Pacific Northwest Laboratory Annual Report for 1983 to the DOE Office of Energy Research

Part 2 Ecological Sciences February 1984

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
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B. E. Vaughan and Staff Members
of Pacific Northwest Laboratory

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Pacific Northwest Laboratory
Richland, Washington 99352

PREFACE

This 1983 annual report from Pacific Northwest Laboratory (PNL) to the Department of Energy (DOE) describes research in environment, health, and safety conducted during fiscal year 1983. The report again consists of five parts, each in a separate volume.

The five parts of the report are oriented to particular segments of our program. Parts 1 to 4 report on research performed for the DOE Office of Health and Environmental Research in the Office of Energy Research. Part 5 reports progress on all research performed for the Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness. In some instances, the volumes report on research funded by other DOE components or by other governmental entities under interagency agreements. Each part consists of project reports authored by scientists from several PNL research departments, reflecting the multidisciplinary nature of the research effort.

The parts of the 1983 Annual Report are:

Part 1: Biomedical Sciences Program Manager - J. F. Park	D. L. Felton, Report Coordinator and Editor
Part 2: Ecological Sciences Program Manager - B. E. Vaughan	B. E. Vaughan, Report Coordinator C. M. Novich, Editor
Part 3: Atmospheric Sciences Program Manager - C. E. Elderkin	N. S. Laulainen, Report Coordinator J. L. Downs-Berg, Editor
Part 4: Physical Sciences Program Manager - J. M. Nielsen	R. M. Garcia, Report Coordinator J. E. Danko, Editor
Part 5: Overview and Assessment Program Managers - S. Marks W. A. Glass	R. W. Baalman, Report Coordinator and Editor

Activities of the scientists whose work is described in this annual report are broader in scope than the articles indicate. PNL staff have responded to numerous requests from DOE during the year for planning, for service on various task groups, and for special assistance.

Credit for this annual report goes to many scientists who performed the research and wrote the individual project reports, to the program managers who directed the research and coordinated the technical progress reports, to the editors who edited the

individual project reports and assembled the five parts, and to Ray Baalman editor in chief, who directed the total effort.

W. J. Bair, Manager
S. Marks, Associate Manager
Environment, Health and Safety Research
Program

Previous reports in this series:

Annual Report for

1951	W-25021, HW-25709
1952	HW-27814, HW-28636
1953	HW-30437, HW-30464
1954	HW-30306, HW-33128, HW-35905, HW-35917
1955	HW-39558, HW-41315, HW-41500
1956	HW-47500
1957	HW-53500
1958	HW-59500
1959	HW-63824, HW-65500
1960	HW-69500, HW-70050
1961	HW-72500, HW-73337
1962	HW-76000, HW-77609
1963	HW-80500, HW-81746
1964	BNWL-122
1965	BNWL-280; BNWL-235, Vol. 1-4; BNWL-361
1966	BNWL-480, Vol. 1; BNWL-481, Vol. 2, Pt. 1-4
1967	BNWL-714, Vol. 1; BNWL-715, Vol. 2, Pt. 1-4
1968	BNWL-1050, Vol. 1, Pt. 1-2; BNWL-1051, Vol. 2, Pt. 1-3
1969	BNWL-1306, Vol. 1, Pt. 1-2; BNWL-1307, Vol. 2, Pt. 1-3
1970	BNWL-1550, Vol. 1, Pt. 1-2; BNWL-1551, Vol. 2, Pt. 1-2
1971	BNWL-1650, Vol. 1, Pt. 1-2; BNWL-1651, Vol. 2, Pt. 1-2
1972	BNWL-1750, Vol. 1, Pt. 1-2; BNWL-1751, Vol. 2, Pt. 1-2
1973	BNWL-1850, Pt. 1-4
1974	BNWL-1950, Pt. 1-4
1975	BNWL-2000, Pt. 1-4
1976	BNWL-2100, Pt. 1-5
1977	PNL-2500, Pt. 1-5
1978	PNL-2850, Pt. 1-5
1979	PNL-3300, Pt. 1-5
1980	PNL-3700, Pt. 1-5
1981	PNL-4100, Pt. 1-5
1982	PNL-4600, Pt. 1-5

FOREWORD

Our Annual Report for 1983 has followed the previous report in highlighting major developments in five prime research areas funded by the Ecological Sciences Division of the Office of Energy Research. In their entirety, these research areas contain 19 individual projects (Field Task Proposal/Agreements, Form 5120.2), each covering specialized tasks. Rather than reproduce detailed information that can be found in Forms 5120.2 or in published reports, we have provided here a concise annual review of the overall program. We hope this will prove to be more useful to field directors, agency office heads, oversight committees, and others who will not have time for details principally of interest to research managers.

The following research areas are highlighted:

- Western Semi-arid Ecosystems
- Marine Sciences
- Mobilization, Fate and Effects of Chemical Wastes
- Radionuclide Fate and Effects
- Statistical and Quantitative Research.

The research described in this report was funded through DOE's Environmental Research Program (HA-02-03) from three budget sources:

HA-02-03-01	Identify Transport & Conversions of Energy-Related Pollutants in the Environment
HA-02-03-02	Biological Responses
HA-02-03-03	Research Logistics, Operations and Support

For your convenience, a listing of interagency services agreements for PNL staff is provided at the end of this report. A separate annual report* should be consulted for highlights of Interagency/Contract research carried out by PNL staff.

Burton E. Vaughan
Subprogram Manager,
Ecological Sciences

*Vaughan, B. E., and C. M. Novich, Editors. *Environmental Sciences Department, Annual Report for 1983 on Interagency and Other Research*. Battelle, Pacific Northwest Laboratories, Richland, Washington, (In preparation).

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INTRODUCTION

Research carried out by Pacific Northwest Laboratory (PNL) for the Office of Energy Research's Ecological Research Division (ERD) is designed to evaluate systematically the problems that energy development activities pose to the environment. Another prime purpose is to identify areas in which energy developments must ultimately meet the intent of the National Environmental Policy Act (NEPA) and various health statutes. Many, but not all, of the research programs carried out by PNL deal with the problems of regional significance to the Pacific Northwest.

Experience has shown that the most practicable way to assess a potential ecological problem is to first develop a basic understanding of the biological and physical processes that control the environmental behavior of contaminants. Once this fundamental understanding has been established, the research can be quantified, and at this point it often becomes pertinent to a wider range of environmental concerns, not just the areas specifically studied. For example, the Laboratory's investigations of the metabolic processes by which trace metals are converted to organic complexes of lesser (or sometimes greater) toxicity adds to our knowledge of how chemical by-products are formed, how radionuclides interact with the environment, and how retorted shale constituents affect regional hydrology. We believe that such triple utility exemplifies the broad application of basic research, which is both a positive force in the scientific world and one worth continued efforts.

Throughout this report we will try to point out applications of our research to practical problems, especially where the data may be directly used by others. In other cases, the research is laying groundwork for later acquisition of meaningful data (mission-oriented basic research), and we hope those interested in technology applications will not be impatient with the necessary approach.

During 1983 several major changes occurred in the non-nuclear (chemical) research program. Earlier projects, conducted under joint collaboration of ERD with the Office of Fossil Energy Research, had uncovered some major difficulties. The difficulties included the inapplicability of RCRA standards to many buried waste situations, the difficulty of applying conventional toxicological approaches to complex (organic) mixtures, the need for approaches to deal with complex geochemical equilibria, and the need for some general principles on how metabolism and biodegradation of organic compounds would influence the long-term fate of compounds released to the environment. While the earlier projects had served to delineate important concerns arising, for example, from shale oil and synfuels technologies, it was clear that a more systematic basic research program was needed to clarify the specific problems indicated. Accordingly, the shale oil and coal synfuels projects were brought to a close in early fiscal year 1983. New work, commenced later in the year, was multitechnology oriented, and it specifically deals with the underlying processes that determine mobilization and fate of chemical wastes in terrestrial and aquatic environments.

Also during fiscal year 1983 concern arose about consolidating and organizing the extensive ecological data compiled under the NERP and ALE terrestrial ecology program. Effort along these lines commenced later in the year. During fiscal year 1984, we hope to be able to show how the regional data base can be used and, particularly, to delineate the more useful ecological approaches that have been devised over many years of experimentation. New initiatives were proposed to ERD, also in the radiological area, and we hope to be able to pursue these lines of inquiry in fiscal year 1984.

An E. O. Lawrence Memorial Award was conferred on Dr. Raymond E. Wildung in fiscal year 1983 for original research on "...metabolic relationships that control pollutant transfer through soils to

plants to animals; the cycling of carbon in soils; nutrient and chemical processes in lake systems; and the organic complexation of plutonium as it affects biological availability....” We are pleased that Dr. Wildung was so honored, and take note of the fact that the several processes mentioned in his award form a coherent body of basic research on soil and sediment systems. This research corpus provided the groundwork on which a large part of our current research in chemical wastes is based.

