.

1.1.1 The preparation of the paper has been facilitated by visits to and discussions with those responsible for current research at *AERE and NRPB (Harwell), BNFL (Risley), MAFF Fisheries Radiobiological Laboratory (Lowestoft) and CEGB (Berkeley Nuclear Laboratories); a comprehensive submission from MAFF Directorate of Fisheries Research, discussions with NERC and information from the other Research Councils; and by discussions within DOE and with UKAEA and the Department of Energy to implement the decision (Cmnd 6820, paragraph 17) to transfer to the Environment Ministers control of the waste management element of UKAEA's research and development programme.

Scope of the review

1.2 Radioactive waste—material of no commercial interest—arising from the nuclear fuel cycle may be divided into 3 broad categories—

(a) waste requiring some form of interim storage or treatment or special methods of disposal;

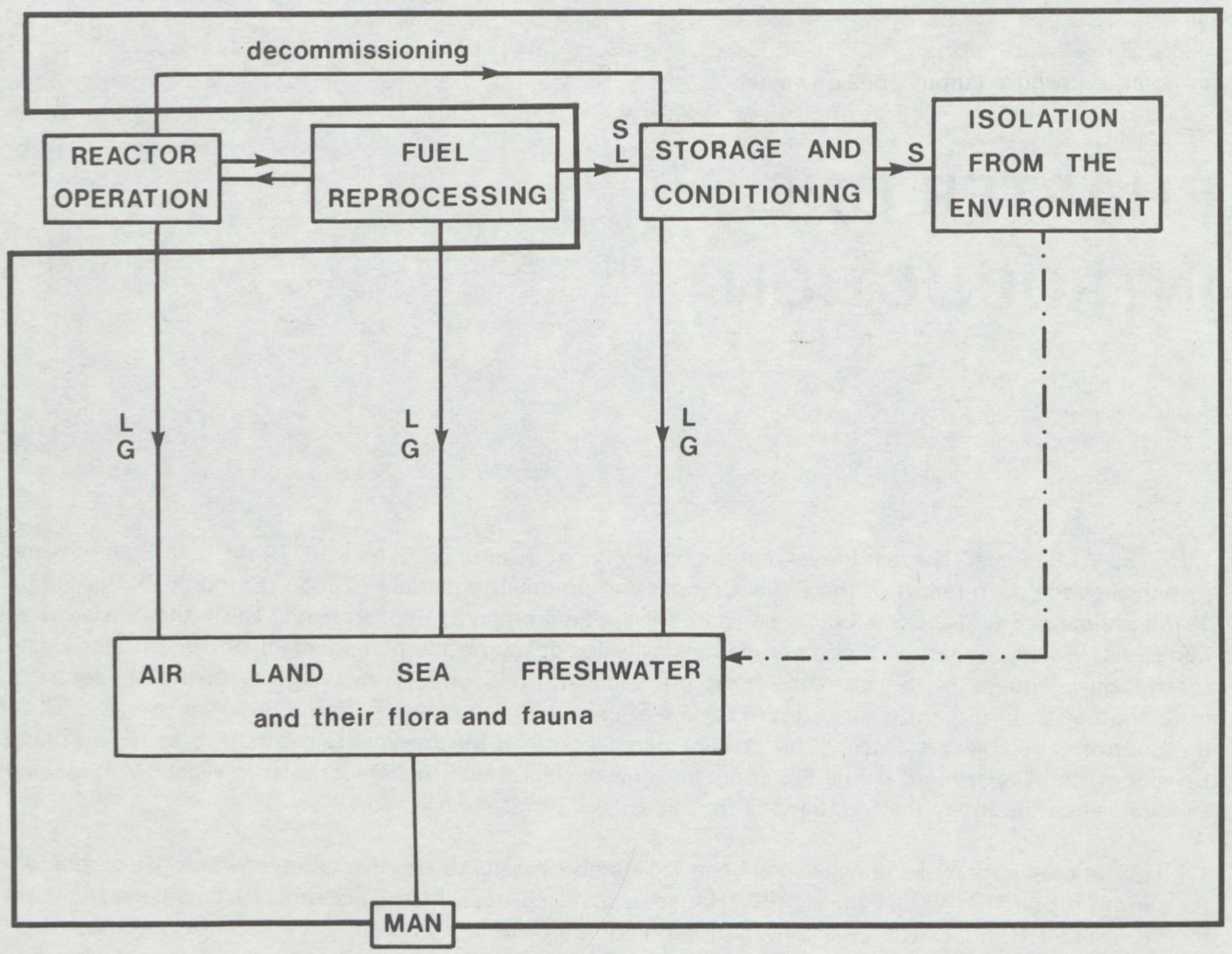
(b) liquid and gaseous wastes suitable (perhaps after minimum treatment) for discharge direct to the environment;

(c) solid waste suitable for disposal by burial at local public sites or by other methods applicable to non-radioactive waste.

The paper considers research on the management† of radioactive waste from the time of its creation, through any necessary storage† and conditioning†, to its disposal† by either dispersion in or isolation from the environment; and, thereafter, its actual and potential progress along environmental pathways leading to man. The general area of concern is indicated in Figure 1. Emphasis is given to waste of types (a) and (b), since solution of the problems associated with these wastes should contribute substantially to solving those of other radioactive wastes—e.g. from industry and medicine. Research on wastes of type (c) has not been included in the review because, in general, they require no treatment before disposal.

1.2.1 Environmental monitoring programmes for radioactivity (the co-ordination of which is another of the Environment Ministers' new responsibilities, and which are currently being examined in the context of environmental monitoring in general) are not considered, although it is recognised that research into, and

*The full titles of the various bodies are given in the table of Abbreviations
†These items are defined at the end of Chapter One.



Waste types : S solid
L liquid
G gaseous

Figure 1 RADIOACTIVE WASTE FROM THE NUCLEAR FUEL CYCLE

Scope of the review of research ————

monitoring of, environmental pollution are not mutually exclusive and that the results of either activity may indicate a need for change in the level or emphasis of the other.

1.2.3 It was not thought useful to draw a precise definition of 'research' as opposed to 'development', and it is recognised that some of the work reviewed later in this paper may not comfortably be described as 'research'. Such work is included primarily to illustrate the progress made or expected in applying the results of 'research' on an operational scale.

Objectives of research

1.3 The prime objective of any policy on the management of radioactive waste must be to protect man and the environment. The term 'man' here includes both the public at large and those employed in the nuclear industry, and the protection of the environment covers not only the interests of agriculture and of fisheries, but also the maintenance of amenity, the protection of wildlife and so on. The general objective of research is to establish, optimise and demonstrate routes suitable for the disposal of all forms of radioactive waste. There are already authorised practices—e.g. direct discharge to the atmosphere and ocean, and dumping in containers in the deep ocean—for the disposal of some forms of waste; these practices must, of course, be reviewed regularly in the light of new information and evolving opinions about their consequences. There are, however, growing accumulations of waste for which no overall disposal strategy currently exists. Research to establish such a strategy will be vital for the successful discharge of two of the Environment Ministers' new responsibilities, namely:

— to secure the programmed disposal of waste accumulated at nuclear sites;
— to ensure that waste management problems are dealt with before any large nuclear programme is undertaken;

having due regard to environmental considerations.

1.3.1 The disposal of wastes not suitable for immediate dispersal in the environment can generally be considered in two, closely related stages: conditioning of the waste into a form, invariably solid, ready for disposal by isolation from the environment (perhaps with concomitant production of waste suitable for dispersal); and disposal itself. The intended disposal route and the rigour of containment required of the conditioning process for each type of waste must clearly be compatible; in practice, it seems likely that the latter will have to be determined by the availability of the former. The choice between options within this requirement will then be the ultimate step of policy development.

Definitions

Conditioning refers to the physical or chemical treatment used to convert waste into a form suitable for disposal, and includes the decay of nuclear activity during storage.

Disposal and *Storage* are used as in the White Paper 'Nuclear Power and the Environment (Cmnd 6820—May 1977) i.e.

Disposal is defined as the dispersal of radioactive waste into an environmental medium or emplacement in a facility, either engineered or natural, with the intention of taking no further action except, perhaps, environmental monitoring.

Storage is defined as emplacement in a facility, either engineered or natural, with the intention of taking further action at a later time, and in such a way and location that such action is expected to be feasible. The action may involve retrieval, treatment in situ, or a declaration that further action is no longer needed and that storage has thus become disposal.

Management is used as a broad term to describe all or part of the process of minimising the creation of waste and the subsequent sequence of its conditioning, storage and disposal.

CHAPTER TWO:

OVERALL VIEW OF CURRENT RESEARCH PROGRAMMES

Introduction

2.1 Research on the subjects central to the present review is widespread throughout the world and it has not been feasible to take account directly of all this work. There are, for example, substantial programmes in America, Canada, Japan and the Soviet Union and relevant work in many other countries which have not been examined in detail. The aim during the review has been to consider research undertaken in the UK and internationally-sponsored research programmes in which the UK shares. It was, therefore, essential to include the research carried out under the auspices of the European Communities [hereafter referred to as EC, to include some or all of the Atomic Energy, Economic and Coal and Steel Communities]; certain UK activities form an integral part of this work. It has also been possible to draw on information from the Organisation for Economic Co-operation and Development (OECD) and the International Atomic Energy Agency (IAEA). There are, of course, extensive international arrangements for the exchange of information and the co-ordination of programmes.

2.1.1 Expenditure in the UK on research on radioactive waste management and radioactivity in the environment was about £7 million in 1977/78. A breakdown of the major part of this expenditure is given in Table 2.1.

A. WASTE MANAGEMENT

UKAEA/BNFL Research on waste conditioning

2.2 Virtually all the basic and more speculative research and initial development of processes for waste conditioning in the UK are undertaken by the United Kingdom Atomic Energy Authority at Harwell (AERE) and Dounreay (DNPDE), British Nuclear Fuels Limited, at Windscale and Risley, then continue development of those processes with promise for operational use. The two organisations' programmes are closely co-ordinated. The UKAEA element includes the research to be controlled by the Environment Ministers, see para 1.1.1. This research expenditure is associated with substantial development expenditure additional to that tabulated: £1.13 m by UKAEA in 1977/78, principally towards the design and construction of waste handling and storage facilities at Dounreay; and £3.16 m by BNFL, largely towards the construction of an active pilot vitrification plant and associated facilities at Windscale.

European Community research programmes

2.2.1 The European Community's research on the management and storage of radioactive waste has two components: a 'direct action' programme conducted by the institutions of the Communities' Joint Research Centre (JRC)—most work is undertaken at the EURATOM establishment at Ispra in northern Italy, although some is conducted at the JRC Karlsruhe; and an 'indirect action' programme carried out, with partial support (normally up to 50%) from Community funds, by research institutes in Member States. Both programmes are steered by the same Advisory Committee on Programme Management (ACPM), which reports to the Commission and, in turn, to the Council; the ACPM also sponsors technical working groups to advise it on specific topics within the programme.

2.2.2 During the first direct action programme (1973 – 76) three main problems were studied:

(a) the feasibility of a strategy based on chemical separation of actinides from waste and their recycling in nuclear reactors;

(b) develoment of methodology for evaluation of the long-term hazards of waste disposal in geological formations (partly to assess the benefits of actinide recycling); and

(c) treatment of fuel before reprocessing to simplify waste disposal problems, by removal of gaseous material and minimisation of insoluble residues.

Work on (a) and (b) is continuing during the second direct action programme (1977 – 80) which also includes research on the decontamination of reactor components. The allocation of manpower and expenditure to the various projects in 1977 is given in Table 2.2.

2.2.3 The indirect action programme nominally covers the five years 1975 – 79, but the first contracts were not signed until 1976. The total budget is 19.16 Mua (£8m), of which 47% (£3.8m) had, by October 1977 been committed or specifically allocated to research projects which, with Member States' contributions, involve total expenditure of £8.1m (average Community contribution 42%). The ACPM has accepted a recommendation for the allocation of a further 41% (£3.3m) to support additional research on the storage and disposal of radioactive waste in geological formations under land, bringing to over 62% the proportion of the total budget devoted to this topic; no part of the existing programme involves research on disposal on or under the sea bed. The allocation of Community funds between the 'sheets' of the indirect action programme and between Member States is shown in Table 2.3. About 10% (£0.8m) of the budget remains to be allocated at the time of writing.

