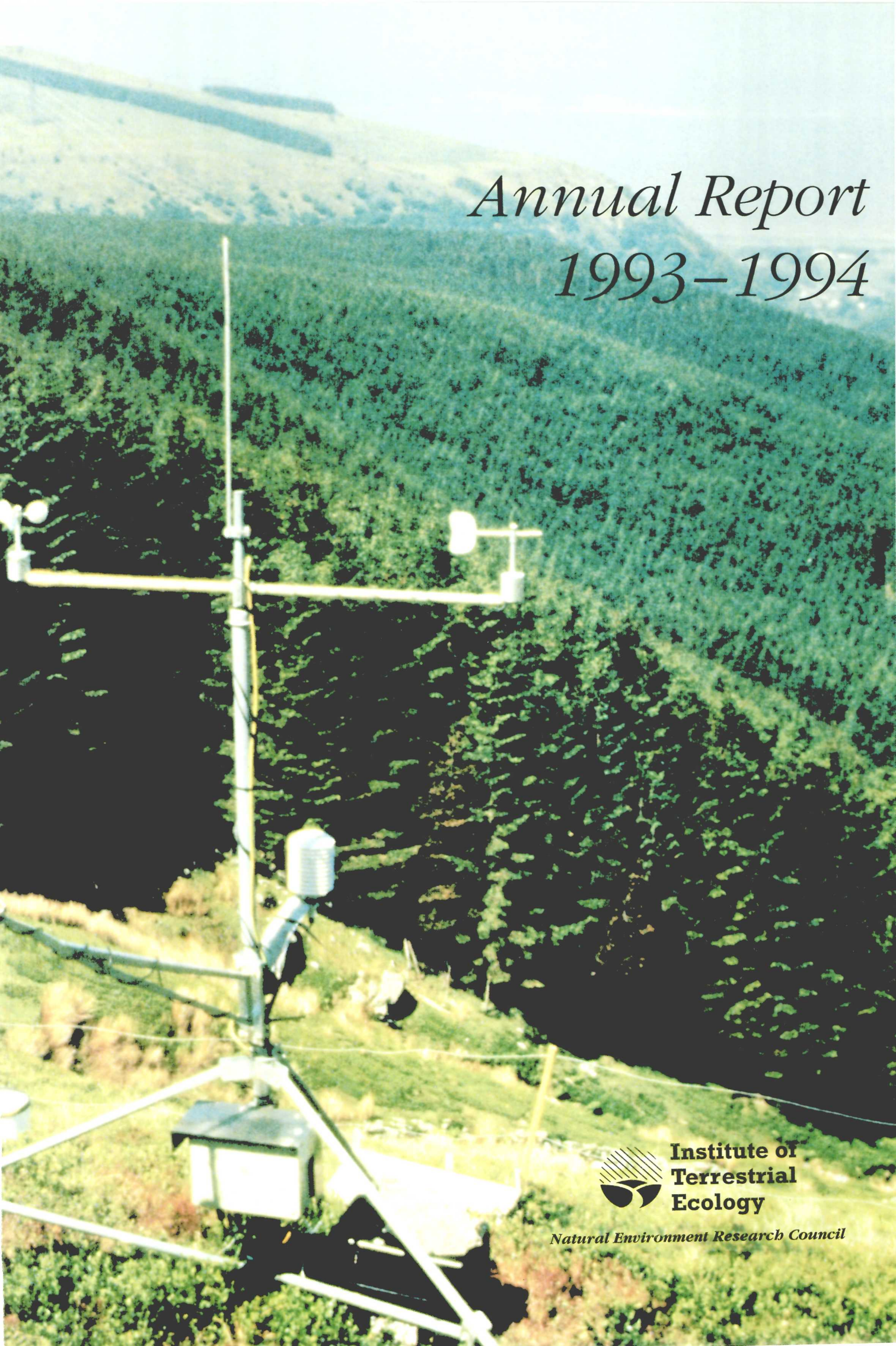

Annual Report 1993–1994

Institute of Terrestrial Ecology

Natural Environment Research Council

Foreword

The past year has been one of considerable change in the Natural Environment Research Council, both in the focus of its science and in its structures. The catalyst for these changes was the publication of the White Paper *Realising our potential: a strategy for science, engineering and technology* (Cm 2250). NERC was given a new mission for its science to embrace the concepts of meeting the needs of its user communities and contributing to wealth creation and the quality of life We have, of course, always paid close attention to these objectives, but there is now a clear need for a sharper focus and better articulation of what we do in these areas Basic science and long-term monitoring are also included in our mission, and due weight must be given to these when developing our science strategies.

The science directorates will cease to exist towards the end of 1994, and new structures will be put in place TFSD Institutes are being regrouped as the Centre for Ecology and Hydrology, with a unified ITE under a single Director However, the report of the Multi-Departmental Scrutiny of Public Sector Research Establishments is awaited, and decisions arising from this report may result in further organisational changes within NERC

An important activity during the year has been the preparation of a new science and technology strategy for the terrestrial and freshwater sciences. Publication is expected in July, and a number of research areas will be identified for priority support over the next five years.

This is my second and final foreword. During my relatively short time with NERC, I have come to appreciate and value the breadth and strength of our work in the terrestrial, freshwater and hydrological sciences Within ITE, for me, highlights of this year have been the report arising from Countryside Survey 1990 and the launch of the Land Cover Map It is because of these, and very many other successes, that I am confident we can continue to produce high-quality and competitive science in the post-White Paper environment. Both ITE(North) and ITE(South) were visited by separate Science Management Audit Groups during the year. It is to the great credit of everyone involved in ITE that the reports of both groups recognised a continued advance in quality across the whole of the Institute over the five years since the previous visits

Finally, I should like to state how much I have appreciated the friendships that I have established with so many members of our community It is these that will be my most valued and lasting memories of NERC

C Arme
Director of Terrestrial and Freshwater Sciences
Natural Environment Research Council