Burton E. Vaughan

Western Semi-Arid Ecosystems

One goal of the western semi-arid ecosystems research program is to find ways to detect deleterious changes in ecosystems while these changes are still relatively small and amenable to technology design or control options. Another goal is to provide and maintain field facilities such as the National Environmental Research Park (NERP) for extramural scientists doing environmental research of interest to the Department of Energy. Our approach to environmental research has been to develop a large data base for use in characterizing biotic communities, successional processes, transport pathways, and ecosystem responses to natural and man-induced perturbations, especially within the western United States. Useful information about the ecological resiliency of semi-arid western areas, where the most intensive energy development is likely to occur, is sorely lacking and must be sought.

The data bases we have developed over a 15-year period, and in a few cases 30 years, provide environmental documentation not being developed by other government agencies or academic institutions. The documentation also leads us to conclude that the environmental impacts from Hanford site operations have been negligible over the past 40 years. Continuation of long-term studies helps ensure the availability of an adequate data base for assessing the environmental acceptability of multiple energy developments in western arid land environments. The NERP program provides scientists from other institutions the opportunity to conduct research in a setting unique to the United States.

HANFORD NERP DEVELOPMENTS

Nuclear energy research and development facilities on the Hanford site are buffered by large, unpopulated land areas as a health and safety measure. To take advantage of these extensive and relatively undisturbed land holdings, the Arid Lands Ecology Reserve (ALE) and National Environmental Research Park (NERP) were established to promote basic short- and long-term ecological research (Figure 1). The studies have produced information on how the construction and operation of energy technologies affect arid and semi-arid regions, and how impacts can be mitigated.

About 300 university and college personnel have used the Hanford NERP since 1968, the year the Arid Lands Ecology Reserve (a more restricted portion of the Hanford NERP) was established. Sixty dissertations at the masters and doctoral level have been cosponsored by PNL, and well over 100 college and university faculty members have participated in these programs. In addition, approximately 40 industrial or other agency consultants have contributed to the programs under our cognizance.

Elk Population Increases by 30 Percent

During the past two years, graduate student research has focused on the American elk and northern Harrier, wide-ranging wildlife species that inhabit the Hanford NERP. The American elk (*Cervus elaphus*) is a new addition to the biota of the semi-arid,

FIGURE 1. The National Environmental Research Park at Hanford is ideally suited for studying ecological processes in the semi-arid shrubsteppe region of the northwestern United States. The data bases established here will help scientists assess the environmental impacts of future energy developments in other dry regions of the United States and in the world.

shrubsteppe region of eastern Washington. Its usual habitat is the cool, moist, forested region of the Cascade Mountains, some 100 miles to the west.

A small, self-sustaining group of wild and wary elk appeared on a remote area of the Hanford NERP in the winter of 1974. Since then, the population has increased to 26. Eleven calves born this spring all survived, bringing the total population to 37.

The elk herd is of considerable scientific interest because the herd occupies the hottest and driest area of Washington. One of the aims of the research is to learn how this isolated elk population accommodates to prolonged summer drought and heat without trees as a shade source and a rather monotonous summer diet consisting mostly of dried grass (Figure 2).

Nesting Harriers Have Extraordinarily Large Foraging Ranges

The northern harrier (*Circus cyaneus*) is a highly mobile hawk of world-wide geographic distribution. A ground nester, the harrier usually selects dense stands of reeds at lakes and ponds and forages by low-level, long-duration flights, barely above the tallest vegetation. Reed communities were scarce on the Hanford site until the 1940s, when chemical separations facilities were constructed. The continuous discharge of large volumes of process waters to broad, shallow basins created shallow lakes and

FIGURE 2. A tranquilized bull elk is fitted with a radio-transmitter that enables scientists to track its movement on the Hanford NERP.

ponds that have, over a period of 20 to 30 years, developed reed communities along their edges. One of these is Gable Mountain Pond. Nesting density and reproductive success of harriers at Gable Mountain Pond are higher than those reported for other areas in the United States. High productivity is attributed to a scarcity of water-loving mammalian predators, especially mink (*Mustela vison*). The scarcity of mink as predators on harrier nests is attributed to the isolation of the pond from historic waterways such as the Columbia River and the absence of an outlet stream leading from Gable Mountain Pond to the river.

The foraging range of adult northern Harriers was determined by capturing adult, nesting birds and fitting them with small, lightweight radiotransmitters. The studies showed that nesting harriers on the Hanford site have larger than expected foraging ranges (Figure 3). The 300-km² foraging range indicates unusual bioenergetic behavior in harriers and is a subject of much contemporary scientific research interest.

River Fluctuations Have Positive and Negative Impacts on Birds

In 1982, another graduate student began a one-year, systematic documentation of the use of Columbia River shoreline habitats by birds. The flow of the Columbia River on the Hanford site has been greatly modified over the past 40 years by the construction of a series of upstream dams. Although the shoreline and islands in the Hanford Reach of the Columbia River retain much of their pre-dam era appearance, subtle changes in shoreline vegetation have been noted, especially the expansion of water-loving willow and cottonwood communities.

Daily fluctuations in water levels as regulated by upstream dams benefitted birds of ground feeder and water gleaner guilds. Receding water levels stranded aquatic invertebrates, small fish, terrestrial insects, and other aquatic organisms on beaches and mud flats where they were easily available as bird forage. In this way, man-induced fluctuating water levels provided food subsidies to some birds. Other species, especially nesting ducks, were negatively affected by the fluctuating water level. In all, 139 bird species used the Columbia River shoreline during the study period. The large number of observations (106,767 birds and 28,092 separate entries) are filed in a computer program. Data can be retrieved according to bird species, specific habitat, or recorded activity.

FIGURE 3. Northern harriers nesting on the Hanford site have unusually large foraging ranges (shaded ellipse). Foraging ranges are estimated at 300 km² for harriers as compared to 10 km² for other nesting hawks.

Some Salt-Tolerant Shrubs Show Unexpected Sensitivity to Wildfire

In July 1981, a wildfire burned through the ALE site, destroying shrubs and understory herbs. A permanently marked shrub-dominated study plot that had been established in 1965 enabled us to study the recovery of two salt-tolerant shrubs, greasewood (*Sarcobatus vermiculatus*) and spiny hopsage (*Grayia spinosa*). According to the scientific literature, both species sprout after burning. These plants are important because they provide food for animals and also have unusual capacities to cycle minerals to shallow-rooted, herbaceous understory plants.

As expected, burning stimulated sprouting of greasewood. The number of discrete greasewood shrubs in 1983 was 12% higher after the fire; however, only 31% of the total shrub canopy was restored. In other words, there were more plants but these were smaller. Canopy cover by greasewood is expected to be restored to pre-burn levels in the next 3 to 4 years.

In contrast, all spiny hopsage shrubs on the plot were killed by fire. Their failure to sprout after burning suggests that hopsage plants on this particular site were growing

under less-than-optimal conditions and were therefore overly sensitive to burn damage. It is expected that spiny hopsage will not return to the study plot for many years if at all.

It is likely that the demise of spiny hopsage in this plant community would have gone unnoticed were it not for the establishment of the study plot and its data record. This study emphasizes the value of permanent field plots as a means of documenting changes in species composition in plant communities after environmental disturbances.

Harvester Ants Can Be Used to Detect the Presence of Chemical Contaminants in Soil

Harvester ants (*Pogonomyrmex owyheei*) may offer a sensitive and inexpensive way to identify the presence of energy-related contaminants in soils in semi-arid regions. Harvester ants are abundant and widely distributed in semi-arid regions of the western United States. They are readily available as bioassay organisms, live in colonies in close contact with the soil, use both plant and animal materials as food, and have limited travel distances from the colony. These are desirable attributes of organisms selected for bioassays.

To determine the sensitivity of harvester ants to a toxic liquid, we collected ants from a Hanford site colony and placed them in simulated nest containers in the laboratory. Each container had 15 g of soil and a small quantity of food. Different concentrations of a toxic liquid were then added to the soil. Ant containers were covered and left undisturbed except for the occasional addition of water during the 40-day test period.

Ant mortality increased as toxic concentrations increased (Figure 4). These results suggest that harvester ants can be used to detect contaminants released to the terrestrial environment. When further refined, the ant bioassay would be the first developed for terrestrial animals and would complement laboratory techniques already developed for testing aquatic organisms and a few species of terrestrial plants.

Populations of Small Animals Forage on More Kinds of Plants Than Do Large Animals

Dietary studies of animals on the ALE Reserve indicate that only a few individuals within some populations eat the same foods as other individuals. This implies that food chains, contaminant pathways, and biotic transport analysis at the population level may be difficult to interpret and, in some cases, interpreted incorrectly.