2.2.4 There are other Community activities in areas adjacent to that of radioactive waste: in particular, there are direct action research programmes (1977 – 80) at Ispra and Karlsruhe on reactor safety and on plutonium fuels and actinide research; an indirect action research (1976 – 80) on radiation protection, including some work on environmental contamination and risk assessment; and the European Community Policy and Action Programme on the Environment includes study of the problems of decommissioning reactors and fuel reprocessing plants.

Other internationally-sponsored research programmes

2.2.5 The Nuclear Energy Agency (NEA) of the OECD—based in Paris—is concerned to stimulate co-operation between the co-ordination of national research programmes. It seeks to achieve this by organising and sponsoring meetings, symposia, and expert groups. Some items of current concern are listed in Table 2.4.

2.2.6 The International Atomic Energy Agency (IAEA), based in Vienna, is the main international body in this area which involves Eastern bloc countries. Like NEA it sponsors workshops and conferences, and attempts to co-ordinate national programmes through the exchange of information. It has no formal research programme, but its work has led to the development of codes of practice on, for example, standards for the treatment and disposal of waste and for evaluating the impact of radioactivity on the environment; decommissioning; operational and safety procedures; and legislative guides. IAEA have produced technical reports which summarise the state of the art in various countries or aspects of waste management.

B. RADIOACTIVITY IN THE ENVIRONMENT

2.3 Expenditure on research specifically on radioactivity in the environment is more widely distributed amongst research institutions and is substantially less than that on the management of stored waste, although in this field the mass of knowledge and research based on non-radioactive substances—i.e. their behaviour and transformation in the environment—finds readier application. Research in this area is usually designed:

(a) to support those Departments (DOE, MAFF, and the Scottish and Welsh Offices) with statutory responsibilities for authorising the routine discharge of radioactivity to the atmospheric, land, freshwater, and marine environments (including sea dumping); and/or

(b) to assess the risks associated with the various options for the storage and disposal of solid waste.

These objectives are clearly complementary in that they are both concerned with improving understanding of the more obvious environmental pathways by which radioactive material reaches and might reach man. The results of monitoring are useful in testing aspects of this understanding. There is also a substantial body of research which uses natural and man-made radioactive materials in the environment as tracers of natural processes e.g. geochemical cycling.

2.3.1 As Table 2.1 shows, current UK research specifically on the environmental aspects of radioactivity (including the environmental aspects of disposal) is undertaken by MAFF (partly on behalf of other authorising Departments), with some other work being undertaken by Institutes of NERC, and by NRPB and AERE; much of the broader expertise of these bodies is also useful in guiding and supporting this work. DOE has until recently sponsored no research specifically in this field (although, of course, it supports much that is relevant in the general field of environmental pollution), but has allocated £100k to initiate research in 1978/79*. NRPB and MRC (largely at their Radiobiology Unit, Harwell) also conduct and sponsor radiobiological research to assess the effects and mechanisms of human exposure to radiation and to develop treatments to remove ingested, radioactive material from the body.

MAFF Directorate of Fisheries Research, Fisheries Radio Biological Laboratory (FRL), Lowestoft

2.3.2 Expenditure by MAFF on research into radioactivity in the aquatic environment was about £650k in 1977/78, including about £80k per annum for the time of MAFF research vessels. The research at FRL involves about 60 scientific and supporting staff and is concerned primarily with investigating the radiological consequences of discharges of radiaoctive waste, including not only the resulting human exposure to radioactivity but also the potential impact on aquatic resources. Some £200k per annum of the total expenditure is also being devoted to a small scale deep sea disposal study in preparation for any major UK research programme in this area. A working group, including members from MAFF and NRPB and later NERC/IOS and BNFL, was set up in 1975 to improve an existing mathematical model and to define work necessary better to describe the behaviour of the deep ocean with reference to the possible disposal of radioactive waste on the sea bed. This group has recently been reorganised to include members from the Department of Applied Mathematics and Theoretical Physics (Cambridge University) and DOE. Current MAFF research projects, including those related to high level waste, are essential to meet problems in relation to current disposals of low level waste in coastal waters and the deep ocean, and could need expansion if such disposals were to increase or new problems to emerge.

Natural Environment Research Council (NERC)

2.3.3 The main involvement of NERC Institutes in research specifically related to radioactive waste has to date been that of IGS (London and Harwell establishments) which, under contracts with AERE and the EC, is studying the geological aspects of problems associated with the disposal of high level waste. Desk studies and some field studies to identify potential sites for investigation are taking place. Research into the characteristics and properties of the more promising types of geological formation is dependent upon planning permission being granted.

2.3.4 Other recent work funded by NERC includes an analysis by IMER (Plymouth) of the processes of uptake and retention of transuranic radionuclides by mussels and, with BNFL, studies of sediments in the Windscale area; and a small study at the University of Lancaster (in association with FRL) on the uptake and redistribution of caesium in near-shore waters and sediments. ITE and IOS are initiating pilot studies in their respective fields and the British Antarctic Survey (for which NERC is responsible) collects precipitation samples for monitoring by UKAEA and IAEA.

National Radiological Protection Board, (NRPB) Harwell

2.3.5 The NRPB was established in 1970 to provide a national, authoritative point of reference on radiological protection. Its statutory responsibilities are to advance the acquisition of knowledge about radiological protection, by research and other means, and to inform and advise those with responsibilities for protecting all or parts of the community from radiation. The Board has recently been given a formal direction to advise the appropriate Government Departments and statutory bodies on the acceptability for application in the UK of recommendations or proposed recommendations by international bodies such as the International Commission on Radiological Protection (ICRP).

*Programmes of work at NERC/ITE, and NERC/IOS, and a joint programme with AEA and BNFL have now been started.

2.3.6 The Board's programme of work, therefore, includes assessing the extent and effects of the exposure of man to radioactivity, and studying the movement of nuclides through the environment to man. With regard to radioactive waste management, this involves identifying the important nuclides and the pathways by which they might reach man, and assessing the potential radiation exposure of the individuals and groups concerned. The Board also helps the authorising departments by defining 'derived limits' which relate the levels of discharges of radionuclides to their concentrations in environmental materials and to the exposure of members of critical groups. The Board co-ordinates its work relating to the aquatic environment with that of MAFF/FRL.

Atomic Energy Research Establishment (AERE), Harwell

2.3.7 The environmental research programme at AERE originally developed around 3 fundamental objectives: the assessment of permissible limits for routine discharges from nuclear installations; the routine protection of nuclear workers; and the field application of radio-isotopes. Following the establishment of acceptable standards, considerable research effort has been diverted to other areas requiring similar expertise and background knowledge. For example, DOE has for the past 5 years supported a major programme of research (£250k per annum) on the atmospheric chemistry of the oxides of nitrogen and sulphur. Current expenditure by AERE (mainly the Environmental and Medical Sciences Division) on nuclear environmental assessment and research is about £90k per annum, and there are one or two relevant projects in the radiation protection research programme (£600k per annum, of which about 30% is under contracts with the nuclear industry, NRPB, MAFF and the EC). The work now includes the first phase of a new programme recently begun in the Windscale area. This programme, developed jointly by AERE and BNFL in consultation with DOE and NERC/ITE, and to be undertaken by AERE staff, has been designed to define in more detail than hitherto the behaviour and fate of such plutonium and other actinides as may be discharged to the Cumbrian environment from the Windscale stacks and pipelines. The programme is estimated to cost about £125k in its first year, to which cost BNFL and DOE will make contributions.

Central Electricity Generating Board (CEGB)

2.3.8 The CEGB carry out research to help ensure that operation of their nuclear stations is not harmful to the public or to their staff. Although directly concerned with only part of the nuclear fuel cycle, the Board must have sufficient knowledge of the whole cycle to be satisfied that it is environmentally acceptable. A major part of this work is the development of computer models to evaluate the effects of activity released from nuclear power stations in both normal operation and in accident conditions. This work is to some degree an extension of the generic research on atmospheric dispersal of plumes emitted from power stations which is applicable to both conventional and nuclear electricity generation. In particular, work is in hand to characterise and establish the effects of particulate activity emitted from stations. Support is also provided to the routine environmental and personnel monitoring programmes of stations by development of improved techniques and provision of specialist services.

2.3.9 In addition the Board is carrying out work on improved methods for disposal of wastes arising on stations, such as wastes from fuel cooling ponds and ion exchange resins, and study of methods for eventual decommissioning of nuclear stations.

Other Research Institutions

2.3.10 In addition to the organisations and establishments whose work is outlined here, some other bodies, particularly some Universities, have relevant expertise and research capabilities. It is clear, however, from the nature and scale of equipment involved and from the interdisciplinary character of much of the research on radioactivity and radioactive waste that the overwhelming majority of research in this field must continue to be undertaken by teams of specialists and at research establishments specifically equipped for the purpose. The association of staff from Universities and polytechnics with such research establishments could, nevertheless, serve to enhance the expertise available.

Table 2.1 TOTAL UK EXPENDITURE ON RESEARCH ON RADIOACTIVE WASTE MANAGEMENT AND RADIOACTIVITY IN THE ENVIRONMENT 1977/78 (£k)

A By funding organisation

£k (Sept 76 prices)

	UKAEA	*BNFL*	*MAFF*	*NRPB*	*NERC*	*CEGB*	*EC*(1)	*Others*	*UK Total*
Waste conditioning	1400	3200	—	—	—	75	405	—	5080
Long-term storage and disposal	380	—	200	20	5	25	120	—	750
Environmental research	90	—	470	175	45	125	—	30	935
Totals	1870	3200	670	195	50	225	525	30	6765

B By Contractor

	UKAEA	*BNFL*	*MAFF*	*NRPB*	*NERC*	*CEGB*	*Others*	*Total*
Waste conditioning	3170	1910	—	—	—	—	—	5080
Long-term storage and disposal	400	—	200	40	110	—	—	750
Environmental research	90	—	470	175	55	125	20	935
Totals	3660	1910	670	215	165	125	20	6765

Notes: (1) EC contracts assumed to run for 2 years, with half expenditure falling in 1977/78.

Table 2.2 EC (EURATOM) DIRECT ACTION RESEARCH PROGRAMME ON RADIOACTIVE WASTE MANAGEMENT AND STORAGE: MANPOWER AND EXPENDITURE 1977

Project	*Manpower*	*Expenditure (£k)*(1) *on equipment andmaterials*
1 Evaluation of the long-term hazard of radioactive waste disposal in geological formations		
1.1 Waste hazard analysis	6	2
1.2 Long-term stability of conditioned waste	8	23
1.3 Interaction of actinides with the environment	5	19
1.4 Actinides monitoring	4	16
2 Chemical separation and nuclear transmutation of actinides		
2.1 Chemical separation of actinides	13·5	45
2.2 Assessment of nuclear transmutation	5	1
2.3 Actinide cross section measurements	6	11
3 Decontamination of light water reactor components	10·5	25
Co-ordination, meetings etc.	1	19
Totals	59	161

Note: (1) Excluding salaries; based on conversion at £1 = 2.4 ua.

Table 2.3 EC INDIRECT ACTION PROGRAMME OF RESEARCH ON RADIOACTIVE WASTE MANAGEMENT AND STORAGE 1977–80: ALLOCATION OF FUNDS £k (OCTOBER 1977)

Sheet / *Country*	*B*	*F*	*D*	*Dk*	*I*	*IRL*	*NL*	*UK*	*Totals*
1 Coating of medium-activity solid waste with plastic resin	150 joint project		50	0	0	0	0	0	200
2 Decontamination and conditioning of irradiated fuel elment cladding	83	73	75	0	0	0	0	30 (45%)	261
3 Incorporation of waste in metal matrices	0	0	0	0	0	0	6	0	6
4 Incineration of plutonium contaminated waste	205	0	101	0	149	0	0	548 (39%)	1 003
5 Properties of substances suitable for high level waste solidification	0	34	42	0	0	0	0	83 (48%)	159
6 Engineered storage for solidified high-level waste	40	0	40	0	0	0	0	0	80
7 Long-term storage and disposal in geological formations:									
(a) Catalogue	12½	12½	12½	0	12½	12½	0	12½ (100%)	75
(b) Existing projects	199	292	578	5	292	0	42	225 (38%)	1 633
(c) New proposals (1978–79)	664	750	675	32	375	0	115	642 (50%)	3 253
8 Storage of gaseous wastes	60	37	83	0	0	0	0	111 (48%)	291
9 Separation and recycling of actinides	0	0	0	0	0	0	0	28 (100%)	41
* Legal, administrative and financial studies	8	0	0	0	0	0	0	0	8
Totals	1 347½	1 273½	1 656½	37	828½	12½	176	1 679½ (44%)	7 010

*known as 'Group 4'

Notes: Includes existing and proposed contracts.