Report of the Institute of Terrestrial Ecology 1993–1994

Natural Environment Research Council

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Environmental pollution

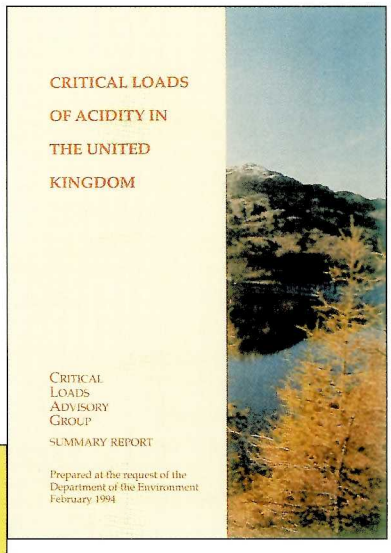

Plate 36. Two relevant reports published during the year 1993–94

The Institute's Programme of research on environmental pollution continues to expand in response to the requirements of its customer community in Government departments, the European Community (EC), the regulatory organisations and industry. Some 70% of the Institute's current work in this area is commissioned research and much of the remaining, more strategic, part of the programme has been developed in discussion with our main customers, to ensure the relevance of the work to their needs. The results of the research, therefore, advance scientific understanding but also support the development of environmental policies and the formulation and implementation of scientifically sound pollution control legislation.

The current programme of research includes work on:

- the dispersal of pollutants in the atmosphere
- chemical transformations during transport
- deposition processes and the quantification of deposition at the local and national scale
- transfers within soil/plant systems and within food chains
- assessment of the possible impacts at the scale of the individual organism, plant and animal community and ecosystem.

The range of pollutants being studied includes toxic heavy metals, radionuclides, organic chemicals, acidic atmospheric pollutants and hydrocarbons; these pollutants originate from industry, transport and agricultural activities, and from controlled releases and disposal, as well as from accidents. ITE's extensive national databases on land cover and the distribution of plant, insect, bird and animal species and populations play a central role in the impact-related part of the work. Most of the research programme is focused in the UK, but the experience and expertise of Institute staff are being increasingly called upon in multi-national programmes and to assist in overseas pollution problems. The strength of ITE's research programme in this area and of the experience and expertise of its staff is reflected in membership of 12 Government and EC advisory committees.

The Institute's work on radionuclides provides an example of the importance of maintaining a strategic science budget programme which can then be directed to meet short-term applied needs. It requires considerable flexibility from the scientists working in this directed-mode environment. It is now eight years since the Chernobyl accident which led to the serious contamination of large areas of the Ukraine, Belorus, Russia, Scandinavia and Germany, as well as areas of upland Wales, Cumbria and parts of Scotland. The Institute directed staff from its Radioecology Section to research into the impacts of the accident in the UK in the first few days after the deposition of the fallout in Britain. Since then, the Chernobyl-related work has examined the processes controlling the cycling of radiocaesium in upland plant/soil systems and its transfer to sheep, deer and grouse; the factors controlling the variability in radiocaesium activity between sheep within a given flock; the impact of heather moor management on the availability of radionuclides; the assessment of amelioration measures; and the development of predictive models. This programme of work continues and is supported by the Ministry of Agriculture, Fisheries and Food and the Scottish Office Agriculture and Fisheries Department. The experience and expertise built up during this research, and earlier work on the fate of the releases from the Sellafield plant, are now being applied in the contaminated areas of the Ukraine, Belorus and Russia, as outlined in the first of the articles in this section. This research aims to enable the respective governments to assess the relative importance of a number of different pathways of radionuclide transfer to man and to identify the most appropriate countermeasures. The studies will also aid in the development of improved predictive models for a range of radionuclides, which will help in assessing the impact of any future accidents.

The Institute's work on acidic atmospheric pollutants, although not reported in this year's Annual Report, continues to be one of the main thrusts of our work on environmental pollution. A sulphur protocol was signed in June 1994 under the auspices of the United Nations Economic Commission for Europe convention on transboundary pollution; a member of the Institute's staff was part of the UK delegation present at the signing. The critical load approach, and critical load maps for sulphur for soils and waters were key elements in the negotiations of the protocol. ITE scientists played, and continue to play, an important role in the development and application of the critical load approach in the UK. The co-ordination centre for the development of the UK maps, and the UK link to the European mapping centre, is based at ITE Monks Wood,while the development of the soil maps is led from ITE Merlewood and carried out in

collaboration with the Macaulay Land Use Research Institute, the Soil Survey and Land Use Research Centre, and the University of Aberdeen. Assessment of current exceedence of critical loads requires national maps of deposition. Staff at ITE Edinburgh have played a key role in the modelling and quantification of deposition and in the development of these maps. A report of the DOE's Critical Loads Advisory Group (CLAG) (Plate 36), released in early 1994, summarises the work of CLAG, and was co-ordinated by ITE. The third report of the UK Photochemical Oxidants Review Group was also published in late 1993 (Plate 36); the Review Group is chaired by Prof David Fowler, from ITE Edinburgh.

Negotiations for a NO_x protocol will begin in 1995 and will inevitably be linked to discussions of an O_3 or photochemical oxidants protocol; the NO_x protocol may also be broadened into a total nitrogen protocol. Critical load and level maps will again play a key part in the negotiations. Experimental work at ITE Monks Wood, Bangor, Merlewood and Edinburgh is seeking to establish critical loads of nitrogen for a range of UK ecosystems, and to evaluate the currently recommended methodologies for calculating the critical loads of N. Databases built up from long-term studies over the last 15–20 years are also proving invaluable in this evaluation. Research on the deposition processes for nitrogen compounds, quantification of nitrogen deposition at the regional and national scale, and the development of N budgets is centred at ITE Edinburgh. The field equipment used to measure inputs of nitrogen as NH_3 and NO_2 gases to semi-natural vegetation and over crop land is shown in Plates 37 and 38. These methods provide hourly averages of the net exchange of the gases over the fieldscale and can be used to investigate processes regulating the fluxes.

To date, the critical load approach has largely been applied at the national and European scale but, over the last year, its application has been explored at smaller scales and with respect to the impact of emissions from a specific source. This work involves linking data on emissions with transport and deposition models, critical load maps and detailed information on the stock at risk in the affected area. The use of geographical information systems is central to the linkage of the models with spatial data. The development of systems to enable the assessment of the impacts of localised accidents or development proposals which may release pollutants requires information on the stock at risk in the affected area, but also criteria for evaluating the ecological quality and value of the species, habitats and ecosystems at risk. The Institute is working with Her Majesty's Inspectorate of Pollution in developing such approaches. An increasing trend in impact assessments is the quantification of the damage, or the extent of the reduction in damage following control of emissions, and, eventually, the valuation of the damage. Institute staff are collaborating with other environmental scientists in developing the necessary dose–response models and with environmental economists in the approaches to valuation.