FIGURE 4. Harvester ants are common in semi-arid regions. Ant bioassays show some promise as a means of inexpensively detecting and mapping toxic chemical contaminants in soils at waste disposal sites.

We noted that the homogeneity of dietary selection within herbivores is a function of size. A characteristic dimension analysis permits comparisons based on relative size rather than relative volume or relative biomass. A characteristic length (L) can be defined as the cube root of the product of the diameter (d) squared and length (l); that is, $L = (d^2 l)^{1/3}$.

The degree of dietary homogeneity within populations increases by a factor of five from very small organisms such as grasshoppers and darkling beetles, to very large organisms such as cattle (Figure 5). Dietary homogeneity within the population is defined as the prey categories used by the average individual divided by the food categories available to the population.

We are hesitant to speculate further on these observations, except to note that it seems clear that small animals may demonstrate little in the way of dietary homogeneity within their populations. Small organisms thus emerge as important subjects for future biotic transport studies.

DETECTING ECOLOGICAL CHANGE

Measurements capable of detecting slowly-paced changes in ecological processes in terrestrial ecosystems allow early detection of effects from widespread contaminants such as acid rain. We are developing minimum cost, minimum variance ecological measurements of the response of forests to stress, and of the level of contaminants in food chains. A new

FIGURE 5. Small animals exhibit more variety in their diets than large animals. Variability in individual diets may obscure the rates of chemical contaminant transport via biotic pathways. Dose assessment modeling may require dietary evaluation where such pathways are important.

research effort begun in mid-1983 demonstrated that stress-induced change in the internal water status of plants could be detected by measuring micron-size alterations in stem diameter. A device for making these measurements on both woody and herbaceous plants is now being tested.

Measurement of Litterfall is a Cost-Effective Way to Detect Long-Term Changes in Ecosystem Function

This year we completed and published our first optimized design for detecting signs of stress in trees. Our design, which focused on annual changes in needlefall rates, dealt simultaneously with four constraints on field measurements: field technique, sampling variance, temporal variance, and cost minimization. Our earlier research had shown that small collectors were optimum, and that hand separation of needles from other litterfall components was most cost effective. This year we demonstrated that the variability of needlefall among years is about the same as variability of needlefall measurements over a standard forest plot (which in our research is one hectare). This result, obtained through an independent analysis of both time and space components of variability in needlefall collections, suggests that needlefall collection can be recommended for routine use for site-specific monitoring. The difficulty of detecting changes through time at a site appears to be no greater than that of estimating homogeneity in space.

Routine application of our needlefall method has already been proposed by the U.S. Forest Service for research to be performed for the National Park Service. Calibrated needlefall collection appears to be a breakthrough for capabilities of detecting and interpreting slowly paced ecological changes.

Heron Colonies Serve as Biological Indicators of Chemical Pollution

A first approximation of a design for tracking the level of contaminants in food chains of a high trophic level, fish-eating consumer species was completed in FY 1983. This research, which currently uses Great Blue Herons (*Ardea herodias*) as a demonstration species, simultaneously considered three components of variation involved in the estimation of contaminant levels: sampling method, sampling variance, and variance over large landscape units.

Optimization of effort was defined by the simultaneous consideration of the non-linear interactions among variance, cost of collec-

tion, and time required for specific tasks in a multi-parameter cost model.

Optimized allocation of effort was determined in two steps. First, the cost per unit effort required to estimate variability within and among colonies of nesting herons was weighted by the respective variance estimates. This step suggested that the optimum number of collectors per colony was about two or three. This estimate allowed us to calculate the number of colonies required to estimate contaminant levels to a specified statistical precision, with optimal allocation of effort, within the constraint of a fixed budget.

The optimized allocation of effort among and within heron colonies suggests that the effort required to estimate background levels of toxic elements in landscapes will vary widely. For example, estimation of background levels of silver (potentially a potent toxicant in aquatic habitats) with a standard error of 50% of the mean might require examination of 24 colonies, whereas an estimation of lead levels to the same precision might require 1000 colonies (Figure 6). Currently, background levels of most other toxic elements appear to be easier to estimate than does the background level of lead. This conclusion suggests that lead sources are distributed heterogeneously, so lead may require site-specific designs.

FIGURE 6. Background levels of toxic elements were estimated, within specified levels of precision, by examining Great Blue Heron colonies. The number of colonies required for sampling depended strongly on the element under investigation.

New Device Can Detect Stress in Plants

A new approach for detecting stress response in plants is under development at PNL. A device invented by Dr. Ronald H. Sauer in 1983 can detect changes of a few microns in stem diameters of herbs. Fluctuations of this magnitude correspond with minute-by-minute changes in the diameter of leaf stomata. This year research into plant responses as measured by this device suggested two important probabilities:

1. Plant responses to toxic gases could be detected within one or two minutes of exposure.
2. Different types of airborne toxins produced different kinds of responses in the test plant, implying that "signatures" for classes of toxins may exist.

Dr. Sauer died before he could quantify these indications into dose-response analyses; however, the promising research that he began is continuing in FY 1984. Our objective in the research is to develop fully the device's capability for providing quantitative measurements of plant responses to environmental conditions in the field. The device has already provided data with unprecedented levels of sensitivity and time resolution.

Steelhead Trout Are More Vulnerable Than Salmon to Dewatering

Streams in the arid western U.S. provide water for energy production and irrigation. These and other uses create fluctuations in water level and declining water quality. Persistent changes can cause subtle alteration of ecological processes and may be environmentally significant if the alterations impair the structure and function of a stream.

PNL scientists are studying the responses of arid-land streams to water uses induced by energy development. The studies will provide information for mitigation strategies to help protect valuable aquatic resources.

This year we examined the effect of dewatering on intergravel phases of rainbow trout (*Salmo gairdneri*) and assessed physicochemical changes in dewatered gravels that might limit the survival of embryos and alevins. Previous studies showed that embryos of chinook salmon (*Oncorhynchus tshawytscha*) could survive continuous dewatering for 12 days, whereas hatched alevins survived less than 24 hours.

Trout embryos were less tolerant of dewatering than salmon embryos under identical test conditions. Intolerance was associated with accelerated development of trout embryos, hence, a shorter pre-hatch period. The studies also confirmed that 100% humidity in dewatered gravel redds was required for embryo survival.

Physicochemical conditions change abruptly in dewatered gravels. At least seven factors will influence survival of embryos and alevins in dewatered gravels (Figure 7). Information from our studies has enabled us to establish firm guidelines for assessing effects of dewatering on natural reproduction of salmonids. On-site monitoring will be required to avoid mortality since hydrographic conditions that limit survival will likely vary with location and season.

PNL's riverine ecology program will be re-directed in fiscal year 1984. Our new objective will be to establish a data base for evaluating ecological processes, trophic relationships, and community structure in arid-land streams. Arid lands are of particular interest because energy facilities are often preferentially located in these areas and water resources are often stressed by development. We plan to measure net daily metabolism, secondary production, and allochthonous input and processing in cold-desert streams near Hanford.

FIGURE 7. Biotic and abiotic conditions will influence survival of embryos in dewatered gravels.

In related work, PNL scientists hosted a session at the 113th Annual Meeting of the American Fisheries Society in Milwaukee, Wisconsin. The discussion focused on impacts of water-level changes to salmonids. The meeting was attended by over 900 resource managers and scientists from North America.

ECOLOGICAL INVESTIGATIONS IN ALASKA

To determine how caribou (*Rangifer arcticus*) are influenced by the environmental changes brought about by oil and mineral resource development in arctic Alaska, we completed a long-term study of migratory movements of caribou herds. Particular phenomena of interest are caribou forage consumption and energy requirements. Field work has been brought to a conclusion. The final report is now in preparation.

The report will document resting, feeding, and walking periods of migrating caribou herds observed in the springs of 1982 and 1983. During the study, fecal pellets were collected and examined microscopically to identify plant species that constitute the caribou's diet. The nutritional content of fecal pellets was determined by chemical analysis. The report will also describe feeding trials conducted on captive caribou at the University of Alaska, Fairbanks, to check the reliability of fecal-pellet analyses as a measure of the caribou diet.

ACKNOWLEDGMENTS

This program consists of research projects 80618/000618, 80836/000394, 81261/001261, 83009/003009, and 83272/003272, which are described in Field Task Proposal/Agreements (Form 5120.2). Principal investigators for these projects are C. D. Becker, W. T. Hinds, W. H. Rickard, L. E. Rogers, and J. B. States. Alaskan studies were conducted under a subcontract with Pacific Northwest Laboratory; co-principal investigators are S. Duquette, University of Alaska, and D. R. Klein, Alaska Cooperative Wildlife Research unit.