Figures in brackets are the proportions of total project costs met by Community funding.

The figures, in £k, are based on conversion from European Units of Account (ua) at the rate of £1 = 2.4 ua. On 1 January 1978, the unit of account was redefined and its value now fluctuates roughly in line with European exchange rates. EC contract values are normally expressed in national currencies, and so the values of existing UK contracts are unaffected.

Table 2.4 ***STUDIES AND RESEARCH BY THE OECD***
NUCLEAR ENERGY AGENCY

Radioactive Waste Management

(a) Advice from specialists on the disposal of radioactive waste into geological formations.

(b) Advice from specialists on:—
—conditioning of low, medium and high level (including α-bearing) waste;
—retention, storage and disposal of gaseous waste; testing of high efficiency particulate filters;
—decontamination and decommissioning of nuclear facilities.

(c) Co-ordination of national activities concerning the disposal of high level radioactive wastes on or under the ocean floor.

(d) Revision of NEA guidelines on packages for sea disposal of radioactive waste.

(e) Eurochemic programme on the conditioning of high level wastes in metal matrices.

Environmental Studies

(a) Biological and environmental behaviour of plutonium.

(b) Radioactive effluent release practices and policies and their environmental impact.

OECD ENVIRONMENT COMMITTEE (1): Items from 1978 provisional programme

(a) Criteria for identification and assessment of suitable sea dumping sites.

(b) Development of methodology for the assessment of the relative safety and environmental aspects of different options for the disposal of radioactive waste.

(c) Environmental guidance on standards of credibility.

(d) Consideration of environmental aspects of international regional agreements on radioactive waste disposal.

(e) Development of criteria to assist in decisions on the use of land for disposal of radioactive waste for long periods, bearing in mind the potential need to develop national resources from the site and other uses of land.

Note: (1) The Environment Committee is concerned with the broad environmental impact of activities including nuclear waste management.

CHAPTER THREE:

RESEARCH ON CONDITIONING OF RADIOACTIVE WASTE

Introduction

3.1 Radioactive wastes arise at all stages of the nuclear fuel cycle. As explained in Chapter 1, the review is concerned with wastes from reactor operation, fuel reprocessing and the decommissioning of reactors and other plant. Of these the second currently receives the greatest attention, although the importance of wastes from decommissioning will increase substantially when existing nuclear power stations are phased out.

3.1.1 Waste can be distinguished in terms of its point of origin in the fuel cycle and the precise composition in which it first arises; for the purpose of developing conditioning processes and procedures, however, it is convenient to consider the following categories:
(a) Highly active liquid waste.
(b) Highly active solid waste.
(c) Medium active liquid wastes, concentrates, sludges and resins.
(d) Low active plutonium contaminated (low $\beta\gamma$) waste.
(e) Volatile and gaseous waste.
(f) Wastes from decommissioning reactors and other plant.

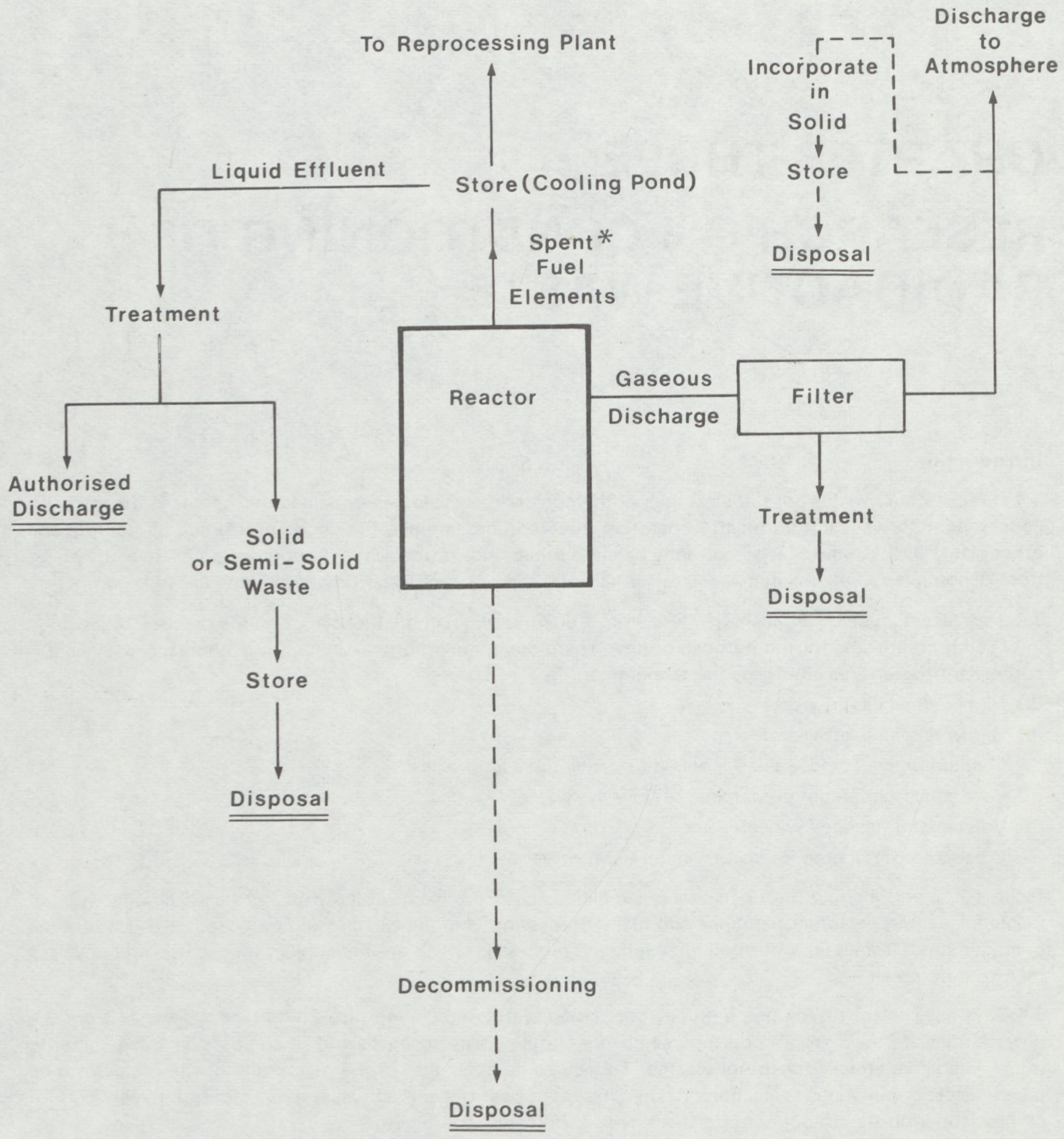
Figures 2, 3 and 4 show, in a necessarily simplified form, the main routes whereby these various types of waste arise during reactor operations and fuel reprocessing, and the existing and proposed methods for their management. Dashed lines in the figures indicate processes which are the subject of research and development programmes.

3.1.2 Most current research is naturally concerned with conditioning of existing types of waste from the present nuclear power programme and, since most future waste arisings are likely to be similar in character to these, will serve equally for future wastes. To give some indication of the magnitude of the problem to be faced, Table 3.1 includes predictions of the amounts of some types of waste expected in the year 2000 for comparison with the amounts of wastes now accumulated.

Table 3.1 ESTIMATES OF THE ACCUMULATION OF WASTE IN THE YEAR 1976 AND PREDICTED ACCUMULATION BY THE YEAR 2000

Category of Waste	*Volume (m^3)*	
	1976	*2000*
Highly active liquid waste		
at Windscale	730	5 000(1)
at Dounreay	800(2)	2 000
Highly active solid waste (fuel cladding)	7 000	20 000
Sludges and miscellaneous wastes	11 000	19 000
Plutonium contaminated wastes	3 000	10 000
Wastes stored at power stations	20 000	36 000

(1) Depending upon the timing of the adoption of a solidification process this might be reduced to some 1500 m^3 in liquid form plus 1250 m^3 of vitrified waste.
(2) Fission product waste at Dounreay is not concentrated by evaporation as it is at Windscale.