The research on acidic atmospheric pollutants is part of a relatively long-term programme, in collaboration with the the Department of the Environment, in support of policy development. The second article in this section illustrates ITE's involvement in the evaluation of the impact of specific, localised accidents and regional pollution incidents, drawing upon underpinning longer-term programmes. The accident involved a fire in an industrial plant which resulted in heavy metal contamination, and the regional pollution incident was a seabird wreck in the Irish Sea. The article highlights the importance of high-quality chemical data in the assessment of incidents of this type and of the ability to draw upon extensive databases accumulated from the underpinning research. Following an industrial accident, or an accidental or deliberate spillage of potentially toxic materials, a clean-up operation usually takes place. Such operations can produce large quantities of contaminated soil or similar material which has to be disposed of in as environmentally benign a way as possible. The final article in this section introduces recently initiated work on the environmental aspects of the disposal of oiled beach materials scraped from contaminated beaches following spills. The study is using a wide range of approaches, from laboratory studies to large lysimeters and extensive field experiments, and is drawing on a range of expertise from a number of the ITE stations, from other NERC Institutes and from the private sector. Supported by the Department of Transport, the study aims to produce protocols for the disposal of the oiled materials which can be implemented by local authorities.

M Hornung

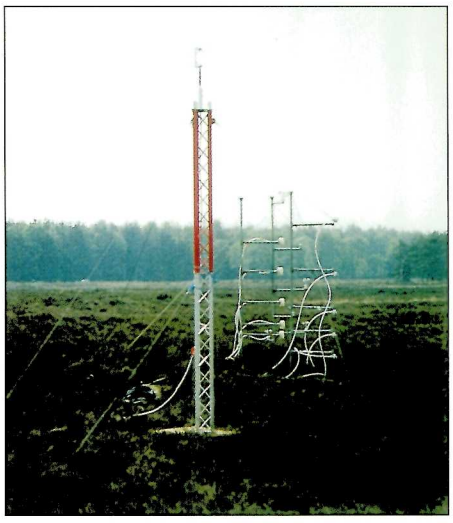

Plate 38. Insturmentation to measure inputs of the trace nitrogen gases NO_2, HNO_3 and NH_3 to Dutch heathland in a collaborative campaign with Dutch, German and UK research groups

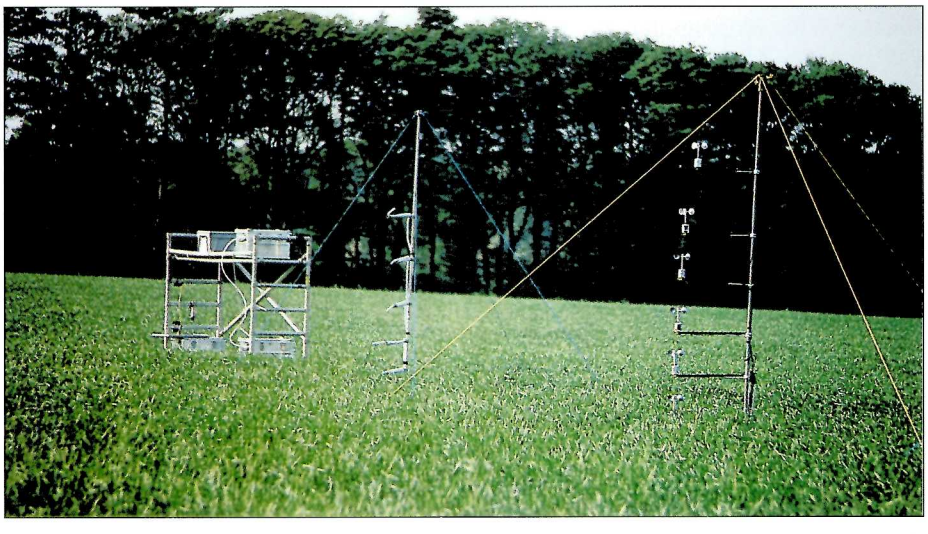

Plate 37. Instruments for measuring the exchange of NH_3 and SO_2 between agricultural crops and the atmosphere in collaborative ITE and University of Nottingham studies

Studies in the Commonwealth of Independent States (CIS) on the transfer of radionuclides to animals

(This work was funded partly by the European Commission)

Since the Chernobyl accident, the Institute's Radioecology Section at Merlewood has been actively involved in studies on the fate of the Chernobyl deposition in the UK uplands. These studies have been examining the cycling of radiocaesium in the upland plant/soil system, the transfers of radiocaesium to sheep, grouse and deer, and possible ameliorative measures to reduce transfers to sheep. Through this research, the Section has developed links with other European groups working on these topics, and has eventually become involved in three multi-national projects supported by the European Commission (EC): two on the transfer of radionuclides to ruminants, and a third on radionuclide transfers in semi-natural ecosystems.

After the initial phase following a nuclear accident, ingestion pathways become increasingly important in determining the dose of radionuclides to humans. Doses from animal products, such as milk, have been shown to be particularly important. The animal production systems in the CIS are very different from those in western Europe: in general, the systems are less intensive. There are also marked differences in management practices within the republics, in particular between collective and privately owned farms (Plate 39), and contamination levels of food products may differ substantially between animals from these two types of farm. Animals bred following normal agricultural management practices in collective farms may be expected to be less contaminated than those herded in semi-natural ecosystems by private farmers. It is, therefore, necessary to compare these differing sources of animal products to assess their comparative importance as sources of radionuclide intake by man in areas where contamination persists following the Chernobyl accident. Furthermore, the relative intake from animal products, as opposed to other sources such as berries, mushrooms and vegetables, needs to be assessed. Once the most important sources of radionuclide intake for the population via animal products have been identified, then the most appropriate countermeasures can be employed.