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Marine Sciences

Coastal marine ecosystems will receive increasing amounts of contaminants as energy facilities are developed and expanded. We are determining the levels at which contaminants will disrupt or degrade coastal ecosystems through studies of the entrance, transformation, and fate of numerous chemical compounds. We have approached the work through a combination of field measurement and laboratory experiments, with particular emphasis on the biologically active chemical forms of specific elements and compounds. At the organism level, we examined the physiological processes associated with sequestering and detoxifying metals. Results of this program may be used to predict, and subsequently minimize, long-range environmental consequences of current and future energy production processes located in coastal regions.

CHEMISTRY AND FATE OF TRACE METALS IN COASTAL WATERS

Trace metals enter coastal waters from the ocean and atmosphere, as well as by industrial and municipal discharges. The fundamental biological and chemical processes that are disturbed in these ways are poorly understood and need better delineation.

Last year, we determined the sources and sinks of lead, silver, and cadmium in Puget Sound, a large estuary flanked by the urban industrial centers of Seattle, Tacoma, and Bremerton (Figure 1). This year we focused our studies on silver, one of the most toxic heavy metals in aquatic ecosystems. Of the 16 metals we examined, silver had the highest enrichment in water, sediments, and organisms. We are now determining the biological availability of complexes of silver in seawater and the geochemical processes that remove silver from the water column.

FIGURE 1. PNL scientists are studying coastal marine ecosystems and organisms to assess long-range environmental consequences of current and future energy production in coastal areas. Contaminant burdens in the vicinity of Puget Sound are now sufficiently high to raise concerns that require a more systematic understanding of how marine ecosystems, and the organisms found in them, adapt or otherwise respond to these changes.

The geochemical model MINTEQ, developed under another program described in this annual report (p. 17), was used to investigate the equilibrium distribution of silver complexes in coastal water. Primary emphasis was placed on examining how complexation of silver is affected by pH, salinity, sulfide, and dissolved organic carbon concentrations. We know that complexation controls biological availability, and are now examining which complex of silver (chloride or sulfide) is more biologically available.

The model predicted that under typical seawater conditions, 0.005 $\mu\text{g}/\text{L}$ of silver would be distributed equally between chloro-complexes and sulfide complexes. Increasing the concentration of sulfide in seawater from 0.01 to 1.0 $\mu\text{g}/\text{L}$ increased the amount of complexed silver from 0.04% to 98%. These studies suggest that even small amounts of sulfide can dominate the chemical form of silver in aquatic ecosystems. Future field studies can be used to verify the respective amounts of chloro- and sulfide complexes in seawater. Future studies will also help identify which complex is more available to organisms.

Many contaminants discharged to coastal waters are rapidly removed from the water column by adsorption on suspended particles. As these particles accumulate in sediments, a portion of the metals is released back to the water column. The rate at which the marine environment will recover from contamination is directly related to the rate of sedimentation and release. A sediment mass balance was calculated for Puget Sound to assist in determining the rate of burial by natural processes. This was done in regions of the Sound where contaminants are now accumulating.

Inputs of sediment from rivers, shoreline erosion, primary productivity, and advection of suspended matter from adjoining basins

accounted for only 50% of the sediment accumulated in the basin. We suspect our estimates of river and shoreline erosion were too low, and believe that erosion of submarine slopes also should be factored in sedimentation rates.

BIOLOGICAL AVAILABILITY OF TRACE METALS IN COASTAL ECOSYSTEMS

When energy-generated residuals, including metals, deposit from the atmosphere, they become concentrated in the sea-surface microlayer (upper 50 micrometers of an ocean's surface). These metals impose a stress on the survival and productivity of neustonic organisms in the microlayer. Neuston include the eggs and larval stages of commercially important fish and shellfish, which often dominate the sea-surface biota. Our studies thus far suggest that the sea-surface microlayer is enriched in metals from atmospheric deposition at concentrations which may inhibit the physiological processes of neuston.

Metal Enrichments in the Microlayer

Both laboratory and field experiments are being used to study the abiotic and biotic processes of contaminant flux at the interface between the atmosphere and ocean. Last year we developed a model to predict microlayer metal enrichments resulting from different rates of atmospheric deposition. Mean residence times of metals in the microlayer were determined to be 1.5 to 15 hours. Maximum predicted surface enrichments (concentration in microlayer ÷ concentration in bulk water) are greatest for lead, followed by copper, zinc, silver, nickel and, finally, manganese.

This year, for the first time, the metal enrichments observed in the laboratory were confirmed by field studies. Development of metal-free sampling devices made it possible for us to collect samples of the microlayer and subsurface water from both urban and rural coastal areas. Metal concentrations measured in the microlayer of Puget Sound were unexpectedly high, e.g., 10 to 100 times greater than those in the bulk seawater.

It appears that significant portions of these microlayer metals remain in a biologically available form which could be toxic to marine organisms.

Effects of Metals on Zooneuston

We are now examining the effects of high metal concentrations on microlayer biota, such as neustonic flatfish eggs (sand sole,

Psettichthys melanostictus). In Puget Sound, flatfish eggs occur in high concentrations in the early spring.

In the laboratory, deposition of atmospheric particulate matter (APM) at rates up to four times greater than those typical of urban coastal areas ($40 \text{ mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$) had no significant effect on the egg hatching and 96-hour survival of neustonic flatfish eggs. Soluble salts of lead and copper, however, even at levels considerably lower than natural deposition rates, markedly reduced egg hatching and larval survival. Copper sulfate was particularly toxic, with a 96-hour median lethal concentration of 94 mg copper/liter. These studies demonstrate that potential changes in metal speciation in the microlayer could have important implications for fisheries recruitment. For example, acid rain might lower microlayer pH, release more ionic metals, and induce additional stress on microlayer biota.

Effects of Metals on Phytoneuston

Several recent studies by other scientists have suggested that the microlayer is depleted in chlorophyll and photosynthetic productivity relative to the bulk water. Our studies indicate that the depletions result from a number of stressors that are enhanced in the microlayer compared to the bulk water, such as high light intensity, high metal concentrations from atmospheric deposition, and daily variation in the cycles of temperature and salinity.

Photosynthesis of phytoneuston appears to be inhibited by deposition of atmospheric particulate matter at rates often found in urban coastal areas. In microcosm studies using carbon-14 and natural *in situ* microalgal populations, photosynthetic carbon fixation was 7 to 32 times greater per unit volume in the microlayer than in the subsurface water. However, when urban atmospheric particulate matter was deposited on the water surface at rates greater than about $2 \text{ mg} \cdot \text{m}^{-2} \cdot \text{hr}^{-1}$, net photosynthesis of phytoneuston decreased markedly (Figure 2). Stressful conditions of high light intensity and/or nutrient depletions in the microlayer also reduce phytoneuston productivity more than phytoplankton productivity. Preliminary results indicate that all these forms of stress result in an increased release of labelled carbon from phytoneuston. Our data also indicate that unlike phytoplankton, phytoneuston adapt to stress through increased levels of accessory pigments and diurnal vertical migration.

FIGURE 2. Photosynthesis in the microlayer was inhibited by deposition of urban atmospheric particulate matter (APM) at rates typically found in coastal areas. Reduced productivity could ultimately impair the larval development of commercially important fish and shellfish.

Our current plans call for further studies of the mechanisms that allow neuston and plankton to adapt to or tolerate metal-induced stress. Organisms in the microlayer constitute the main point of impact for contaminants entering the water column.

Symposium Organized

Dr. John Hardy's recent findings have attracted national attention, and he is now organizing a symposium for the American Association for the Advancement of Science on "The Importance of the Sea Surface Microlayer." AAAS meetings offer a forum for the presentation of the latest and most significant developments in all branches of science and engineering and are generally attended by a large, interdisciplinary audience. By bringing together scientists working on different aspects of the microlayer, the symposium should provide a better understanding of how the unique physical, chemical and biological processes at the sea surface interact and function as a system.

BIOLOGICAL EFFECTS OF TRACE METALS ON MARINE ANIMALS

Marine organisms can adapt to metal exposure through the induction of mechanisms which increase their tolerance to metal toxicity. Recent evidence indicates that short-term, non-genetic adaptation is one of the strategies available to marine animals subjected to metal exposure.

In recent studies, we demonstrated that enhanced tolerance to mercury toxicity can be induced in the mussel, *Mytilus edulis*, by prior exposure to low concentrations of mercury, copper, cadmium, or zinc. Enhanced tolerance occurred when prior exposure concentrations were sufficiently high to result in bioaccumulation of the metal but below levels in which the exposure itself was toxic. The apparent requirement for bioaccumulation before tolerance was attained suggested an intimate interaction between metal and cellular components. Such an interaction could be involved in "switching on" or inducing relevant cellular processes.