* Parts of the Fuel Assembly are removed and stored at Power Stations

——— Established Process
– – – – Possible Process

Figure 2 WASTES FROM REACTOR OPERATION

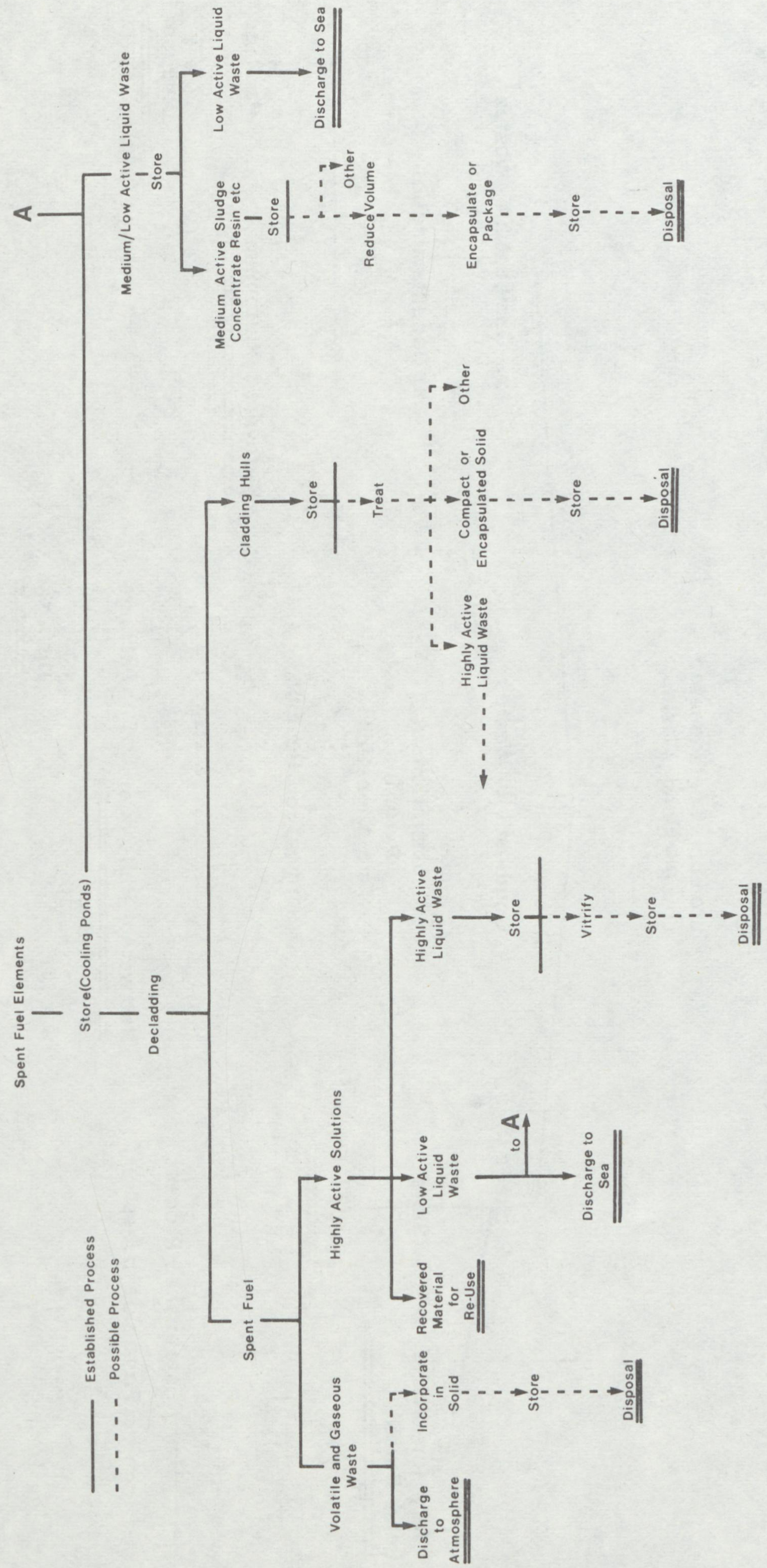


Figure 3 WASTE ARISING FROM FUEL REPROCESSING

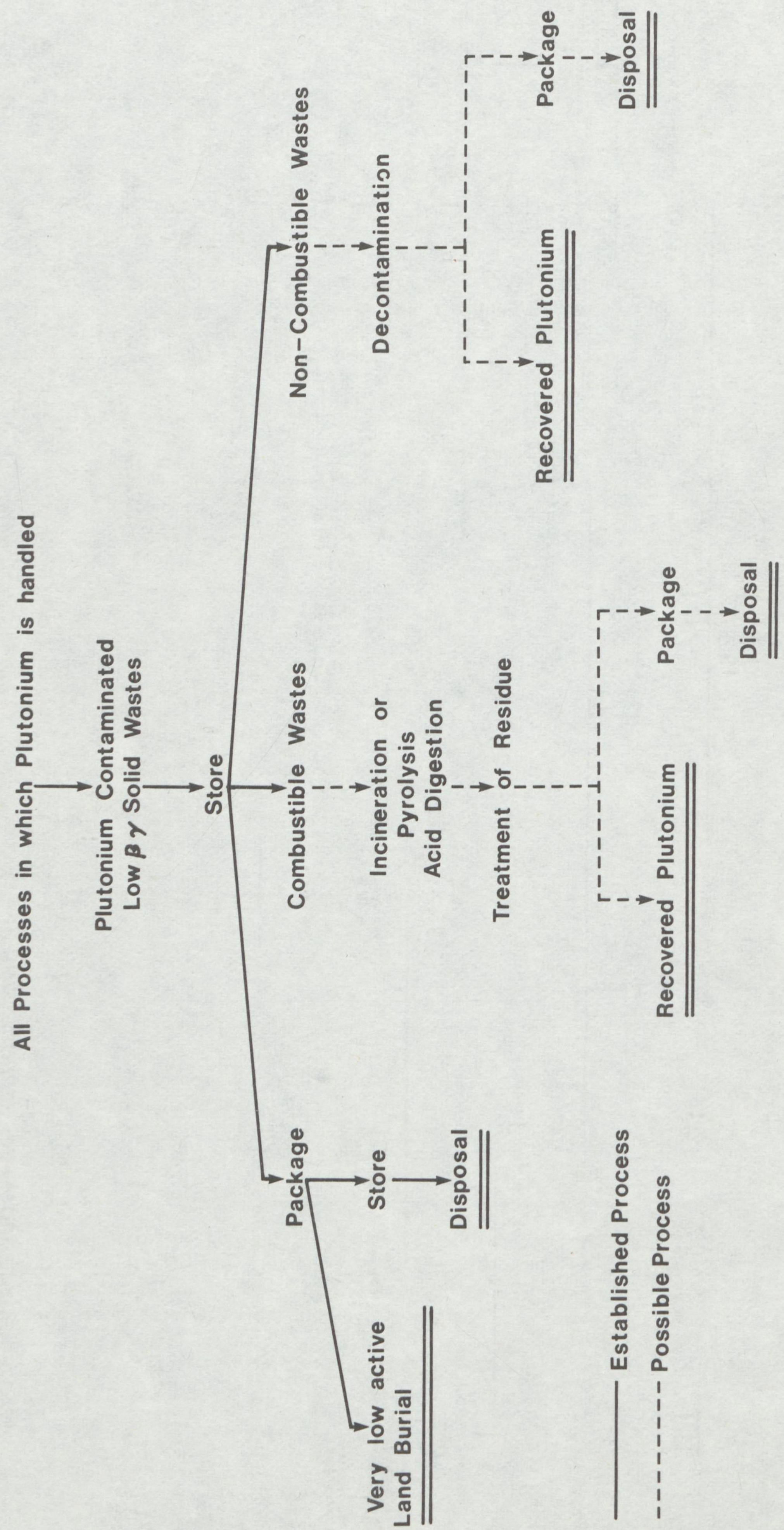


Figure 4 PLUTONIUM CONTAMINATED LOW $\beta\gamma$ SOLID WASTE

High Level Liquid Waste

3.2 This arises, at a rate of about 7 m^3 annually per GW of installed nuclear electrical capacity, from concentration of the waste stream from the first solvent extraction stage of fuel reprocessing at BNFL's Windscale plant. It contains about 99·9% of the non-volatile fission products, some unextracted plutonium and almost all the higher actinides (neptunium, americium and curium). Soon after production its activity and potential hazard are dominated by the fission products; eventually, however, the actinide component becomes the more important because of its considerably longer half-life. The waste is stored in shielded high-integrity tanks and must be cooled to remove fission product decay heat. In 1976 there was about 730 m^3 of waste at Windscale with a total activity of 0·5 MCiα and 500 MCiβ.

3.2.1 There is general agreement that high level liquid waste should, after a period of storage to allow decay of nuclear activity ('cooling') be solidified and packaged to make its continued storage, for further cooling, less onerous and to permit its ultimate disposal. Separation of the unextracted actinides from the fission products—the former for partial conversion in fast reactor fuel elements to less long-lived nuclides and the latter for separate storage and disposal, possibly in solidified form—may be one means to ease disposal problems in the longer term, at the expense of increasing occupational exposure and generating additional lower level waste.

3.2.2 Research in the UK centres on the FINGAL/HARVEST vitrification process for incorporating waste into cylindrical glass blocks. The proportion and period of prior cooling of the waste determine the heat generated by the resulting glass blocks and, consequently, the need for measures to prevent the blocks overheating and damaging their surroundings or themselves (e.g. by melting). A full-scale experimental HARVEST plant, with simulated fission products, is operated by UKAEA at Harwell; BNFL are constructing a small fully-active glass-making plant and a full-scale inactive pilot plant; a full-scale active plant should be commissioned in the late 1980s. The objectives of current research are to solve (using the inactive plant) the outstanding engineering problems of handling highly active waste and the gas evolved during the vitrification process; and to optimise the physical and chemical characteristics of the glass produced, including its stability to radiation.

3.2.3 AERE Chemistry Division are studying the properties of glass compositions that might be suitable for vitrifying high level waste from spent Magnox fuel. They have demonstrated that exposure of glass to α radiation equivalent to over 10 000 years storage has no effect on the integrity of the glass and only a slight effect on the leach rate; that the leach rate in tap water at ambient temperature of a glass formed at 1000°C is equivalent to about 70 microns (70×10^{-6} metres) per century (i.e. 1 cm in about 14 000 years); but that some glasses formed at lower temperatures are much less resistant to leaching, particularly under acid conditions. The Chemistry Division is also undertaking, under a contract from the EC, comparative testing of two UK, one French and two German glass compositions. Further comparative testing of the glasses is being undertaken in France and Germany.

3.2.4 Research by AERE Chemical Technology Division is designed to establish the chemical and engineering principles of the vitrification and gas treatment systems and to maximise throughput at a maximum glass temperature of 1050°C; above this temperature reliable furnace engineering and uniform heating are more difficult to achieve. Five full-scale runs were performed on the inactive plant in 1976/77, leading to a basic understanding of the thermal behaviour of the vitrification zone and its boundaries. The glass produced by the experimental plant has a leach resistance comparable with that of glass produced on a laboratory scale.

3.2.5 BNFL's work, at Windscale and Risley and also by extra-mural contractors, is mainly on the design and construction of the active pilot plant and 'caves' for preparation, examination and necessary storage of the solid waste produced. The work includes safety and reliability studies for the pilot plant and work is planned on methods for further encapsulating vitrified waste should this be necessary for ultimate disposal.

3.2.6 Research in other countries on the solidification of high level liquid waste also includes vitrification in glasses of various compositions and at various temperatures, and also calcination—i.e. evaporation of waste to dryness, followed by heating to produce a powder or granular material. The calcined waste is not generally suitable for long-term storage or disposal—it has low leach resistance, low thermal conductivity and can be easily dispersed—but may be a useful interim product for conversion to, incorporation in or coating with other, more robust material (including glass). However, vitrification is the most developed and promising of the techniques being studied and seems generally accepted as capable of producing satisfactory solidified material on laboratory and pilot plant scales. Proof on an industrial scale has yet to be achieved, although a plant at Marcoule (France) is expected to start operation soon.*

3.2.7 The success on an industrial scale of a vitrification process for 'fixing' highly active waste is regarded as crucial to the overall development of a satisfactory system for managing existing and future radioactive wastes in the UK, virtually irrespective of what the preferred disposal option(s) may be. Although there are still substantial engineering and other problems to be solved; as mentioned above (paragraph 3.2.2), current plans are that a full-scale active plant should be ready by the late 1980s.

Actinide separation and transmutation

3.3 As mentioned in paragraph 3.2.1, a capability to remove the unextracted actinides from the high level liquid waste stream and 'incinerate' them to shorter-lived nuclides in reactors would offer the prospect of easing disposal problems by requiring waste repositories to be guaranteed only until the fission products had largely decayed (about 500 years). In the UK, however, this prospect is only slight (already about 99% of the actinides—mainly plutonium—are extracted before the spent fuel stream becomes 'waste') and the question is more one of minimising the residual actinide content of the high level waste consistent with environmental and economic requirements. Research on the chemical separation and nuclear transmutation of actinides forms part of the EC programme; and the Commission has been designated by the Nuclear Energy Agency as the leading organisation for studies in this field. The first NEA/EC technical meeting was held at the JRC, Ispra, Italy in March 1977.

3.3.1 In the direct action programme 3 aspects of the problem are being studied (see Table 2.2): chemical separation; the technological implications of incorporating actinides in nuclear fuel; and actinide/neutron cross-section measurements (to assess transmutation efficiencies). Solvent extraction followed by oxalate precipitation is the method currently being tested to remove actinides from simulated high level wastes. To be effective, the recycling of actinides must be almost complete (and the actinides must be extracted from other wastes e.g. cladding hulls), so the optimum separation conditions at each stage of the process, including those to prevent irreversible absorption of some plutonium on precipitated material, are being determined. Lead cells to permit work on real high active waste are being constructed. The second and third sections of the programme are essentially concerned with basic nuclear physics; progress has been limited, but a start has been made to define the actinide mixture at the various stages of recycling and to assess the possible efficiency of the process.

3.3.2 The only work undertaken in the indirect action programme was an assessment, by AERE in collaboration with the Netherlands Energy Centre (ECN), of the state of the art (Report EUR 5801e, 1977). This noted that the efficiency required of the recycling process should become clear from existing hazard studies related to geological disposal of radioactive wastes; and that the development of a recycling procedure would not eliminate the need for a disposal route for the fission products, but would enable the requirements for this to be greatly relaxed.

3.3.3 The AERE/ECN report found no insuperable technical objections to actinide recycling, though it noted that important aspects of the scheme had so far been examined only very superficially. The situation in the various areas was assessed as follows:

A. Nuclear physics: information already adequate to establish feasibility.
B. Chemical separation: difficult, but probably feasible; detailed writing and testing of flowsheets necessary.
C. Nuclear incineration strategy: a crucial area little studied so far; complete fuel cycle consequences of different strategies must be investigated.
D. Fuel and fuel elements containing recycled actinides: little development so far: fuel preparation, choice of cladding, fuel/cladding compatibility, and decay heat problems must be investigated.

Research by the US Department of Energy (formerly ERDA) is intended to establish feasility (or otherwise) in the next 2 or 3 years and, like the EC research at Ispra, places its main emphasis on B. Preliminary studies of C and D are included in the AERE/ECN report, but a substantial long-term programme will be needed to develop suitable fuel formulations and cladding and to prove a thermal fuel cycle that can accommodate actinides for recycling. If a realistic European assessment of the feasibility of actinide recycling is to be made within a timescale similar to that envisaged in the United States it would seem necessary for greater research effort now to be devoted to the post-separation aspects of the process.

*It is now in operation

3.3.4 It should be remembered that, even if the technical problems of actinide recycling can be overcome, cost/risk/benefit studies will still be needed to weigh the short-term penalties, which may prove substantial, against the prospective long-term benefits. Cmnd 6820 (Annex A, paragraph 7) stated that a programme of research into actinide separation will continue both in the UK and in the European Community, and that the advice of the RWMAC on this research would be sought.