Plate 39. Traditional methods of transporting hay in the Ukraine from common land to privately owned farm

In 1993, members of the Section became involved in a large multi-national programme, financed jointly by the EC and the CIS states under an 'EC/CIS agreement for international collaboration on the consequences of the Chernobyl accident'. The project in which ITE is involved, referred to as ECP9, is working in each of the three republics affected by the accident – Ukraine, Belarus and the Russian Federation. The overall objective of the ECP9 project is to identify the most important pathways of radiocaesium and radiostrontium to man via animal products in two different agricultural regions within the CIS, taking into account the different agricultural production systems in these areas, and to devise appropriate countermeasures. A detailed study is examining the transfer of radionuclides to animals in specially selected areas where problems of contamination of animal products persist as a result of the Chernobyl accident. More specifically, the group is trying:

- to compare and contrast the radiological behaviour of radiocaesium and radiostrontium, and to compare transfers in the different animal production systems;
- to determine the comparative importance of different sources of radionuclides from animal products to man;
- to identify and apply appropriate countermeasures;
- to calculate ecological half-lives of radiocaesium and radiostrontium in animal products in the different regions/systems.

Over the first year of the study, the group has identified appropriate study sites for which there is an established data set in two contrasting study areas, with different soil types. One site, in the Novozybkov district in the Bryansk region of Russia, has a predominantly sandy soddy podzolic soil and was highly contaminated by the accident. A second site, in the Dubrovitsa district of the Ukraine, was less contaminated, and, although dominated by sandy soddy podzolic soil, also has areas with highly organic soils. Both soil types allow recycling of radiocaesium (like the upland areas of the UK still affected by the Chernobyl accident). Studies at a third site, based on two villages in Belarus, are focusing only on private farmers.

Geographical information from these sites is being digitised and held in an Arc/Info geographical information system (GIS), and the resulting maps are being used as the basis for the

collection of all subsequent information Current activities include

- describing land use and agricultural management practices within the study sites,
- determining production budgets,
- characterising the soil types, and
- quantifying the radioactive deposition

The group has implemented sampling regimes of animal food products, and is making initial assessments of the dietary intake of the population in the study areas The animal products being considered include cows' milk, beef, pork, chicken, goats' milk, eggs, wild boar and other game Detailed studies of seasonal variations in contamination levels in roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) are ongoing elsewhere in the Chernobyl zone and will be extended to the study sites next year

The next stage of the work will involve an investigation of the mechanisms controlling the primary routes of transfer of radionuclides to animal products, and the description of differences in transfers and long-term behaviour It will provide the CIS authorities with a better understanding of the relative importance of the various animal and agricultural production systems as pathways for radionuclide intake by man A thorough understanding of the radionuclide transfer processes and contamination levels in animal products is an essential basis for identifying those products and systems for which we would need to develop and apply countermeasures

The project brings together a wide range of radioecological, agricultural and ecological experience, with particular expertise covering the transfer of radionuclides to animals in both agricultural and semi-natural systems, including housed, free-ranging and wild animals The participating institutions in the European Union (EU) are shown below

- **Norwegian Radiation Protection Authority (NRPA),** Østeras, Norway
  NRPA is co-ordinating the study in collaboration with ITE It is analysing existing data to make an initial estimation of the long-term behaviour of radionuclides It also has a particular interest in dietary surveys of the study areas

- **Institute of Terrestrial Ecology (ITE),** Merlewood Research Station, Grange-over-Sands, UK
  ITE co-ordinates the study in collaboration with NRPA and is currently responsible for the incorporation of geographical, radioecological and agricultural information into the GIS and database The main objectives for ITE in the first year of the ECP9 project have been
  - to describe the land use of the two study sites, and
  - to devise and implement a routine sampling protocol, for both the collective and private farming systems, which will enable the changes with time in levels of ^{137}Cs and ^{90}Sr in animal food products to be determined

  The results of the analyses from 1994 onwards will be compared with the historical data collated by NRPA and AUN, in collaboration with CIS participants This comparison, together with the data collected over the next few years, will provide the required information on the long-term behaviour of radiocaesium and radiostrontium

  In a summer field campaign in July 1994, we used geographical positioning satellite equipment to relate sample collection to the GIS information in order to provide further data on land use Other information, such as soil deposition and contamination levels of products, will also be incorporated into the database as it becomes available It is hoped that linking models which describe radionuclide transfer to animal products with the GIS will provide a powerful interpretive tool, allowing us to quantify the potential effects of various countermeasures for the actual production systems operating in the contaminated areas

- **Department of Animal Science, Agricultural University of Norway (AUN),** Ås, Norway
  AUN is responsible for describing the land use and agricultural production systems of the study areas, and is also analysing trace element levels in animal products to see whether the application of countermeasures has had a detrimental effect on trace element levels in food products

- **Clinical Chemistry Department, Swedish University of Agricultural Sciences (SUAS),** Uppsala, Sweden
  SUAS is determining ^{137}Cs and ^{90}Sr activity concentrations in wild boar and roe deer inhabiting the 30 km exclusion zone surrounding the Chernobyl Nuclear Power Plant (NPP) The aim is to describe the seasonal variation in contamination levels, and to try and explain any variation by examining dietary habits and ground deposition levels

- **Nuclear Physics Laboratory (NPL), University of Ioannina,**
  Ioannina, Greece
  NPL is co-operating with the Belarussian participants in a study focusing mainly on private farmers in two villages in Belarus NPL is also measuring transfer coefficients to various tissue compartments of three species of ruminant in the 30 km zone, and this information should be useful in linking models of radionuclide behaviour to the GIS information

The major CIS participating institutes are listed below

- **Russian Institute of Agricultural Radiology and Agroecology (RIARE),** Russian Federation
  RIARE is responsible for the investigation at one of the study sites in the Novozybkov district in the Bryansk region of Russia The **Institute of Radiation Hygiene** (IRH), St Petersburg, is carrying out a dietary survey in the study site

- **Ukrainian Institute of Agricultural Radiology (UIAR),** Ukraine
  UIAR is responsible for the investigation at the Dubrovitsa district in the Rovno region of Ukraine, with the **Sarni Research Station** In addition to the study site work, the group is also undertaking regular sampling of wild boar and roe deer in the 30 km zone around the Chernobyl NPP **RIA Pripyat** has responsibility for sampling wild animals in co-operation with the **Institute of Geography**, Academy of the Sciences of the Ukraine, with the **Institute of Zoology**, Academy of the Sciences of the Ukraine, and the **Institute of Nuclear Research**, Academy of the Sciences of the Ukraine, Kiev

- **Belarussian Institute of Agricultural Radiology (BIAR),** Belarus
  BIAR is responsible for the Belarussian

study villages of Savichy and Dvor Savichy and for a wild animal study similar to that being conducted in the Belarussian territory of the 30 km zone.