The dual considerations of bioaccumulation and toxicity during prior exposure establish upper and lower limits for a range of metal concentrations that can effectively induce enhanced tolerance to mercury toxicity. Below this range, exposure concentrations would be insufficient to induce enhanced tolerance, while above this range, the toxicity of the prior exposure would override the capability of induced systems to provide protection. Induction of enhanced mercury tolerance by mercury, copper, and cadmium pre-exposures was also accompanied by the apparent induction of metallothionein-like, metal-binding proteins, which are believed to function in the detoxification of these metals. A preliminary model of tolerance to metals in seawater is shown in Figure 3.

Metallothionein and similar proteins appear to play a fundamental role in the metabolism of potentially toxic metals such as mercury, cadmium, copper, and zinc. A better understanding of how these proteins function will likely lead to a better understanding of the effects of metals on marine organisms.

We are developing immunological assays for the proteins from *Mytilus edulis*, since direct assays are not currently possible. We expect to use such assays in both biochemical and immunocytochemical determinations of the proteins. Antibodies against the proteins have been developed and used in preliminary radioimmunoassays. The results show that the antibodies are highly specific since they are reactive against materials extracted from mussel tissues, but not from those of clams, oysters, polychaetes, or rats in which similar proteins occurred. Since techniques for additional purification of the protein have been developed, in future work we will use more highly purified material as antigen.

We plan to continue our examination of adaptation to metal-enriched environments and the mechanisms underlying such adaptation. In

FIGURE 3. Marine organisms pre-exposed to metal concentrations display an enhanced tolerance to metals in seawater. However, once a critical maximum is reached, their tolerance diminishes and chronic injury is likely.

future research we will examine the interactions between metals and other environmental factors, such as temperature, that may influence adaptation to metal exposure.

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Mobilization, Fate and Effects of Chemical Wastes

A number of energy technologies produce large volumes of liquid and solid wastes. The composition of these wastes will differ between and even within technologies, and both inorganic and organic chemical compounds are of concern. Environmental pathways for transport, transformation and accumulation of these compounds often result in the potential exposure of people to toxic materials. We have made progress in recent years in delineating the major environmental routes for such exposure. However, the current state-of-the-art does not yet permit an adequate evaluation of the relative importance of many detailed processes known to affect transport and transformation of solutes, or the biological availability, uptake and metabolism of particular chemical forms of these contaminants.

The current program is conducted in three parts. We are studying hydrogeochemical processes governing transport, chemical uptake and metabolism by green plants, and chemical uptake and metabolism by aquatic organisms (fish and shellfish). The program focuses particularly on commonalities in abiotic and biotic processes controlling chemical transport and effects.

HYDROGEOCHEMICAL PHENOMENA CONTROLLING SOLUTE BEHAVIOR

The composition of solutes mobilized through wastes will change with residence time in the environment and with the location of the disposal site. Several common processes, however, influence the mobilization, transport, and biological effects of solutes in wastes disposed of in the ground. To elucidate these processes as they change with waste residence time in the environment, a conceptual basis was developed for research that uses linked geochemical and hydrologic models as a framework. The model is being used to integrate the activities of a multidisciplinary research team (geochemistry, microbiology, inorganic and organic chemistry, hydrology, biology) necessary to examine different, but related, environmental processes. The model is also used to focus research on priority, rate-controlling processes and functional relationships necessary for generic applicability of the results. Laboratory studies are used to establish basic mechanisms and functional relationships. Field studies establish the range for parameters influencing these relationships and allow validation of models.

The integrated effects of mineralogical and microbiological processes control chemical dissolution, solute distribution between the solid and aqueous phases, and solute form. Hydrologic processes govern the rate and extent of solute movement in waste embankments. Key geochemical and hydrologic processes are being modeled to estimate hydrologic transport of the inorganic and organic solutes. The model is being validated at above-ground disposal sites; at the same time, we are determining mutagenicity and availability of solutes for plant uptake, and

how organic and inorganic solutes are mobilized with time and weathering.

Research in this program has demonstrated that simple assays required by the Resource Conservation Recovery Act are not adequate for estimating the long-term effects of oil shale solid waste disposal on water quality. This is because a complex succession of interrelated chemical and microbiological processes alter the entire chemistry of re-torted shale embankments and leachates with time. New methods and concepts were developed to identify, measure, and explain the integrated effects of these processes. Similarly, comparison of hydrologic transport in laboratory and field measurements is allowing us to identify controls on water movement. Controls, for example, include the quantity of water added to the waste at the time of disposal and the effects of water use by plants used in surface stabilization.

The studies already have markedly improved capabilities for site evaluation and waste management. The results are currently being used by several state and federal agencies in the permitting and regulatory process, and also by industry for design and construction of disposal sites.

In fiscal year 1983, the PNL geochemical computer code MINTEQ was modified and linked with a hydrologic flow model to enable calculation of complex geochemical interactions (e.g., precipitation, adsorption) in a hydrologically dynamic system. Formulation of the combined code was accomplished by incorporating a subset of the calculations performed by MINTEQ into a compact geochemical code (MININR) to reduce computation time. MININR accesses the large thermochemical data base in MINTEQ but performs speciation, solubility, and adsorption calculations at a single

temperature for a reduced number of aqueous and solid components specified by the user. MINIR is linked to the hydrologic code with a new algorithm, which keeps an inventory on precipitated solid/mineral phases in the system. The combined code was used to simulate the leaching behavior of macroions (Ca^{+2} , Mg^{+2} , K^+ , Na^+ , SO_4^{2-} , CO_3^{2-}) from laboratory columns of retorted shale. Model predictions were close to the experimental observations for most constituents (Figure 1). Predictions were accomplished assuming equilibrium conditions using putlandite [$\text{Ca}(\text{OH})_2$]; brucite [$\text{Mg}(\text{OH})_2$]; high Mg calcite ($\text{Ca}_{1-x}\text{Mg}_x\text{CO}_3$); and gypsum ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$) and inputting mass quantities for key amorphous salts (e.g., Na_2SO_4 , K_2SO_4 , K_2O , Na_2O). Model verification will continue using retorted shales and solid wastes of differing mineralogic characteristics and leachate composition.

FIGURE 1. The linked geochemical transport code successfully predicted effluent concentrations from a laboratory retorted shale column.

Detailed studies of leachates from lysimeters containing Paraho retorted oil shale were continued for a sixth year. The weathering processes within the originally, chemically reduced waste are continuing and, after six years, still do not appear to be approaching a steady or equilibrium state. Major changes are occurring in the lysimeter leachates, which have profound significance for the oil shale industry. The total salt content of the leachates, as reflected by the specific conductivity, increased markedly in 1983 to 70% of the peak (pulse) levels observed in 1977. Maximum conductivities for ~0.25 column volume (fraction of air space occupied by water) in 1977 were ~30,000 $\mu\text{mho's/cm}$; minimum levels occurred in 1981 (~6,000 $\mu\text{mho's/cm}$) and subsequent increases have occurred to 21,400 $\mu\text{mho's/cm}$ in 1983. The macrochemistry of the shale has shifted from the original Na_2SO_4 system in 1977 to, currently, a MgSO_4 system.

The second major change is the concentration of NO_3^- that is now appearing in the leachate. The initial leachates obtained in 1977 did not contain nitrate. In fact, nitrate present in the applied irrigation water was removed by the retorted shale. This likely occurred through chemical reduction of NO_3^- by sulfide (with appropriate catalysis) to NH_4^+ and subsequent sorption of NH_4^+ . During 1977 and 1978, NO_3^- levels in the leachate were less than 10 $\mu\text{g/ml}$. Increasing levels since that time have occurred each year with 1983 peak concentrations of 205 $\mu\text{g/ml}$.

The third major change in the leachate composition is in the increased levels of molybdenum present. Peak concentrations of molybdenum in 1977 were 5.4 $\mu\text{g/ml}$ at 0.25 column volume. Each year since that time, a small pulse of molybdenum is eluted, and maximum concentrations increase. In 1983, maximum molybdenum levels were at 8.5 $\mu\text{g/ml}$ (~1.3 column volume). The appearance of the pulse each year and the increase in maximum concentrations could indicate that oxidation of Mo^{+3} to the anionic MoO_4^{2-} ion is occurring as weathering continues. Since the concentration of Mo in the retorted shale is approximately 25 to 30 $\mu\text{g/gm}$, significant concentrations of Mo in the leachate may occur as oxidation continues in the future. These observations are under study in the laboratory to establish basic geochemical mechanisms, and the results will be incorporated into predictive, linked geochemical and hydrologic models.