Highly active solid waste

3.4 Most of this waste is the cladding hulls removed from spent fuel elements before reprocessing; it is currently stored at Windscale. Magnox (from the fuel used in the majority of UK nuclear power stations) constitutes most of the 7000 m³ of waste, so far accumulated. Magnox and zircaloy claddings (from light water reactor fuel) are stored under water to avoid a fire hazard, while stainless steel cladding (from advanced gas-cooled reactor fuel) is stored dry in concrete silos. Existing and planned storage capacity for Magnox will be full by 1985. The nature of future arisings depends, of course, on the types of reactors operated in the UK and by BNFL's overseas customers; and on whether fuel reprocessing continues—although even if reprocessing were to cease, Magnox fuel elements would require some treatment since they deteriorate after about 2 years' storage. Significant research and development is required, and some is in hand, to identify the means of removing solid waste from the present silos.

3.4.1 Current UK research on the treatment of Magnox cladding waste stems from the conclusions of a BNFL Working Group set up in 1976. Their initial appraisals indicated that, even if raw Magnox waste could be converted into a stable solid form which could be readily packaged, the necessary engineered storage of the package pending establishment of a disposal route would be an expensive interim measure (about £3m per year, to handle annual Magnox arisings of 135 tonnes) leading to massive accumulations of waste. The scheme eventually adopted and now being developed for BNFL by several UKAEA establishments has the following objectives:

- Selective dissolution of Magnox waste in acid, leaving the vast majority of adhering material as the solid;
- Purification of the Magnox solution, leading to the formation of more concentrated floc or other wastes, before discharge of the remaining liquid to sea in quantities amounting to a small fraction of the authorised discharged limits;
- 90% recovery of the uranium and plutonium (for reuse) and fission products (for vitrification) originally associated with the cladding;
- Storage of the waste arising from Magnox solution purification (about 200 m³ per year) ready for appropriate conditioning when a disposal route is available.

The scheme has the important advantage that solutions arising from the chemical (rather than the usual mechanical) decladding necessary for badly corroded or deformed Magnox fuel elements can easily be incorporated. The scheme still requires the storage of floc or other wastes, but this is much less onerous than storage, even in conditioned form, of the original cladding; and this waste can be disposed of by whatever means are adopted for other similar sludges and resins.

3.4.2 Progress to date has been rapid and current research is designed to optimise the effluent treatment process, particularly to reduce the ruthenium content of the effluent; to assess an alternative ion-exchange effluent treatment; and to test the performance of gas filtration equipment. Inactive dissolution units of up to 25 kg capacity are now being constructed, and development work is directed to the design and operation of an optimised 100 kg inactive dissolver at Winfrith by late 1978 and a 5 kg active pilot plant at Windscale by 1980.

3.4.3 The Chemical Technology Division of AERE are also studying methods—the most promising is leaching in acid, assisted by ultrasonic treatment—for removing adhered material from zircaloy and stainless steel cladding wastes (which will arise in quantity if the THORP programme is authorised). For these wastes, however, the cladding material itself is retained in solid form; it contains more induced radioactivity than does Magnox and any solution of it would be too active and difficult to treat for direct discharge. The current objective is to derive a preliminary flow sheet for a pilot scale decontamination process to be operational in about 3 years. It is intended that simple procedures be used for conditioning and packaging decontaminated cladding to await disposal viz. drying, compacting and drumming for stainless steel; and encapsulation in cement or lead, followed by drumming, for zircaloy (which can be unstable in air). Also, as part of the EEC indirect action programme, AERE are attempting to characterise the radioactivity in 12 zircaloy and stainless steel specimens from reprocessing plants or directly after irradiation. Work involves visual inspection to relate appearance to later analytical results and measurement of the surface depth and distribution and total content of actinides and fission products.

3.4.4 Further research in the EEC indirect action programme includes a study by CEN (Belgium) into techniques for compressing cladding wastes, other than Magnox, and embedding them in a low-melting alloy. The work includes measurements of the dispersion of actinides and fission products into the alloy, long term leach tests, definition of the optimium dimensions for compacted waste, safety assessments, and cost estimates for plant. GFK (Germany) are studying the possibility of incorporating waste in concrete (a pilot scale plant is to be built), while CEA (France) are developing methods of embedding or fusing the waste in glass.

Medium and low active liquid wastes and their residues

3.5 Liquid wastes unsuitable for direct discharge arise at various points in the fuel cycle—e.g. the water in which spent fuel elements and cladding have been stored, solvent extraction residues from reprocessing plant, and general liquid waste from contaminated areas. Some parts of this waste are of sufficiently low activity to require only collection and monitoring, to guard against unexpected activity, before discharge; other parts are stored for periods of up to a few years until their activity falls to this level. The storage, however, of some waste—particularly water from fuel element cooling ponds, which becomes contaminated by fuel cladding corrosion products and by some leached fission products—is either impractical, undesirable or would have to be very protracted. Hence this waste is treated to extract the active components in concentrated form and permit discharge of the bulk of the liquid. Orthodox water treatment methods, such as ion exchange and filtration (with or without the addition of flocculants), have been specially modified so that they can be used although, because of the exacting requirements placed on the extraction process and the need to minimise the volume of the residual solid or semi-solid active material, research is also being undertaken by AERE on reverse osmosis and ultrafiltration techniques.

3.5.1 The residual material—filter sludges and sands, ion exchange resins, floc, etc.—is currently stored pending development of conditioning processes. The decontamination process proposed for Magnox cladding will also give rise to waste requiring similar conditioning (see paragraph 3.4.1). The principles of the required conditioning processes are that the waste should be reduced in volume as much as possible, converted if necessary to a physically and chemically stable form, and then incorporated in solid material such as glass, ceramic or cement. Dewatering is normally all that is done to inorganic materials but organic materials can be reduced to a very small volume of inorganic ash, with little potential biological activity, by acid digestion, pyrolysis or incineration. (The availability of these treatments is, in fact, an incentive to use organic rather than inorganic materials for purifying effluent). Acid digestion appears to deal satisfactorily with a very wide range of organic materials and incineration is highly developed for active material at Windscale. The incorporation of incinerator ash into ceramic which is subsequently glazed has been demonstrated on the laboratory scale. Research on the incorporation of medium level wastes in polymer impregnated cements and in resins is being undertaken in France and Germany as part of the EC indirect action programme. The possibility that concentrated, salt-free effluents from medium active liquid wastes may be incorporated with high level wastes is being considered for wastes from the THORP plant.

3.5.2 The objectives for the next few years must, therefore, be to select and develop the conditioning processes to be used on a routine basis. There will be advantage in keeping to a minimum the number of different processes necessary to accommodate the complete range of semi-solid wastes (and, indeed, other medium level wastes); the possibility of combining waste streams (e.g. incinerator ash for different sources) for subsequent common treatment should not be overlooked. In the general field of medium level solid and liquid wastes there appears to be a need to define the characteristics that will qualify waste for subsequent management i.e. storage or disposal, although if conditioning specifically for storage is needed—e.g. in the absence of a disposal route—then clearly it should be designed not to hamper any further treatment prior to disposal.

Plutonium-contaminated low $\beta\gamma$ waste (PCM)

3.6 Solid material contaminated with plutonium also arises at various points during fuel fabrication and reprocessing, notably at Windscale and Dounreay. It ranges from suspect laboratory and office wastes (e.g. towels) from controlled areas to materials and plant actually used in handling plutonium (e.g. gloves,

glove boxes and various types of container). Such waste is currently stored in drums at Windscale and Drigg where there are now about 460 tonnes of PCM (over 80% of which is combustible), containing 560 kg of plutonium, plus about 1000 used air filters; also over 100 tonnes of redundant plutonium—contaminated equipment are stored awaiting decontamination at Windscale.

3.6.1 Because PCM consists entirely of items that have been in contact with or near plutonium, rather than itself being a primary waste stream, there is considerable scope for reducing arisings by optimising sorting and handling procedures and selecting process materials and equipment with their eventual disposal in mind. Since 1973 these procedures alone have enabled arisings to be reduced by 30% in volume and 60% in plutonium content per unit of plutonium throughput. Also 95% of the plutonium in current combustible PCM is contained in 20% of the volume, thus permitting more efficient use of equipment capable of handling the more concentrated PCM.

3.6.2 Some of this more concentrated PCM may not, of course, qualify as 'waste' in that it may contain sufficient plutonium for economic recovery, although the level for 'break-even' recovery clearly depends on the market for plutonium (e.g. fast reactors) and could only by chance coincide with any level that was instrumental in setting conditioning requirements. Improvements in the efficiency and cost at which plutonium could be recovered would, however, clearly contribute greatly to easing disposal problems. Shop-floor materials at a very low level of activity are suitable for land burial.

3.6.3 AERE/BNFL research and development on PCM involves many of the techniques also available for medium level non-plutonium wastes, although with a greater degree of containment. Accurate measurement of plutonium content is essential for optimum grading of the waste and remote facilities are needed for this and for preliminary treatment (e.g. washing), for size reduction of larger items (e.g. by crushing, shredding, melting or sawing depending on the material) and for inspection and sorting. Research on all these items is in progress. The actual treatment processes being studied, and the current status of each, are as follows:

Incineration:	active pilot plant operating at Windscale; 40 tonnes per annum plant envisaged by 1984.
Acid digestion:	inactive 0·5 kg/hr plant operating at Harwell; 10 kg/hr inactive unit under construction; active plant for Dounreay in 1981 being considered.
Pyrolysis:	inactive 1 kg/hr batch rig under construction at Harwell; small unit for Dounreay after 1982 being considered.

The objectives are that plutonium recovery should be high (in the case of incineration and pyrolysis plutonium is recovered by leaching the residue—a pilot leaching plant at Windscale should be completed in 1978) and that processes should tolerate a range of feed composition. The balance of advantage will not be clear for some years and, indeed, cannot properly be determined without reference to the nature of the PCM eventually requiring treatment; the best option could well be a mix of the various processes.

3.6.4 The residues from decontamination processes will usually require further conditioning before disposal. The residue from non-metallic PCM is a fine powder and a method for incorporating this in high alumina cement which is then fired and glazed has been developed using inactive material; active blocks are now being produced for leaching and other quality tests. Research on metallic PCM has shown that, provided the items can be dismantled so that all sections are accessible, decontamination (e.g. by spraying or grinding of surfaces) sufficient to permit land burial of the bulk of the metal is possible. Techniques for encapsulating items which cannot be dismantled will have to be developed before major plant is decommissioned.

3.6.5 A technical exchange agreement between UKAEA/BNFL and the US Department of Energy in the field of PCM should permit comparison of British and American research; the latter includes work on acid digestion (an active plant should be operating at Hanford in 1978) and incineration (a 9 kg/hr fluidised-bed incinerator for low active PCM has been in operation at Rocky Flats since 1972). The EC indirect action programme also includes substantial research on PCM: CEN (Belgium) are developing incineration processes that can either fix or free the plutonium in the resulting ash depending on whether it is to be recovered; while Agip Nucleare (Italy) are studying the incineration of PCM in molten salts, a process which might serve both to incinerate the waste and to separate the plutonium it contains. Much of AERE's research described above also forms part of the indirect action programme.

Volatile and gaseous wastes

3.7 The principal gaseous discharge of radioactivity from gas-cooled reactors is of argon-41; this has a half-life of 1·8 hours (i.e. its activity falls by a factor of 10^8 within 2 days) and so procedures for its containment are unlikely ever to be required. Raw gaseous wastes generated at reprocessing plants may contain nitric acid fumes, dust and aerosol particles carrying radioactive material, and fission product gases or volatile elements. Various processes are used routinely to clean gaseous wastes before discharge to the atmosphere (thus generating filters etc. requiring special treatment), but krypton-85, iodine-129 and -131, tritium and some compounds of carbon-14 are not removed. krypton-85, tritium and xenon-133 are also expected to be discharged in relatively small amounts from fast breeder reactors. There is general agreement that these nuclides will not need to be removed from discharges on the grounds of any hazard before the year 2000, although several of them have long half-lives—e.g. Kr-85, 10·8 years; tritium, 12·5 years; C-14, 5700 years; I-129, 17 million years—and so the monitoring of their expected gradual build-up in the atmosphere, and the transfer of some of them to other environmental sectors, is clearly important. Techniques are already being developed to condition these wastes for storage/disposal.