In addition to the scientific aspects of the programme, each experimental collaboration project (ECP) supplies its CIS collaborators with equipment needed for radioecological studies. ITE has been responsible for the selection and supply of this equipment, through an intermediary in Dresden, Germany. The international programme also incorporates funds to support working visits of young scientists from the CIS Institutes to the EU Institutes.

B J Howard, M K Gillespie and A D Horrill

Heavy metal contamination in wildlife and quality assurance for analytical data

A large number of investigative studies which involve analysis of heavy metal residues in wildlife are carried out each year. Because residue data are fundamental to such work, it is essential that the chemical analyses are accurate and repeatable. This report describes briefly two investigations which were carried out in 1993–94, and outlines the means by which the accuracy and repeatability of the chemical analysis for such studies is ensured.

Heavy metal contamination of a forest ecosystem caused by an industrial accident

There is increasing concern about the impacts of major chemical accidents on the environment and human health. This concern has led to the development of the European Community Seveso Directive and the UK Control of Industrial Major Accidents and Hazards (CIMAH) Directive. This legislation is designed to prevent chemical accidents and limit the environmental impacts of those that do occur. The development of strategies for assessing such impacts is critical for the successful implementation of the legislation. However, the effects that accidents have on the environment depend largely on the type and amount of chemical(s) involved, the mode of release, and the physical and biotic character of the accident area; each accident is, therefore, a unique event. To develop sampling protocols which can be used to assess environmental damage caused by *any* given accident, it is necessary to determine if there is commonality in the dispersal and impacts of pollutants for different classes of accident. This is being done by studying the impacts of a wide number of accidents.

One accident, a fire at a plastics recycling factory involving 600 t of polyvinyl-chloride (PVC) and 400 t of a range of other plastics, provides a good illustration of the type of environmental contamination caused by an industrial accident and the resultant movement of pollutants through the food chain. As a result of the fire, approximately 800 m^2 of ground in an adjacent forestry plantation (predominantly Scots pine (*Pinus sylvestris*)) was capped by a 10 cm layer of semi-combusted, molten plastic. Two years after the accident, a substantial organic layer which supports a wide range of invertebrates had formed on top of the plastic. The concentrations of heavy metals, which are used in plastics formulations, were determined in litter, earthworms (*Lumbricus castaneus*) and wood mice (*Apodemus sylvaticus*) taken from the contaminated area, and compared with those in equivalent samples taken from a nearby but uncontaminated control area.

The litter layer from the plantation near the factory was found to be significantly contaminated with cadmium (Cd), lead (Pb) and antimony (Sb), concentrations of these metals being 6–15 times greater than in litter from the control site (Table 8; Figure 52). Although the levels of Cd in the litter were much lower than those of Sb and Pb, it was evident that Cd was readily bioaccumulated by earthworms, the concentrations in the earthworms being much higher than those in the litter. In contrast, Pb and Sb were poorly accumulated by earthworms, the earthworm body burdens for these metals being much lower than concentrations in the litter. Nevertheless, the levels of Pb and Sb present in the earthworms were still found to be considerably greater than levels present in worms from the control site (Table 8; Figure 52).

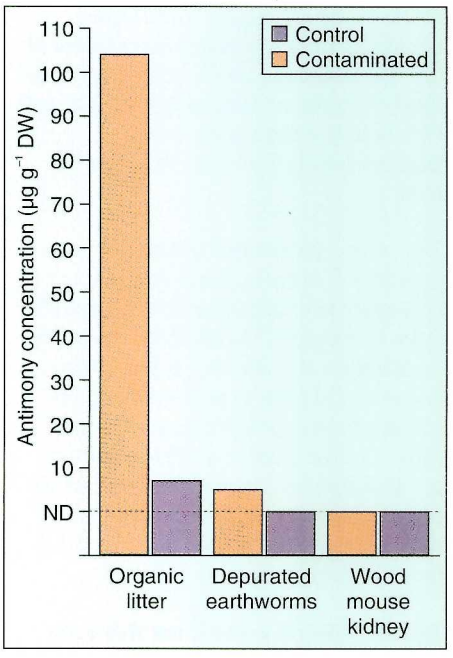

Figure 52. Mean concentrations of antimony in the organic litter layer and in biota from a site contaminated by a plastics fire and from a nearby control site (ND not detectable)

Metal levels in mammal kidneys are sensitive indicators of heavy metal exposure of mammals. Wood mice captured on the area contaminated by the plastic deposits had considerably higher levels of Cd and Pb present in their kidneys than animals from the control site (Table 8). However, the concentrations of Sb in the kidneys of animals from both the contaminated and control sites were below the limit of detection (Figure 52). It is not clear if the metal burdens of the mice on the contaminated site were due to animals eating contaminated vegetation, contaminated invertebrates, or both; wood mice are normally

Table 8. Heavy metal concentrations in litter and biota from a site contaminated by a plastics fire and from a nearby uncontaminated (control) site (ND not detectable)

Metal	Site	Mean concentration (µg g^{-1} DW) Litter	Depurated earthworms	Wood mouse kidneys
Lead	Control	76	51	0.5
	Plastic	820	140	32
Cadmium	Control	1	4	ND
	Plastic	7	30	6

omnivorous although invertebrates usually form only a minor component of the diet (Hansson 1985). However, it is clear from the present study that Cd and Pb present in the plastic were transferred via the food chain into the mice.

This case history clearly illustrates the potential of industrial accidents to contaminate a habitat and for pollutants to be transferred via the food chain. The distribution of antimony, in particular, appeared to give a good index of the extent of contamination from plastics fires. Similar studies at other locations are building up a more detailed picture of the extent of pollution caused by accidents and the routes of transport of those pollutants to biota.