SOLUTE SORPTION AND PLANT AVAILABILITY

Once solutes are mobilized from wastes, they may interact with substrata or become available for plant uptake through root intrusion. We are studying representative model compounds and complex mixtures to learn how subsurface adsorption and microbiologic degradation control transport to ground water, and how plant uptake and metabolism govern biological fate in and transfer through terrestrial food chains.

Subsurface transport studies are used to determine how subsoil characteristics such as pH and mineralogy influence the adsorption and desorption of several nitrogen-containing aromatic compounds. Quinoline is one such compound common to waste materials. Though many subsoil properties were observed to influence quinoline retention, pH was a dominant factor. Adsorption was greatest in acidic soils and decreased markedly as hydrochemical conditions became more alkaline. Additionally, quinoline adsorption was markedly affected by the composition of cations in solution (e.g., Ca^{+2} , Na^{+}) and the presence of competing ionizable organic constituents (pyridine). Changes in adsorption suggest that ion exchange is a prominent retention mechanism at pH levels near or below the compound pKa. Future studies will investigate the adsorption and desorption behavior of two- and three-ring phenols, aromatic amines, sulfur and nitrogen heterocycles, and neutral aromatic hydrocarbons. Emphasis will be placed on determining how subsurface hydrochemical conditions and competing organic solutes affect the sorption and desorption of these compounds.

To date, a data base on pesticides provides the only information available on the behavior and fate of organic residues in terrestrial plants and food chains. Pesticide data, although useful in providing insight into the metabolic capabilities of plants when accumulating xenobiotics, provide little information on the broad compound classes of organic residues encountered as a result of fossil and synthetic fuel production. To collect much-needed data, we recently began studies to establish the behavior of quinolines in plant systems and to identify the types of metabolic processes that affect quinoline persistence. The studies will also help us establish the comparative fate of quinoline in light of earlier studies on phenol and aniline. Plant absorption rates for phenol, quinoline, and aniline in soybean plants were 180, 30, and 13 $\mu\text{g/gm}$ fresh wt. root/day, respectively.

Phenol and quinoline were more mobile than aniline. Phenol and quinoline accumulated in both roots and leaves, whereas aniline remained primarily in roots. Determining the tissue fate of these xenobiotics will require detailed chemical analyses and mass balances; however, these studies demonstrate the complexity of chemical transformations once the compounds enter living plants. For example, 90% of the phenol, 70% of the aniline, and 5% of the quinoline which accumulated in plant tissues were no longer in the original form. Studies indicated that the majority of the phenol has been degraded and respired; a substantial fraction of the aniline had been oxidized; but no oxidative decomposition of quinoline was detected. A significant portion of the root-absorbed quinoline (>60%) had been volatilized from leaves as quinoline and its modification products. This kind of information is critical to understanding the behavior of organic residuals in soils and plants, particularly their chemical transformations.

In other studies, we examined the interaction of nitrogen heterocycles in soybeans. Our efforts concentrated on developing assay methods for both extractable and bound forms of quinoline, and using these methods to study the fate of quinoline after plant absorption. Initial work conducted with non-radiolabeled quinoline demonstrated the potential for quinoline bioconcentration in these plants. In addition to the quinoline, a number of other quinoline-related nitrogen-heterocyclic compounds were identified in the exposed plant leaves, but which were not present in the stem or roots. These compounds, which are not found in unexposed plants, constituted 10% to 20% of the quantity of quinoline recovered from the leaves.

Subsequent work with radiolabeled quinoline confirmed the above findings. About 2% of the radioactivity was recovered as hydroxylated quinoline, which indicates that mechanisms for binding of quinoline molecules to plant macromolecules are present. The presence of macromolecules would lead to permanent storage of quinoline in the plant. Chromatography experiments indicated that the quinoline-related compounds found in plant leaves after quinoline had been absorbed were not derived from the absorbed quinoline, but rather have arisen from plant metabolic dysfunction.

A significant portion of the radiolabeled quinoline was not recovered by plant tissues. Experiments were therefore conducted (Figure 2) to trap organic material volatilized from the plant canopy. These experiments clearly demonstrated that quinoline was

FIGURE 2. A specially designed apparatus is used to measure volatilization of organic compounds from the plant canopy.

volatilized unchanged from the plant leaves. Catabolism of quinoline to carbon dioxide by plants is apparently not a significant mechanism for release of quinoline from the plant canopy.

AQUATIC PATHWAYS OF CONTAMINANT TRANSFER

The aquatic environment serves as the ultimate repository for solutes originating from wastes and transported through subsurface hydrologic regions. It also serves as a repository for solutes originating from product spills. Therefore, aquatic organisms and related pathways are among several important routes for the transfer of these contaminants to people. The current state of research on biological pathways and food chain transfer of chemical contaminants was

critically reviewed by Dr. Burton E. Vaughan (see publications) at a special symposium of the American Association for the Advancement of Science, organized by Dr. Frank J. Wobber of OHER.

Our research is designed to generate information needed to understand active biological processes controlling the fate of organic materials in aquatic systems. Initially, we are addressing the uptake, depuration, and metabolism of single compounds by aquatic organisms. The exposure systems are relatively simple and carefully controlled to provide a basic understanding of the behavior of test compounds. Direct uptake from water is hypothesized to be the major route of accumulation of the low molecular weight single- and two-ring compounds. We are testing this hypothesis through experiments to quantify uptake of ingested materials as well as uptake directly from water. The experiments we are conducting are designed to examine tissue distribution and metabolites of the study compounds which have been selected to represent several classes of compounds found in fossil fuels and their derivatives.

Two- and three-ring compounds such as quinoline, naphthol, p-amino biphenyl, thiophene, and naphthalene were selected for study. These compounds are found in wastes and liquid products, and are relatively mobile in aquatic systems.

In the past year we have studied the uptake, depuration, tissue distribution, and metabolism of radiolabeled quinoline by rainbow trout. A substantial portion of our effort has been expended on chemical analysis to identify the presence of the parent compound and to identify metabolic products resulting from hydroxylation and conjugation. Radiolabeled quinoline was taken up from water by rainbow trout (Figure 3). The radiolabel was present in all tissues examined, indicating the presence of either quinoline or its metabolic products. Concentrations in muscle tissue were relatively low.

Seven different hydroxylated quinoline metabolic products were isolated from gall bladders of exposed trout after hydrolysis and derivitization to the corresponding acetates. Figure 4 shows the gas chromatograms obtained from this analysis and the identified structures. Quinoline turned out to be readily metabolized, and we expected that little of the material would be transferred through food chains. Biomagnification would also be relatively insignificant. These findings, however, pertain only to direct uptake from water, rather than uptake through ingestion. The results are also

FIGURE 3. Almost half of the radioactivity taken up by trout was eliminated during the depuration period. Of that remaining, essentially all of the radioactivity was associated with metabolites. These results demonstrated the importance of identifying the metabolites of organic compounds to predict their movement through and persistence in aquatic pathways.

FIGURE 4. Nitrogen specific chromatography was used to identify quinoline and acetylated hydroxyquinolines isolated from gall bladders of rainbow trout after quinoline exposure.

species, and especially invertebrates, may metabolize quinoline differently.

A common route for elimination of organic materials by fish is through partial catabolism in the liver (hydrolysis mediated by mixed function oxidase) and conjugation, which tends to increase solubility. The metabolites tend to accumulate in the bile and to be excreted through the gastrointestinal tract. Tissue distributions of radiolabel following uptake of quinoline indicate that this pathway of elimination is active in the fish we studied (Figure 5). The gills were probably the primary site of uptake, although some transcutaneous transfer no doubt also takes place. Gills contained only a small portion of the body burden, indicating that the material was carried away by the blood. Levels of radiolabel in liver were low, but the gall bladder and bile contained over 60% of the body burden following a 24-hour period of depuration. The radiolabel in the gall bladder was nearly all associated with hydroxyquinolines. This suggests rapid kinetics of transfer from liver to bile following hydrolysis and conjugation. The low levels in kidney tissue indicate that it is not an important route for elimination. This point had not been definitively established in the existing scientific literature.

The portion of quinoline metabolites in muscle is relatively low, especially following 24 hours of depuration. Since the concentrations of quinoline and its metabolites are lower in muscle tissue, we infer that people are not too likely to receive a significant exposure to quinoline through consumption of fish. Fish exposed to low levels of quinoline for short periods of time

can be expected to catabolize the chemical fairly rapidly. If the exposure ceases, tissue levels would likely return quickly to a minimal level. Metabolic activity transforms the quinoline taken up by trout, and the resulting metabolites that are excreted are more water soluble than the parent compound. Hence, they are more readily available to other aquatic organisms. Nevertheless, metabolite uptake over the long-term is probably even lower than that associated with the parent compound, because the higher solubility of metabolites will lead to their dilution and removal from an open system.