3.7.1 AERE have shown that krypton-85 can be incorporated in copper by an elegant ion implantation and sputtering technique. Material produced on the laboratory scale contains about 1 atom in 10 of krypton (equivalent to gaseous krypton at a pressure of over 300 atmospheres at room temperature) and construction of a half-scale pilot plant is currently planned. AERE plan also to study techniques for immobilising tritium, iodine and carbon; and a recycling technique to increase the concentration of tritium and so make most efficient use of any conditioning process. Much of AERE's research on gaseous wastes forms part of the EC indirect action programme, which also includes the following:

- incorporation of krypton in zeolites (Germany), and on active charcoal (Belgium);
- feasibility studies for engineered storage of krypton in pressurised cylinders (Germany), and for marine disposal of krypton (Holland/Germany);
- immobilisation of iodine in epoxy resins (Belgium) and in low-melting glasses.

3.7.2 The need to develop techniques for conditioning gaseous wastes is not considered to be highly urgent[1] and even though some of the projects mentioned above are only in their early stages, it seems reasonable to assume that the basis for such techniques will be firmly established well before such a need may arise.

Decommissioning of reactors and other plant

3.8 Many of the problems of decommissioning reactors and other major plant are ones of procedures (i.e. access and handling) and mechanical engineering rather than conditioning. The magnitude of the problems to be faced depends, perhaps more than for any other category of waste, on the subsequent management policy to be applied. The alternative policies range from disposal 'in situ', perhaps even using the biological shields of redundant reactors as repositories for waste from elsewhere, to complete removal of all material and restoration of the site for unrestricted use. This last policy clearly poses the greatest problems of waste management.

3.8.1 By the end of the century various UKAEA experimental reactors and most, if not all the 26 Magnox reactors currently in operation (at 11 power stations) will have been withdrawn from service. UK experience to date—e.g. a continuing feasibility study on decommissioning the Windscale AGR, and initial work to decommission the Dounreay fast reactor—has suggested a 3 stage progressive approach to total decommissioning:

1. removal of fuel, coolant and control systems;
2. reduction to minimum size outside the biological shield;
3. complete removal to leave site safe for unrestricted future use.

There may need to be lengthy pauses at or between stages to allow the radioactivity associated with particular components to decay to a level appropriate to their subsequent management. Continuing surveillance is necessary until the end of stage 3.

3.8.2 Wastes arising from stage 1 are mainly of types that arise during normal reactor operation—spent fuel, gaseous and liquid wastes—and so require no additional conditioning processes. At subsequent stages, however, the wastes are unique—large concrete and steel structures, heat exchangers, reactor cores (graphite). Some of these will have become contaminated by contact with fuel and it may prove possible to decontaminate some of them sufficiently to permit their reuse after dilution with inactive material; the EC direct action programme includes research at Ispra into the mechanisms of chemical and electro-chemical

(1) It should be noted that the Report of the Windscale Enquiry recommended that BNFL should give attention to krypton 85.

decontamination of reactor components and the characteristics of typical contaminant layers. Most of the activity of reactor decommissioning waste, however, is induced and decays only slowly; preliminary studies have shown that the most highly irradiated components (mainly stainless steel) of the Windscale AGR would require 350 years' storage before being suitable for low level disposal.

3.8.3 A policy of total decommissioning of reactors and other large items of nuclear plant implies a need to dismantle and transport major items of equipment. Research on decommissioning and especially on the conditioning and transport of the resulting waste should therefore receive greater emphasis once the options for the management of this waste have been clarified.

CHAPTER FOUR:

STORAGE AND DISPOSAL OF CONDITIONED RADIOACTIVE WASTE

4.1 This Chapter is concerned with the storage and disposal of conditioned waste by isolation from the environment. It is usual to consider separately the fate after conditioning of highly active vitrified (or otherwise solidified) waste, whose heat output is significant, and of wastes of lesser activity (but considerably greater total volume) with no heat problems.

Storage of vitrified high level waste

4.2 Newly vitrified waste (suitably packaged) must be cooled to prevent its melting by fission product decay heat. The period for which this is necessary depends on the age and proportion of waste in the glass block, on the physical properties of the block itself, and on the rate at which heat is removed from the block. The medium surrounding the block—e.g. air, water, salt, clay, or rock—must be able to provide appropriate conditions of heat transfer without unacceptable rise in temperature.

4.2.1 It is generally accepted that the cooling requirements of newly vitrified waste (variously quoted as up to anything between about 10 and 75 years old) should be met by storage of the waste, during which time its retrieval for any necessary remedial action would be possible. Several countries are currently considering the design of man-made structures capable of satisfying these requirements. The main options involve storage under circulating water in ponds; in air-cooled concrete vaults; in natural or man-made underground caverns; and in concrete on land in a desert. Each option has particular benefits and drawbacks: storage under water offers the most efficient heat removal and greatest thermal inertia if circulation of coolant is interrupted, yet requires strict control of water quality, possibly giving rise to substantial low level waste (e.g. ion exchange resin), to minimise corrosion; air-cooling is less efficient but offers the advantage of simplicity. In all cases similar methods of storage are either well developed or already practised for other wastes and so research in this area is mainly concerned with identifying the optimum approach from an economic and safety viewpoint. It is part of the HARVEST programme to provide a store, probably water cooled, ready to receive vitrified waste from the first demonstration plant.

4.2.2 Current design studies by UKAEA (at Harwell and Risley) include preliminary designs for air-cooled underground vaults for vitrified (and medium level) waste; the approach takes account of the possibility that such storage might in time, and by means of a series of simple civil engineering operations, become accepted as disposal. In the EC indirect action programme, proposals have been accepted for Belgonucleaire to study water-cooled storage (including handling and monitoring equipment) and to make an economic assessment of storage options; and for Nukem (Germany) to study air-cooled storage and to assess the transport, security and safety problems and general strategy of engineered storage.

Current research on the disposal of vitrified high level waste to geological formations on land

4.3 Cmnd 6820 acknowledged that insufficient information was available to rule out or confirm any of the 3 options generally thought realistic for the disposal of vitrified high level waste—disposal on or under the bed of the deep ocean, or in geological formations on land. It concluded, in particular, that there should be a continuing research programme into methods of disposal to geological formations. The majority of European research on this subject comes under the auspices of the EC direct and indirect action programmes (see Tables 2.2 and 2.3).

4.3.1 Under the indirect action programme each Community country's Geological Institute—the Institute of Geological Sciences (NERC) in the UK—has been identifying geological formations which, prima facie, meet criteria such as stability and freedom from circulating groundwater necessary for the disposal of high level radioactive waste. For purposes of field work individual countries have adopted particular geological formations for further study of such aspects as response to heat, effects on waste containers, and pathways by which waste could return to the surface environment. The objective of the German (GFK) programme is the construction of facilities, with handling and transport equipment, for a disposal experiment using genuine waste in the Asse salt mine, although some research on salt formation elsewhere has suggested that the combination of water and heat from the waste could lead to waste migration rates considerably larger than previously expected. CEA (France) are studying crystalline rock and, in particular, the successive barriers to release of waste presented by the waste container, the crystalline rock itself and its surrounding; one objective is the development of a model, to be tested in situ and on core samples, describing the long-term behaviour of actinides in such circumstances. Disposal of waste in clay formations is being studied at the CEN site at Mol (Belgium) and by CNEN (Italy); the chemical, physical, mechanical and ion exchange properties of the clay are being investigated and its response to heat and intense radiation are being measured. Outside the EC programme NERC/IGS are examining geological records to identify argillaceous and evaporite formations in the UK that appear suitable for detailed investigation to assess their suitability as potential repositories for appropriately treated radioactive waste.

4.3.2 UKAEA are also investigating disposal in hard rock and, in co-operation with NERC/IGS, have identified areas of the UK where geological surveys, and other experiments, not involving radioactive waste, would be advantageous. Field studies on the thermal and mechanical properties of granitic rocks are under way in Cornwall. Planning applications for test borings in Scotland and Northumberland are being made*, and NERC has emphasised the need for investigation of possible host materials other than granite. Attempts are, therefore, being made by AEA, and by other EC contractors to broaden the areas of study where this may usefully be done. Meanwhile further desk studies and laboratory research are proceeding. One of the studies being carried out by NRPB under a contract from UKAEA, is to assess the radiological implications of disposing of high-activity waste in geological formations on land; this is complementary to an earlier NRPB study of the radiological implications of deep ocean waste disposal. Proposals for development by IGS of a computer model of a waste repository in crystalline rock have recently been put forward by NERC; the work would involve modelling of the host geology of the repository, the effects of constructing the repository and storing waste in it, and the interaction between waste and rock under normal and abnormal conditions.

4.3.3 The isolation of disposed waste from the environment cannot, of course, be guaranteed in perpetuity and it is necessary, when planning disposal facilities, to assess the relative hazards of different options. Evaluation of the long-term hazards of disposal is one of the major projects in the EC direct action programme at Ispra. The aim of the project is to place a quantitative value on the barrier system between waste and man. Building on work done as part of the JRC's 1973–76 programme, and using information obtained from projects in the indirect action programme, the project is using fault tree and critical path analyses to define mechanisms and probabilities for the release of waste from, for example, salt formations. The JRC, in collaboration with the Nuclear Energy Agency, organised an international workshop on risk analysis and geological modelling at Ispra in May 1977; and an EC Working Group on risk analysis has recently been established.

Current research on the disposal of vitrified high level waste on or under the sea bed

4.4 The two plausible options for ocean disposal of high level radioactive waste are the placing of suitably packaged waste on the bed of the deep ocean, and its disposal under the ocean floor, perhaps by using a projectile-shaped penetrometer in soft sediments or by placing it in boreholes which are subsequently backfilled. The distinction between the two options is not absolute: it is probable that the environmental research programme necessary to support the first option will also be needed as part of the total research required for the second since the same basic oceanographic knowledge is required to predict the behaviour of radioactive material once it reaches free water from whatever source. Research primarily in support of other activities—e.g. disposal to geological formations under land, and sea disposal of low level waste—may also find application in this area.

4.4.1 Current UK research on the ocean disposal of vitrified waste is considerably less extensive than that on geological disposal and has tended to concentrate on the physical rather than the chemical and biological

* By late 1978 one application for boring in Caithness had been granted.

processes potentially involved; and on the theoretical aspects of predicting the behaviour of radioactivity once it enters the ocean or its sediments rather than on the engineering problems of waste disposal, although UKAEA have attempted a broad assessment of the costs of the various options. MAFF's current research programme is designed as the forerunner to a long-term programme yet to be agreed. Work to date has involved current measurements, float tracking and hydrographic sections in the area of the North-east Atlantic 45° 50′ – 46° 10′ N 16° 00′ – 17° 30′ W, used for the annual low-level waste dump supervised by NEA. Long-term current meters have also been laid by IOS (NERC) as part of their general programme of research in both this area and several others in the North-East Atlantic. MAFF have laid current meters in the Gibbs Fracture zone of the mid-Atlantic Ridge to estimate the transport of deep water from east to west through this zone; along 41°N to the east of the mid-Atlantic Ridge; and at the southern entrance to the Rockall Channel. The results from all these observations should help improve the diffusion/advection model of the Atlantic now being set up within MAFF.

4.4.2 The United States has done most of the work on the feasibility of the oceanographic options for waste disposal (although in the Pacific rather than the Atlantic) and has placed the emphasis almost entirely on the under-the-seabed option. The UK is now developing its own programme. France and Japan have also begun, or are planning, programmes of research, and representatives of these 4 countries have met 3 times under NEA auspices—at Woods Hole (1976), Washington, (1977) and Albuquerque (1978)—to attempt to co-ordinate these national programmes. Many of the major aspects of the necessary research are related to the broader objectives required in deep sea physical oceanography and to a lesser extent air/sea interaction studies which underlie meteorological and climatological problems and on which, of course, many millions of pounds are being spent in internationally co-ordinated programmes.