1994 seabird wreck on the east coast of Britain

During February 1994, there was a large seabird wreck on the east coast of Britain. Initially, dead birds were washed ashore in Shetland but the problem was reported along the whole length of the east coast within a few weeks. The Royal Society for the Protection of Birds (RSPB) estimated that the total number of mortalities was 75 000 birds, 50 000 of these being found in Shetland alone. Most of the wrecked birds were guillemots (*Uria aalge*), although razorbills (*Alca torda*), shags

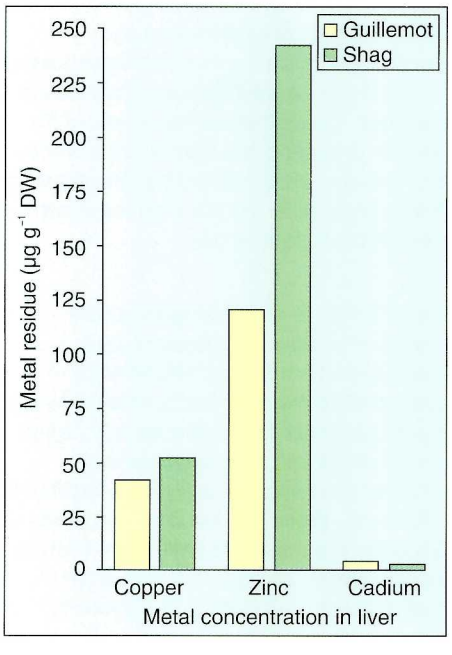

Figure 53. Mean copper, zinc and cadmium concentrations in the livers of 34 guillemots and four shags from the UK east coast seabird wreck in February 1994

(*Phalacrocorax aristotelis*) and little auks (*Alle alle*) were also reported to have died.

Post mortem examinations were carried out on seabird carcases from several sites. No gross abnormalities were found but the birds were in a starved condition and there were signs that some had begun to metabolise protein reserves. Some birds had successfully moulted into breeding plumage which would have been a recent demand on energy reserves. Samples of liver and fat (where present) were analysed for a variety of pollutants and pesticides, including heavy metals.

An inductively coupled plasma mass spectrometer (ICP-MS) was used to analyse the tissues of wrecked birds for metals. Initially, the ICP-MS was used in 'scan mode', a procedure particularly useful in the analysis of samples from wildlife incidents as it provides information about which elements are present and a very approximate indication of their concentrations. The scans revealed that there were significant amounts of zinc, copper and cadmium in the bird tissues. Copper and zinc are essential elements normally present in tissues but they can be toxic if present in excessive amounts; elevated concentrations of these elements are also associated with exposure to organic chemicals. Cadmium has no biological function and can cause kidney lesions in pelagic seabirds (Nicholson & Osborn 1983). The ICP-MS scans indicated that there were no other elements which may have contributed to mortality present in the tissues.

On the basis of the scan information, the concentrations of copper, zinc and cadmium in the birds were determined (Figure 53) using the ICP-MS in 'quant' mode. The concentrations of these metals in the livers of the wrecked birds were not abnormally high, being similar to levels measured in healthy auks in earlier studies (NERC 1983; Osborn, Harris & Nicholson 1979). Therefore, the concentrations of these metals in the wrecked birds were not considered to have been toxic. The cadmium residues in the livers of wrecked birds were also smaller than those associated with the occurrence of lesions in the kidney; thus, there was no evidence that cadmium caused even sublethal effects in these animals.

It was concluded that the levels of copper, zinc and cadmium present in the wrecked birds were unlikely to have contributed to their death. Similarly, analysis for organic compounds revealed that the concentrations of organochlorines and polychlorinated biphenyls (PCBs) were also low and were unlikely to have exerted a toxic effect. The cause of the mass mortalities has been attributed to starvation, although why the birds were in a starved state has not been determined at present.

Table 9. Mean and standard deviation (SD) from 48 subsamples of reference material

	Metal concentration (µg g⁻¹ DW)	
	Mean	SD
Lead	1.36	0.17
Cadium	2.94	0.37
Mercury	2.06	0.11
Tungsten	1.17	0.17
Zinc	103.00	6.26
Copper	17.40	0.93
Rubidium	25.40	1.10

Quality assurance in residue studies

To ensure the accuracy and repeatability of metal analyses in studies such as those described above, it is important that there is a quality assurance (QA) scheme for the chemical analyses. This involves analysing reference material in conjunction with unknown samples, thereby enabling the detection of inaccuracies arising from poor laboratory technique or machine failure, and also revealing any variation in extraction or detection efficiency with time which might bias 'time series' data. Although certified metal reference materials are commercially available, they often contain amounts of heavy metals which are unrealistic of concentrations routinely found in the body organs of wild species; furthermore, the large-scale use of commercially available reference materials is highly expensive.

A QA scheme has recently been developed at ITE Monks Wood using in-house reference material. This material consists of freeze-dried liver which contains a variety of essential and non-essential metals, the liver tissue being obtained from cockerels dosed with subtoxic amounts of cadmium, lead, mercury and tungsten. The mean concentrations of non-essential metals, and also of essential trace metals which occur naturally in liver tissue, were determined by analysing 48 subsamples

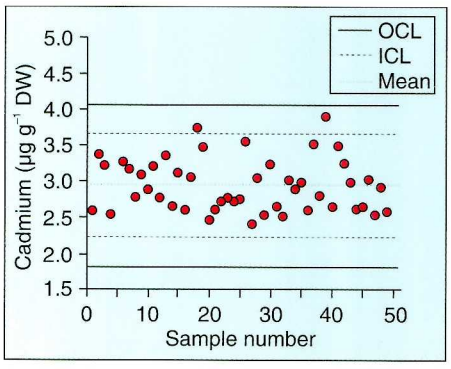

Figure 54. Concentrations of cadmium in the 48 subsamples used to initiate a QA scheme; 95% and 99.9% confidence intervals are indicated by ICL and OCL respectively

of the reference material (Table 9). The results of this analysis were also used to calculate the 95% and 99.9% confidence intervals for the data and these were classed as the 'inner control limits' (ICL) and 'outer control limits' (OCL) respectively (Figure 54).

A large number of possible QA schemes exist which vary greatly in complexity. It was decided that the most acceptable scheme would be a simple one where the process could be easily implemented and explained. This scheme involves a single subsample of the reference material being processed with each batch (maximum of 25 samples) of unknowns and analysed for the metals of interest. Inspection of the data for the reference subsample results in one of three outcomes.