It should be noted that the results above for quinoline in fish may not necessarily hold true for other aquatic organisms. Differences, particularly in the trophic relationships and physiological chemistry of shellfish, for example, suggest that the results in fish should not be generalized to these lower forms of life consumed as food.

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FIGURE 5. Quinoline and metabolites moved to bile and gall bladder during depuration. Most of the radiolabel was hydrolyzed quinoline, which is readily eliminated by fish and, thus, most most likely to persist in food chains. This may not be true for other life forms (shellfish).

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Radionuclide Fate and Effects

PNL has pioneered research on how soil and plant processes can alter biological availability of pollutants. Our objective is to develop a basic understanding of radionuclide chemical behavior in soil systems and determine biological availability and transport through ecological pathways. By defining basic mechanisms at the chemical, cellular, and organism level, we are able to incorporate the information into predictive models, which are subsequently validated in the field at reactor and waste management sites.

Through our investigations of critical geochemical, microbial, and plant phenomena, we hope to improve markedly the precision with which human dose assessments are made. By design, we focus more on the biologically and chemically mediated transport processes and food-chain pathways than on the purely physical forms of contaminant transport, such as transport by wind and water. Results can also be used to predict the behavior of non-nuclear pollutants such as heavy metals, and to provide a basis for new designs and remedial measures (chemical treatments, biobarriers) that will minimize hazards associated with extended waste disposal and isolation.

BEHAVIOR OF LONG-LIVED RADIONUCLIDES

Technetium, neptunium, and plutonium can be released into the environment at several stages in the nuclear fuel cycle. Field and laboratory studies are being conducted to identify basic chemical and biological processes within plants and soils that control the biological availability and potential food-chain transfer of these long-lived radionuclides.

Previous laboratory studies have shown that technetium (TcO_4^-) has high biological availability and a large transfer coefficient from soils to plants. We have demonstrated that technetium is absorbed in plants by mechanisms in place for nutrient species, specifically sulfate, selenium or phosphate.

Studies to date suggest that plant metabolism at least partially controls the distribution and perhaps total concentration of technetium in different plant species. We recently studied how technetium is distributed in plant species having a greater-than-normal requirement and tolerance for sulfur. In all species of plants examined so far, the quantity of technetium transported to the aerial portions of the plants was reduced when a significant fraction of technetium present in the roots was some chemical species other than TcO_4^- . Further study is required to determine whether the reduction is the result of internal differences in root metabolism or some other cause.

Investigations of technetium solubility in a broad range of surface soils indicated major differences in technetium behavior as a result of differences in competing ions, chemical transformations, and sorptive surfaces. In addition to our technetium work, we are

studying the role of neptunium and plutonium in food-chain transfer. In soil, neptunium can exist as Np^{+5} , while plutonium predominates as Pu^{+4} . Neptunium has a lesser tendency than plutonium to hydrolyze under environmental conditions, and is therefore more mobile than plutonium.

The presence of organic complexing agents or increased microbial activity can increase the soil-to-plant concentration ratio or plant availability of plutonium from 10^{-5} to 10^{-2} . Once transported across the plant's root membrane, Pu^{+4} is complexed by plant metabolites for both transport and storage. The effect of these physiological processes, particularly complexation, is that plutonium incorporated by the plant is 10 to 100 times more available to animals via ingestion than are inorganic forms of Pu^{+4} .

Methodology developed in our plutonium studies is being applied to study mechanisms that control the environmental behavior of neptunium. Plant availability of neptunium is substantially higher than that of plutonium. Concentration ratios for Np^{+5} range from 0.25 to 1.5.

Our studies demonstrate that concentration ratios for neptunium are concentration independent at soil concentrations up to 10^2 ng/g soil (Figure 1). When soil concentrations are low (10^{-6} to 10^2 nanograms of neptunium per gram of soil), the concentration ratio for bushbean is 0.3. Above 10^2 nanograms per gram of soil, the concentration ratio increases to 1.6.

Concentration ratios of neptunium at 10^{-5} nanograms per gram of soil were lowest for

FIGURE 1. The absorption of neptunium in plants increases as the concentration in soil increases. The high mobility and solubility of absorbed neptunium make this radionuclide a likely candidate for transfer through food chains.

bushbean (0.2) and higher for barley (0.35), soybean (0.45), and alfalfa (1.0).

It is clear that early studies at the higher neptunium soil concentrations overestimated concentration ratios over the range of concentrations likely to occur in environmental situations.

The metabolic fate of neptunium in plants may have a dramatic effect on gut absorption rates in animals, as noted for plutonium, and is currently under investigation. We know that neptunium is substantially more mobile after it is absorbed by roots, and that approximately 35% of neptunium absorbed by bushbean accumulates in leaves, while another 5% accumulates in seed pods. In addition, neptunium accumulated in roots, stems, leaves, and seeds is twice as soluble as plutonium. Similarly, greater than 75% of the soluble material accumulated in tissue is associated with metabolites of less than 10,000 molecular weight, compared to approximately 10% for plutonium. Because neptunium's solubility, mobility, and distribution in plants are greater than those for plutonium, we would expect neptunium to have the higher gut absorption rates in animals.

Effect of Plant Age on Chemical Transport of Plutonium

In earlier studies, we used plants of different ages in examining the uptake, fate and distribution of plutonium in tissues. Evidence from other studies with iron indicates that plant age is important in determining the chemical form of elements transported throughout the plant. The reason for this is that the organic components of the xylem exudate, which form complexes with metal ions, change significantly as the plant grows from

a seedling, sets seed, and eventually undergoes senescence.

We evaluated the effect of plant age on the apparent transport forms of plutonium as a function of plant age (17-115 days) by mixing Pu^{244} with the xylem exudate and chemically separated (amino acid and organic acid) fractions after incubation. The resulting complexes were identified using thin-layer electrophoretic chromatography.

In the plant xylem exudate, up to about 32 days of age, only weakly complexed or neutrally charged plutonium complexes were in evidence. After 32 days of age, and peaking in concentration at approximately 74 days, a single anionic component was present. However, when plutonium was reacted with the separated organic acid fraction, two anionic components were present in 32-day-old and older xylem exudate, and only one anionic plutonium complex was present in plant xylem exudates of the younger plants.

The presence of the different components in the organic acid fraction and not in the intact xylem exudate when reacted with plutonium could result from competition from other elements (e.g., Fe^{3+}) and reaction kinetics that are unfavorable to formation of the plutonium complex in the intact xylem exudate. Competition studies, using iron and other elements present in the xylem exudate, will be required to define the actual transport forms.

Modeling Behavior of Actinide Elements

A suite of process-oriented, computerized mathematical models now being developed will enhance our understanding of the long-term bioavailability and geochemical cycling of transuranic elements. The models also allow us to simulate the behavior of transuranics in soils and plants. So far, we have begun to develop and calibrate a model that can be used to predict the rate of dissolution for particulate plutonium and uranium deposited on soils, surface waters, and lung fluids. We are also validating the aqueous speciation-solubility model for uranium and developing a plant accumulation model that is driven by levels of plutonium in soil solutions.

The analytical speciation of uranium into its charge forms (anionic, cationic and neutral) has been compared to that calculated with a thermodynamic model. The results are in agreement within the uncertainties of the analytical data. Uranium was primarily present as anionic complexes in these waters, suggesting that uranium has less likelihood

than other actinide elements of becoming mobile in soils and substrates. The thermodynamic speciation identifies the anionic complexes as those of carbonate and phosphate.

In a related study, the charge on the element was examined as a function of its distance away from a low-level nuclear waste disposal site. The charge was compared to that calculated with the thermodynamic model. Excellent agreement was obtained for magnesium-54, cesium-144, and iodine-131. Partial agreement was obtained for zinc-65, cobalt-60, and iron-59, perhaps because these metals complex with natural dissolved organic matter.

Sensitivity analyses performed with the particulate plutonium and uranium model indicated that the key factor influencing solubility is particle size. The analyses also indicated a need for more and better data on the dissolution rates of plutonium in water over time.

TRANSURANIC CHEMICAL SPECIES IN GROUND WATER

Results of field studies at a low-level aqueous waste disposal site support PNL's laboratory findings with respect to mobility of different valence states of plutonium.

We have two new wells that can be used for sampling at the disposal site. The wells enable us to study the chemical speciation that occurs as ground water travels through soil. Our objective is to identify the mobile form and valence state of plutonium.

Plutonium and americium analyses were performed on water samples taken from the trench, the two wells, and the springs for four sampling dates from February to June. Corresponding analyses were conducted by PNL and Don Nelson of Argonne National Laboratory.