Future research on the disposal of high level waste

4.5 It is probably unrealistic to expect any disposal route for high level waste to be established before the end of the century; this is acceptable in as much as the first vitrified blocks are unlikely to be old enough for disposal by then. Although the international dimensions of the disposal problems are bound to increase it would be imprudent to rely to a large extent on research overseas to establish the principles of UK disposal routes. There will always be local, site-specific factors to be taken into account. It is, therefore, essential that the UK should adopt a sufficiently broad research programme to support its interests in establishing the most appropriate disposal route(s) for UK wastes.

4.5.1 At some time in the future a decision will have to be taken as to which of the 3 basic disposal options should be pursued, since the expenditure involved in pursuing all three to the final stage may be insupportable. Research into the feasibility of the three options must, therefore, proceed in parallel and, as far as possible, with a common approach and time scale permitting clear comparisons of results.

4.5.2 Research in the EC indirect action programme should go some way towards establishing the feasibility of disposal to rock formations on land. The research has 4 main elements:

- The safety and reliability of suggested isolation options in the climatic, seismic and other conditions expected in the future.
- The determination of leakage paths for the components of the wastes back to man's environment.
- The physico-chemical conditions of the wastes within the rock as they are affected by corrosion and nuclear heating.
- Engineering requirements and procedures for isolation of the wastes.

The study is intended to include detailed geological investigation of a number of sites, and should provide sufficient information to allow initial assessment of possible host rocks and to identify areas for further detailed work. Initially it is intended to drill at least 2 boreholes to depths of up to 1000 metres to investigate the characteristics of host rocks. Much of the work is being undertaken by IGS and includes some of the projects proposed by NERC in January 1977. The UK also proposes to investigate clay and salt as waste isolation media, both for heat-generating and cold wastes.

4.5.3 Two major programmes for research on sea disposal have been independently proposed by MAFF (November 1977, 'on the bed' option only) and NERC/IOS (January 1977, 'on' and 'under the bed' options). The former are based on earlier proposals updated in the light of discussions, particularly within the NEA Co-ordinating Group; both involve drawing on the expertise of NERC/IOS. The need for research within the MAFF proposals of 1977 is seen as including the following at a cost of about £7M over 10 years; some aspects are underway at a reduced level (£200K per year):

1. Deep water releases of (probably radioactive) tracers to estimate local horizontal and vertical diffusion rates.
2. Estimation of the vertical circulation of the deep ocean.
3. Estimation of horizontal dispersion processes.
4. Co-operation in an on-going current meter programme.
5. Continuation of spatial variability studies using arrays of current meters.
6. Continuation of long-term current measurements at various sites in the North East Atlantic.
7. Bottom sediment sampling.
8. Expansion of existing studies of natural or man-made tracers giving information about ocean circulation and mixing processes.

4.5.4 The proposals by NERC for the 'on the bed' option include work on the movement of water and particulates in the deep ocean, but also on the effects of radioactivity on the fauna near the ocean floor and the rates and routes of biological transfer of radioactive material; it will, of course, be important to establish whether physical or biological processes are potentially the more rapid in carrying material back to man. NERC estimate that the research they propose would cost at least £10 million over a decade; this would cover much of the preliminary research on the 'under the bed' option. The further programme required for this option includes a reconnaissance study of potentially useful sites, drawing on experience gained during an earlier deep sea drilling programme and the examination of the present characteristics of old drill holes. It would also include studies of the long-term stability of consolidated sediments, the influence of water movement immediately above the deep ocean bed, and the geochemical processes controlling the movement of radionuclides across the sediment/water interface.

4.5.5 Most studies of disposal so far carried out in the UK have made the initial assumption that the material disposed of will result from reprocessing and subsequent solidification. The characteristics assumed for the various parameters and the relative proportions of different radionuclides are appropriate to these assumptions. If unreprocessed fuel elements were to be disposed of, studies would be needed to consider the effect of the much higher proportion of uranium and plutonium and the quite different physical and chemical form of the waste. NRPB are carrying out preliminary studies of the relative potential human exposures which would result from this option as compared with the others.

Disposal of Other Wastes

4.6 In view of the relatively small quantities of radioactivity involved at that time, no very complex or comprehensive assessment of the environmental impact of these wastes was required for early sea dumps. A simple model was refined and then adopted by the IAEA as the basis for defining high-level waste unsuitable for dumping at sea under the London Dumping Convention. This definition is now being reviewed by the IAEA, and MAFF Directorate of Fisheries Research has undertaken considerable research to improve the necessary radiological hazard assessments. Further research is directed to selecting a new dumping area; the results of some of the research originally used to evaluate the high-level waste option are finding further application here.

CHAPTER FIVE: ENVIRONMENTAL RESEARCH

5.1 This chapter is concerned with the environmental effects of those discharges of radioactive materials which are permitted to occur in the normal operation of nuclear reactors and reprocessing plants, as distinct from the effects which may arise as a consequence of the disposal of packaged and conditioned waste. It is not easy to make any firm distinction between *research* on radioactivity and its pathways and effects in the environment, and *monitoring* the presence, form and concentration of radioactivity in the environment; the same data might well serve both purposes. For the purpose of this report, however, monitoring is considered to imply measurements made primarily for some immediate purpose by plant operators (e.g. to check plant performance) or by authorising Departments (e.g. to check compliance with discharge conditions); whereas research implies the attempt to achieve a greater understanding of the pathways and effects of radionuclides in the environment or the development of a general methodology.

5.1.1 The numerous possible pathways for radioactive material in the environment are set out in abbreviated and diagrammatic form in Figure 5. Most of these pathways have been the subject of at least some research, the ultimate object of which has been the protection of man. Since man appears to be one of the organisms most sensitive to the effects of radiation, measures taken for his protection will normally, although not necessarily invariably, result in the adequate protection of the rest of the living environment. In this respect radioactivity differs from some other forms of air and water pollution.

Marine Environment

5.2 The start of many of the more important pathways for radioactive pollutants is, in the case of the UK, the discharge of liquid effluent to the sea. The Fisheries Radiobiological Laboratory of MAFF has a long record of interest and responsibility in the marine environment. Its work other than routine monitoring may be divided into three main areas:

(a) Direct support of statutory responsibilities as regards discharge evaluation and assessment;

(b) Radioecology;

(c) Radiobiology.

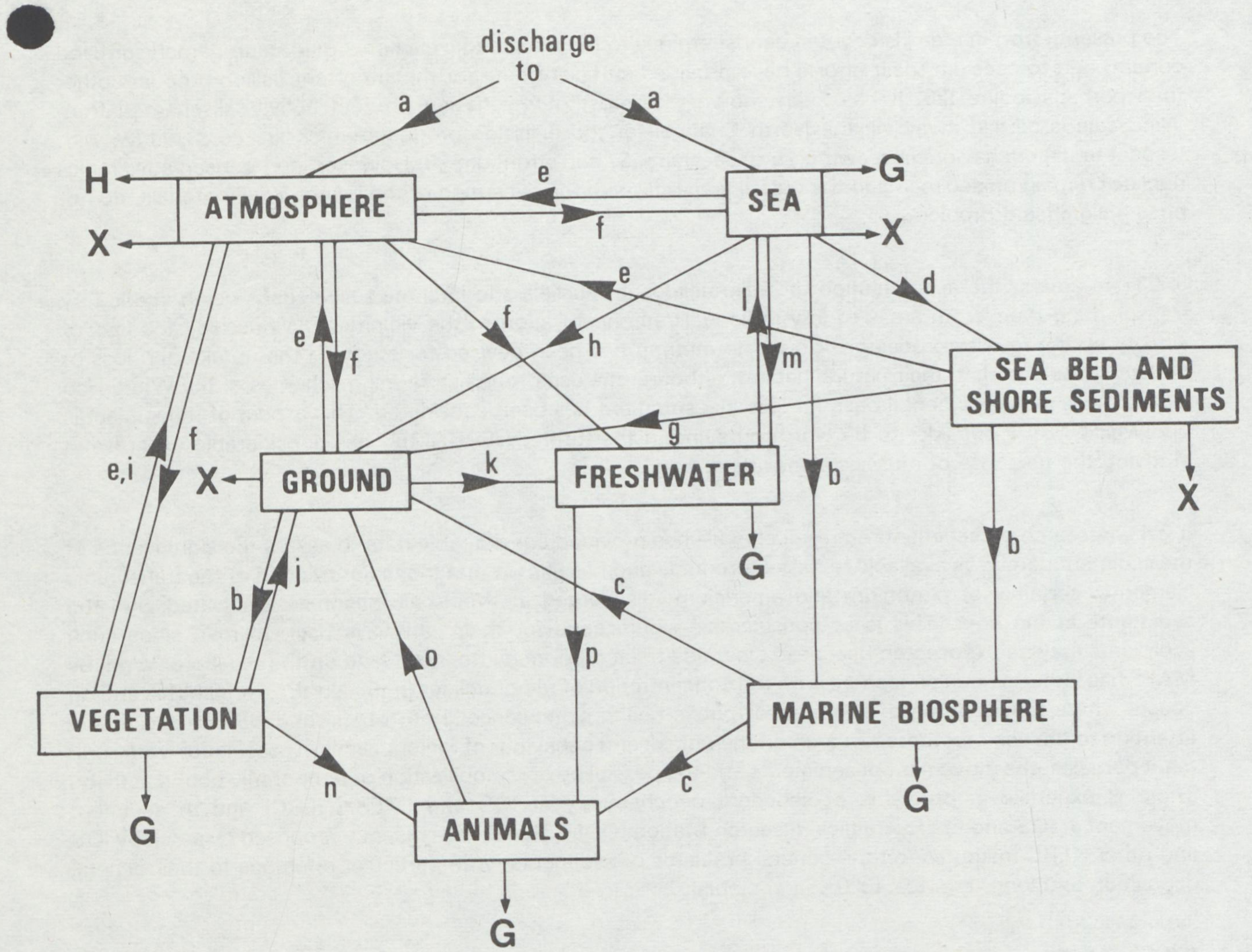
5.2.1 The main research element of work in category (a) above is the identification and evaluation of environmental pathways. This is done at each discharge site by surveys designed to identify, first qualitatively and then quantitatively, potentially critical routes by which radioactivity might reach man. The nature of the effluent and knowledge of the dispersion conditions prevailing in coastal waters are then used to assess the relationship between the rate of discharge for each radionuclide and the radiation exposure of the critical individuals or groups to the full extent of the ICRP recommended dose limit. Research effort to date has been largely concentrated on what appear to be critical pathways although, to identify these, one must logically also have studied those pathways considered non-critical. MAFF consider that further research on these supposedly non-critical pathways is important.

5.2.2 Research on radioecology—area (b) above—may be subdivided also into three main areas:

i The inventory and distribution of radionuclides (mainly from fuel reprocessing) in British coastal waters and adjacent seas.

ii The accumulation and excretion of radionuclides in fish, shellfish, and seaweeds.

iii The behaviour of radionuclides in sediments.



KEY

POTENTIAL HUMAN EXPOSURE

H Inhalation of airborne activity
G Ingestion of foodstuffs
X Direct external radiation

PATHWAYS

a Dispersion
b Biological uptake
c Use of marine products in agriculture
d Sedimentation
e Resuspension
f Deposition
g Land formation following coastal sedimentation
h Tidal flooding of coastal agricultural land
i Transpiration
j Wash-off and plant decomposition
k Surface and ground waters
l Rivers and rain
m evaporation
n Animal fodder, etc
o excretion
p Animal drinking water

Adapted from NRPB evidence to the Windscale enquiry

Figure 5 ***MAJOR PATHWAYS TO MAN FOR ATMOSPHERIC AND MARINE DISCHARGES OF RADIOACTIVITY***

The present effort in area i is devoted almost entirely to the transuranic elements (plutonium, americium and curium) and to caesium; past efforts have provided sufficient data for the important fission products other than perhaps iodine-129. It has been shown that most of the fission product activity discharged from Windscale is carried away via the North Channel for those fission products which are conservative with respect to their behaviour in seawater, e.g. caesium-137 and strontium-90. However, non-conservative radionuclides remain on sediments in the outfall area but, with the exception of the longer-lived materials, do not pose a significant problem.