- If the subsample metal concentration falls within ICL, then the determinations for the batch of unknowns are accepted. It would be expected that, under correct operating conditions, 95% of batches would be accepted outright.

- If the subsample metal concentration falls between the ICL and OCL, the batch of unknowns has to be re-analysed together with a new reference subsample. If the new subsample value falls within ICL, the redeterminations of the original digests of the unknowns are accepted. It would be expected that, by chance, just under 5% of batches would have to be retested under normal conditions.

- If the subsample metal concentration falls outside the OCL, the determinations of the whole batch would be rejected. Outright rejection should normally occur by chance only once in 1000 batches.

This QA system is being monitored for performance and, if necessary, modifications will be carried out to ensure reliability in the determination of heavy metals. To determine the percentage recoveries associated with the QA system, the in-house reference material is currently being calibrated against certified metal reference materials. Further work will be carried out so that QA systems can be introduced for essential macroelements, such as sodium, potassium and calcium, which are naturally present in large amounts in the reference material. Further work is also underway to introduce QA systems for organochlorine and PCB analyses.

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Disposal of oiled beach material in sandy coastal environments

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The UK coastline is subjected from time to time to oil pollution resulting from marine oil spill accidents or ships cleaning their tanks. Oily residues are washed ashore and become stranded on beaches and other coastal areas. Local authorities have a duty to clean up these areas and to dispose of the oily materials. Oily residues may be removed and recycled, but often significant amounts of sand and other materials contaminated with oil are produced. They are usually taken away to landfill sites, but these sites are now becoming less available for the large volumes of oiled beach materials (OBMs) derived from shore clean-up operations.

Burial and landfarming (ploughing into topsoil) of oily residues in sandy coastal environments of low conservation value are now being considered as practical alternatives, provided these operations can be shown to be environmentally acceptable. With this in mind, an ITE-led consortium of specialists, comprising scientists from ITE, the Institute of Freshwater Ecology and the British Geological Survey, and engineers from Sir William Halcrow and Partners (Scotland) Ltd, was commissioned to carry out both a feasibility study and a research programme to investigate the impacts and management aspects of these methods for the disposal of oiled beach materials.

The feasibility study has been completed. It covered topics ranging from the general availability of coastal sites, the logistics and costs of disposal by burial and landfarming procedures, and environmental aspects such as the persistence of oil residues, potential leaching of hydrocarbons to groundwaters, site rehabilitation and site monitoring.

Feasibility study

Though many locations around the UK coast are designated as nature reserves and Sites of Special Scientific Interest, possibly precluding their use for disposal, there are still potential disposal sites which can be used in most regions without infringing nature conservation interests. Many sand dune systems in various areas have been modified by agriculture, military activities and forestry. Areas of reduced nature conservation value might be found in such situations. However, the availability of coastal sites for disposal may depend not only on whether the methods are environmentally acceptable with respect to the effects of the oily residues, but also on the sensitivity of the sites to disturbance caused by the disposal operation, and the costs and success of site rehabilitation methods.

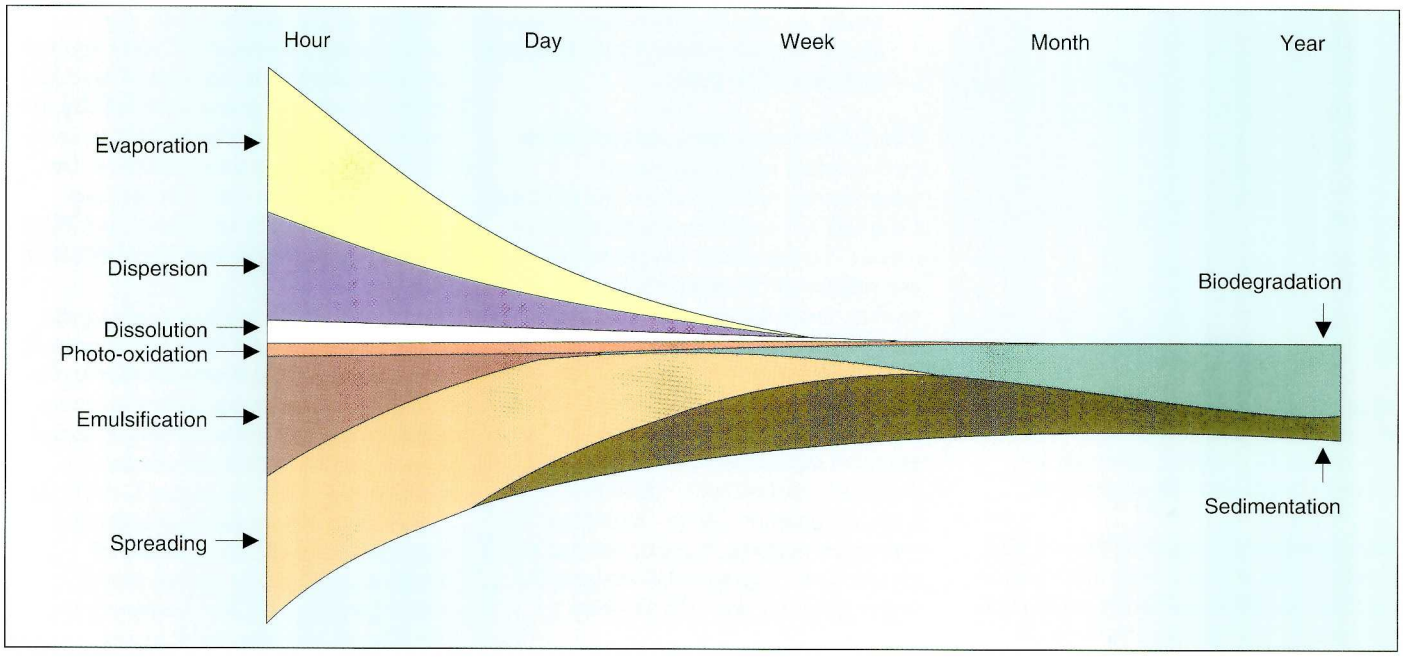

Figure 55. A schematic representation of the fate of a crude oil spill showing changes in the relative importance of weathering processes with time – the width of each band indicates the importance of the process (reproduced with permission from the International Tanker Owners Pollution Federation Ltd)

Views of several conservation and environmental agencies on the proposed methods of disposal were sought. Fears were expressed about the level and persistence of toxicity to vegetation and animals and about potential groundwater pollution due to the oily residues in the environment. However, the behaviour and the potential environmental impacts of the oil residues present in OBMs are likely to be strongly influenced by the effects of weathering processes on oils prior to stranding on beaches or coastline. Even after comparatively short periods (hours to days), crude oils lose most, if not all, volatile and soluble components (Figure 55). Weathered oil residues (WORs) are therefore likely to be much less toxic, and far less environmentally mobile and damaging, than fresh crude or lighter oils. This aspect needs to be taken into account when considering the impacts of OBM disposal by burial and landfarming.