5.2.3 In area ii, the accumulation of radionuclides in mussels and in some seaweeds is being studied by transplanting them from areas of low radionuclide concentration to the vicinity of Windscale, and loss of activity by the reverse procedure. So far no method has been devised for studying the uptake and loss of radionuclides by fish in their natural habitat, although the use of the fish farming schemes of the White Fish Authority as an experimental base for loss measurement has been considered. This aspect of the subject is one which MAFF consider to be worth pursuing in the future. NERC/IMER has considerable expertise in studying the response of mussels to pollution.

5.2.4 Research on sediments—area iii above—has provided considerable data to assess the significance of the sediment pathways available to fission products and has shown that the major fraction of the transuranic elements, certainly of plutonium and americium, discharged at Windscale becomes associated with the sediments in the area. This is of considerable significance for their pathways back to man since such sediments may be exposed on beaches at low tide or incorporated into 'new' land on the seashore. Work by MAFF has hitherto been concerned with the concentration of radionuclides in the North East Irish Sea and on coasts where they may be of some direct public health significance. Both MAFF and NRPB have drawn attention to the need for more research on the uptake and behaviour of radionuclides in association with sediment particles, the movement of sediments and the possibility of remobilization of temporarily bound activity. There is expertise in problems of sediment geochemistry at IOS and IMER (NERC) and of sediment movement at IOS and the Hydraulics Research Station (DOE). NERC have recently proposed research by IOS and other NERC Institutes, on the general problems of sediments, with particular reference to their general deposition and long term (ca 1000 years) stability.

5.2.5 MAFF's radiobiological research—area (c) above—includes studies in aquaria under controlled laboratory conditions and has been carried out to derive information such as concentration factors, rate of biological turnover and tissue distribution etc. which cannot readily be obtained from studies in the natural environment. Further to this, information has been gained on the relative roles of food and water as sources contributing to observed distribution in tissues, and also of the comparative behaviour of different stable elements, some of them in more than one chemical form. Another aspect of the work has been the assessment of the exposure to radiation of aquatic resources and its effects. The majority of the studies have been concerned with fish (including eggs, larval, and post-larval fish) rather than shellfish since these represent the major pathway back to man for the UK population in general. Relatively few studies of invertebrates have been made by MAFF, although species of interest have been studied by other laboratories (notably mussels by NERC/IMER/MBA) and FRL regularly evaluate the data produced both on account of the significance of shellfish as food, and because of their value as biological indicators of specific radionuclides. Future work (by MAFF) in radiobiology will be largely concerned with the evaluation of the present impact of transuranic radionuclides in the marine environment and the prediction of long-term effects.

Freshwater Environment

5.3 While there is extensive monitoring of radioactivity in rivers and streams in the Windscale area, there is comparatively little work of a research nature involving the freshwater environment. AERE have one project on the transfer and fate of radionuclides across a water catchment into, and through, a lake. The initial study was made at Brotherswater because of its relatively simple catchment configuration; the FBA (NERC) is able to assist by virtue of its interest in the use of radionuclides as tracers of environmental processes. AERE hope to extend this programme to lakes more directly related to Windscale such as Wastwater.

5.3.1 MAFF/FRL has for 10 years maintained a research project on the radioecology of Lake Trawsfynydd, which receives wastes from the Trawsfynydd nuclear power station; the study started before the power station commenced operation. The research has permitted assessment of the significance of discharges to the lake in terms of exposure to man and the evaluation of freshwater pathways leading to man via fish.

Atmospheric and Terrestrial Environments

5.4 The most important gaseous discharges of radioactivity from fuel reprocessing are those of krypton-85 and of tritium. The former will not enter biological pathways while the latter, when oxidised to HTO, will follow environmental pathways just like ordinary water. Thus, while both gases will contribute to the local and general levels of background radiation, they will not usually feature in programmes of research on pathways. However, AERE have a programme to study the physical processes through which atmospheric HTO may gain access to food chains; this is supported by the EC Biology, Radiation Protection and Medical Research Programme.

5.4.1 The stack discharges can, of course, carry with them to the atmosphere particles of radioactive material which may form the start of a number of possible pathways of radioactivity to man. They may be washed out by rain and the radionuclides deposited in the soil and thence taken up by crops, deposited upon crops to be eaten by man or farm animals or, if they are of respirable size, directly inhaled. Material deposited on land or in water, from the atmosphere or otherwise, may of course become airborne under certain conditions. The process of resuspension of material on land is very complex but it is now considered sufficiently significant to merit thorough study. Some aspects of the subject are included in the AERE/BNFL research mentioned below (paragraph 5.4.3).

5.4.2 BNFL maintain an extensive programme of environmental monitoring in the vicinity of Windscale in which many terrestrial and atmospheric measurements are made as well as those taken at sea, on the seabed, and on the foreshore. In 1977 MAFF (Food Science Division) carried out a programme of sampling soil, grass, rootmat, and some animal tissues in the Windscale area. This work is being continued with the addition of other food crops as available.

5.4.3 The preliminary stages of some new research (see paragraph 2.3.7) have been started by AERE, largely in the Windscale area but supported by considerable work at Harwell. This research involves a search for areas of high concentration of caesium-137 and of transuranic elements; measurement of air concentration in areas where there could be risk of significant resuspension; studies of the transfer to and concentration of particulate material at the sea surface and its resuspension in sea spray; measurement of sea bed activity; and, in association with NERC/ITE, measurement of activity in soil and vegetation. This work is in addition to the long-standing AERE fallout monitoring programme to provide baseline measurements (notably of caesium, other long-lived emitters, and plutonium) against which to observe change, and to a 5 years programme supported by the EC Biology and Health Protection Programme on the resuspension of particles from terrestrial surfaces. NRPB are also determining air concentrations in the coastal plain around Windscale and undertaking other studies in the atmospheric and terrestrial environments.

5.4.4 NERC's research proposals of January 1977 (para 4.5.3) include 4 projects on environmental radioactivity. Two of these are in the marine environment—the geochemistry of radionuclides in coastal and marine sediments, and the properties and movements of sediments in estuarine and inshore waters in relation to radioactive effluent. The other 2 concern terrestrial pathways and relate to the feasibility of monitoring and tracing radioactive materials in terrestrial and freshwater environments. DOE has asked NERC (ITE) to make a literature survey of radionuclides in the terrestrial ecosystem and is considering research contracts in the terrestrial and off-shore areas.

5.4.5 When considering potential contracts for the research proposed above it will be important to realise that research on radioactivity in the environment may often call for the measurement of very low levels of radioactivity and of low concentrations of many radionuclides. There are only a few laboratories which possess the necessary facilities and expertise, especially for handling transuranics. It is possible, however, to distinguish between research such as that on the movement of marine sediments which does not necessarily call for sophisticated measurements of radioactivity, and work such as that on the uptake of radionuclides by plants and animals and on geochemical fluxes between sediment, water and air which inevitably calls for elaborate analytical facilities. Consideration is being given by several bodies to the need to extend facilities for research and monitoring.

Other Environmental Research of Relevance

5.5 A proper appreciation of the significance of measurements of radioactivity in the environment often depends upon the background of knowledge of physical and biological systems built up over many years as a result of research carried out for quite different purposes. Examples in the marine area are the knowledge of deep ocean currents, of the nature of the seabed, of the mechanism of sediment transport near to the shore, and of the life cycles, migration, and feeding habits of a wide variety of sea creatures. In the area of terrestrial and airborne radioactivity the interpretation of results may involve knowledge of meteorology, of plant and animal situations, and of the feeding habits and migration of many birds and animals. The existing knowledge in such areas and its likely future development for other purposes will always be essential to the proper understanding of the pathways of radioactive materials in the environment. General research currently supported by DOE, MAFF, NERC, MRC, ARC, CERL and others is helpful in this respect; clearly it is important that full advantage be taken of the knowledge that this research, can provide; and that further such basic work is supported as necessary.

Research to be supported by the Environment Departments

5.6 While this survey of research on environmental effects of radioactivity is necessarily broad, it is nevertheless sufficient to permit certain conclusions to be drawn. The various research programmes have naturally tended to develop in relation to the particular needs and responsibilities of the organisations concerned and, while the normal processes of exchange of scientific information have helped to reduce gaps or overlaps, it is not yet clear that the scale and balance of the total effort is right. For example the Royal Commission, in their sixth report (Cmnd 6618), saw need for further research on radioactivity in the atmospheric and terrestrial environments; and their conclusion was noted in Cmnd 6820 (Annex A, paragraph 12). Some of the research now in progress or planned in these environmental sectors has been described above.

5.6.1 Cmnd 6820 gave the Environment Ministers responsibility 'for initiating and co-ordinating research into the effects of radioactivity on man and the environment, and for identifying gaps and overlaps'. It also stated that the Departments concerned would collaborate closely with MAFF. While it is not yet possible to recommend in great detail a future programme of research for DOE in the environmental (as distinct from the waste management) field, the general areas of interest are reasonably clear where research is in support of statutory responsibilities: work which is fairly directly related to farm animals and crops and the marine environment in the context of commercial fisheries falls to MAFF; the assessment of effects on man is a matter for NRPB and MRC: while the Environment Departments are concerned with the more general problems of the pathways available to radioactive substances in the environment, including those terminating in organisms other than man and which may serve as indicators of environmental quality. There will, of course, also be problems of common concern to two or more bodies and the scope for joint sponsorship or execution of research will need to be carefully considered.

5.6.2 The subjects worthy of further attention in this area are: the particle size, dispersal, and deposition of aerosols, and their resuspension from land surfaces and from sea spray; the movement of sediments, particularly in the Windscale area, including the build up of new land on the coast and the pathways and effects of radioactive materials reaching freshwater and terrestrial ecosystems. The Environmental Departments in collaboration with MAFF, will continue to develop suitable programmes of research, in consultation with the principal research contractors in these fields, for implementation through normal Departmental research machinery; additional funds are likely to be needed but DOE has already initiated some new work (See paragraph 2.3.1). The Research Councils may wish to support fundamental work in these areas.

CHAPTER SIX: IN CONCLUSION

6.1 Research expenditure in the UK on conditioning radioactive waste is currently (1977/78) about £5 million per annum. Expenditure will increase gradually in real terms over the next few years as more projects progress from the laboratory stage, through inactive and active pilot plants, to full development. Research in other countries, particularly the United States and those of the EC, should give substantial support to UK work.

6.1.1 Research currently in progress indicates that there are plausible methods for conditioning, into a stable form suitable for prolonged storage or disposal, many of the wastes from nuclear power production in the UK. In some cases the chemistry, materials science and technology have been developed to the point where demonstrations of their feasibility have been completed. In other cases bench scale work shows the way in which materials of suitable composition can be produced. There remain many cases in which the industrial scale operation has not been demonstrated, the optimisation of properties has not been completed, and reliable safe technology has not been completely developed. A theme common to many research projects is that research can proceed only so far in the absence of detailed specification of the properties of 'conditioned' waste—i.e. ready for subsequent management; further work towards this end, taking such account as is possible of the likely options for this subsequent management, is therefore urgently needed.

6.1.2 Expenditure on disposal options research in the UK in 1977/78 was somewhat less than £1m. The requirements are expected to increase substantially over the next few years and to extend the investigation into geological formations other than hard rock, and into disposal at sea. Cmnd 6820 noted that the main contractors for research on disposal options were likely to be UKAEA, the Directorate of Fisheries Research of MAFF, and the Institutes of Geological and Oceanographic Sciences of NERC. UKAEA and IGS are, of course, already appointed as contractors (directly or indirectly to the Environment Departments and to the EC) for research on the geological disposal option. Interdepartmental discussions on the development of research on the sea disposal options are planned, bringing in the major research contractors. All of this work will be developed in the knowledge of the research interests of such bodies as EC, NEA and IAEA.

6.1.3 In accordance with Cmnd 6820 (para 17), administrative control of the waste management element of UKAEA's research and development programme (i.e. research on disposal to geological formations under land, as well as on conditioning) has already been transferred to the Environment Ministers; a programme for 1978/79 has been approved by DOE within the Department's normal procedures for determining research requirements. Further requirements in this area (and for environmental research) will be considered similarly in future years in the light of advice from the Radioactive Waste Management Advisory Committee.

6.1.4 While attempting to solve the technical problems of radioactive waste management, research should also seek to take account of the public disquiet over some aspects of nuclear energy—most notably, in the present context, over the problems of disposal of high-level waste—and to provide a basis for informed public discussions of the relative benefits and hazards of options available for meeting future UK energy requirements.

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