Conditions in sandy soils, particularly permeability to air, are likely to favour the degradation of WORs as oil decomposition is a strongly aerobic process. Low nutrient availability may, however, be a retarding factor. Natural microbial populations present in the soils are expected to develop hydrocarbon-degrading capabilities rapidly when WORs are incorporated. Decomposition of the WORs could thus potentially be quite rapid. With landfarming, tillage and soil warming, due to the reduced albedo effect, will encourage oil degradation. Buried WORs may degrade more slowly than those disposed of by landfarming, but the costs of the latter may actually be higher both in financial terms and in the land area required for disposal.

In 1992, as part of the feasibility exercise, a special study was carried out at an OBM disposal site at Pendine Sands, south Wales. Here, approximately 3000 m^3 of beach sand containing an estimated 20% of WORs were dumped over an area 25 m × 35 m in a dune hollow following the *Christos Bitas* accident off the south Wales coast in 1978. The WORs had been at sea for two to three weeks prior to being beached, and thus had been well weathered. The sandy OBM matrix, black/brown at the time of disposal, was found to be natural sand colour, and analysis showed that more than 98% of the oily residues had been microbially degraded. Populations of hydrocarbon decomposer microbes were still present in the site 15 years after the original spillage. No groundwater pollution was reported. No specific attempts were made to rehabilitate the vegetation, though a mixed plant community had developed characteristic of both sand and the slate–clay overburden.

The feasibility study concluded that these disposal methods can be environmentally acceptable under suitable site and management conditions, but there needs to be practical evidence to substantiate this conclusion. There also needs to be a scientific database on the likely behaviour and persistence of WORs under the range of environmental conditions around the UK coast, upon which protocols for OBM disposal can be based.

Main research programme

Following on from the initial desk study, a five-year research programme has been designed to test the possible environmental impacts of burial and landfarming disposal methods. The studies will cover the behaviour of weathered oil residues (Figure 55) in sandy soils under a range of environmental conditions plus vegetation rehabilitation and site monitoring requirements. Three basic approaches are being used to test the efficacy of these disposal methods:

- intensive field trials at one site;
- assessments of oil residue behaviour in plots at various locations around the UK coast;
- manipulation experiments in a suite of large tubular lysimeters situated in an experimental garden, to examine oil residue behaviour under various simulated conditions.

Plate 40. View in late February of the January 1994 oiled beach material deposit located at Pendine Sands, south Wales (reproduced with permission from the Ministry of Defence)

Intensive field trials of both the burial and landfarming disposal methods will be conducted in separate, replicated, split-plot design experiments in a dune pasture site in west Cumbria, in co-operation with the Ministry of Defence at Eskmeals. The studies on weathered oil residue behaviour will include measuring the hydrocarbon degradation by microbes and the potential for hydrocarbon leaching to groundwater. The former will involve monitoring both CO_2 emissions and hydrocarbon disappearance, and the latter analysis of water samples obtained from specially installed piezometers. Site revegetation trials will also be carried out, which will involve testing the efficacy of known seeding and transplanting techniques.

The second aspect will examine the fate of oil residues under different environmental conditions around the UK coast. Two approaches are to be taken:

- examination of OBM deposits arising from past oil spill incidents, eg that of *the Eleni V* in Norfolk in 1978;
- establishment, with appropriate approvals, of small burial and landfarming plots at sites around the British coastline, representative of a range of environmental conditions.

In the former case, the site conditions are being recorded and samples of the OBM analysed for hydrocarbon content, from which the degree of degradation can be calculated. With the other multi-site study, the 'half-life' (the time for the content to be reduced to 50%) of the hydrocarbon content will be determined from regular samplings and then related to climatic, site and soil microbial data.

In the third approach, manipulative experiments will be conducted in large lysimeters located at ITE Merlewood to investigate the effects of 'site' factors, such as sand type, water table depth, differing rainfall inputs, interaction with different oil types and degrees of oil weathering. Rates of microbial degradation of hydrocarbons, measured as CO_2 and volatile hydrocarbon emissions, will be determined along with the potential for hydrocarbon leaching to an artificially maintained water table. Rates of movement of leaching hydrocarbons will be assessed from waters sampled using porous cups at different heights above the water table, together with sampled outflow waters monitored by tipping buckets. Rates of the processes will be related to weather conditions recorded by an automatic weather station.

In addition, the project has been extended to monitor the fate of weathered fuel oil residues in OBM derived from an actual beach contamination incident at Pendine Sands in January 1994 (Plate 40). An estimated 6000–7000 m^3 of OBM was deposited by the Carmarthen District Council, in agreement with the Countryside Council for Wales and the National Rivers Authority, alongside the site of the deposit from the previous incident in 1978 referred to above. The monitoring is being conducted with the co-operation of the Ministry of Defence at Pendine Sands. Regular samples are being taken to determine the rates of weathered oil residue degradation, reflected in the the emissions of CO_2 and volatile hydrocarbons. The adaptation of the natural microbial populations to the weathered residue decomposition is also being investigated. Even after six months results show that the weathered oil residues are undergoing rapid degradation. Though the site is also becoming sparsely recolonised by a variety of dune and beach plant species, it is intended to enhance the revegetation of the site by seeding or transplanting appropriate species combinations.

The end product of the research programme will be a collated database of information on the fate and behaviour of weathered oil residues when disposed of by burial and/or landfarming in sandy coastal soils, under a variety of environmental conditions. The information will form the basis for selecting disposal sites and for practical protocols for local authorities, should they have to deal with beach contamination following a marine oil spill.

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