Particulate plutonium accounts for a significant portion of the total plutonium in the trench for all sampling dates. In the wells and springs, the concentrations of particulate plutonium were almost undetectable, indicating that particulates were removed rapidly from the ground water. In the trench, the dominant oxidation state of dissolved plutonium was V and VI for the February, March, and June sampling dates. For the May sampling date, the dominant oxidation state of dissolved plutonium was III and IV. These elevated levels of dissolved plutonium (III and IV) corresponded to high particulate plutonium levels.

The dominant oxidation state of the dissolved plutonium at the springs was plutonium V and VI for all sampling dates. These data support our previous ground-water studies, which showed that traces of plutonium are transported in a soluble, anionic chemical form and that plutonium is predominantly in the V or VI oxidation state.

The data for the wells are less conclusive, although it does appear for the May sampling date that oxidation of the plutonium has occurred by the time the water has reached the first well.

The americium data for the trench and springs follow that of the plutonium data; particulate americium is removed from the ground water by the time the water has travelled to the first well.

The geochemical model MINTEQ was used to calculate the distribution of plutonium among its aqueous species. Due to major discrepancies in the thermodynamic data for plutonium, the results are tentative. The plutonium appears to be in redox equilibria with the ground waters. Further work is needed to determine the existence and importance of plutonium (VI)-carbonate complexes and the role of organic complexation in the mobility of plutonium in the water.

BIOTIC TRANSPORT OF RADIONUCLIDES

Once disposed of in soil, radionuclides may be transported to other components of an ecosystem through root intrusions and animal burrowing. Both forms of biotic transport are significant, though root intrusion is thought to be more common. Plant uptake of radioactive materials is often the first step in the transfer of contaminants through the food chain.

Laboratory-determined concentration ratios (concentration of radionuclide expected in dry plant divided by concentration in dry soil) are used in dose assessment models to estimate the amount of radioactive material that will be transferred to plants growing on contaminated soils. Concentration ratios have frequently been determined in the laboratory by growing plants in pots with uniformly mixed radioactive material in the soil. In actual field conditions, however, the radioactive materials may not be distributed uniformly in soil. Low-level waste burial, fallout, and other accident conditions result in a layering of nuclear contaminants in the soil profile.

We are conducting a series of field experiments to determine how plants respond when they are exposed to radionuclides under realistic environmental conditions. We completed long-term studies of plants exposed to cesium-137 under configurations that represent accident or waste management scenarios. In these experiments, plants were grown in 0.5-m-long cylindrical containers in which cesium-137 was distributed through the soil in various concentrations. Our results indicate that the basis for calculating the quantity of radioactive material that may be transferred from soil to consumable plant material depends less on the actual concentration of radionuclide in the contaminated soil layer than on the total amount of radioactivity available to the plant root. Thus, existing methods for estimating dose to humans from soil-based food chain contaminants can be improved substantially. By expressing the total quantity of radioactivity occurring within the active root zone on a unit-area basis, we can estimate dose to humans more accurately.

Predictive modeling of moisture dynamics at low-level waste sites and calculations of dose to humans require knowledge of the rooting depths of potential crop and cover plants. The role of plants in extracting soil moisture has important implications for low-level waste burial, because plants remove infiltrating surface water that can cause leaching and mobilization of contaminants.

In fiscal year 1983, we initiated laboratory and field studies to define functional root zones for cover plants likely to occur on waste burial sites in semi-arid environments. Dr. Leslie Fraley, Jr., Associate Professor of Radiology and Radiation Biology, contributed substantially to this work while on sabbatical leave from Colorado State University.

For the past nine years, we have conducted studies with plutonium, americium, cerium, neptunium, and uranium to determine the long-term biological availability of these radionuclides (actinide elements) under realistic field conditions.

The experimental method involves layering the actinides at subsurface depths in soil columns (lysimeters) that are planted with range and agricultural plants and maintained outdoors. The plants are cropped according to standard agricultural practices. Annual progress involves maintaining the lysimeter system; recording climatic variables; and tilling, seeding, irrigating, weeding, and harvesting the crops.

Approximately five years after the soil columns were placed in the field, we began observing the unexpected presence of alpha activity on the soil surface. We initially suspected that the surface contamination was the result of anomalous physical transport occurring as radioactivity moved up along the walls of the containers in response to irrigation. This year, however, we discovered that the upward movement of the actinide elements was caused, at least in part, by the burrowing behavior of a small, colorful bee, *Agapostemon* sp. (family halictidae), which was bringing quantities of the contaminated soil to the surface.

The bee tunnels ranged from about one-third to one-half meter in depth and were 0.004 m in diameter. The head of one of the bees is shown in Figure 2 as the animal is emerging from an opening at the center of a mound of soil that was brought to the surface.

Preliminary estimates indicate that one burrowing bee moved approximately the same amount of plutonium-239 to the surface as would be translocated by plant roots and above-ground plant parts in 1000 kg dry weight of barley. Thus, transport of actinide elements by these small bees can be of comparable or greater importance than translocation by plant root systems.

To date, burrowing activity of the bees has been observed only in irrigated soils being cropped with both peas and barley. Grasses grown in non-irrigated soil have shown neither burrow entrances nor the presence of surface contamination.

FIGURE 2. Soil containing buried actinide elements is transported by bees to the surface (see mound at base of plant). One bee can move the equivalent radioactivity (^{239}Pu) taken up by one metric ton of dry barley.

The presence of burrowing invertebrates that can move large quantities of radionuclides (relative to translocation by plants) suggests other pathways through which humans could be exposed. Some potential pathways include inhalation of the alpha-emitting actinide elements after their transport to the surface, and the resuspension/surface contamination pathway that can result in an additional ingestion component via the agricultural pathway. We plan to place additional emphasis on quantifying the importance of this natural environmental transport process to the long-term bioavailability of actinide elements.

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Cadwell, L. L., and R. E. Fitzner. "Nuclear Fuel Cycle Radionuclides in a Birds of Prey Food Chain: Occurrence and Implications." Health Phys. (Submitted).

Eberhardt, L. E., L. L. Cadwell and E. E. Hanson. "Radionuclide Concentrations in Mule Deer Residing Near Waste Management Ponds on the Hanford Site." Health Phys. (Submitted).

Eberhardt, L. E., and L. L. Cadwell. "Radio-Telemetry as an Aid to Environmental Contaminant Evaluation." Environ. Monitor. (Submitted).

Statistical and Quantitative Research

Environmental impacts may escape detection if the statistical tests used to analyze data from field studies are inadequate or the field design is not appropriate. To alleviate this problem, PNL scientists are doing theoretical research which will provide the basis for new sampling schemes or better methods to analyze and present data. Such efforts have resulted in recommendations about the optimal size of study plots, sampling intensity, field replication, and program duration. Costs associated with any of these factors can be substantial if, for example, attention is not paid to the adequacy of a sampling scheme. In the study of dynamics of large-mammal populations, the findings are sometimes surprising. For example, the survival of a grizzly bear population may hinge on the loss of one or two adult females per year.

DEVELOPING STATISTICAL METHODS TO EVALUATE ENVIRONMENTAL BEHAVIOR OF RADIONUCLIDES

Efficient field sampling designs and statistical analyses enable scientists to define the movement of radionuclides in the environment, estimate amounts and concentrations of contaminants in an ecosystem, assess the need for cleanup, and evaluate compliance with environmental guidelines and regulations. Because statistical analyses are used to make decisions that will affect public health and safety, the best analytical methods should be used.

During fiscal year 1982, our scientists evaluated twelve formulas for estimating the transfer of radionuclides from one component of an ecosystem to another, such as from soil to plants. Our results show that for lognormally distributed data, the geometric mean of ratios (y_i/x_i) is the preferred estimator of a true (constant) underlying ratio relationship, even if large measurement errors are present. When data are normally distributed, the ratio of means ($\bar{y}/\bar{x}$) or a slight modification of the ratio ($\bar{y}/\bar{x}$) is preferred.

Statistical methods developed and adapted for describing the impacts of radionuclides on the environment are published in the PNL quarterly report, TRAN-STAT, and in journal articles. Also, a book is being written on statistical aspects of contaminant field studies.

These publications improve technology transfer and communications between statisticians and scientists engaged in radionuclide studies.

The book, scheduled for publication by Lifetime Learning Publications in 1985, is being written specifically for radioecologists, environmental scientists, and health physicists. It will be of use to scientists in other areas of research as well. Topics discussed include estimating concentration ratios, designing studies, testing for com-

pliance, assessing the uncertainty of dose-transport model predictions, and estimating the spatial distribution and inventory of contaminants.

TRAN-STAT is distributed to 165 recipients, including Department of Energy contractors and other interested parties. Four additional issues (Numbers 21 through 24) of TRAN-STAT were written and distributed during fiscal year 1983. In these issues, we discussed sources of errors in field studies and described a new technique for plotting probability, and illustrated the need to match sample collection techniques with study objectives. We also reported the latest results of a comparison between mathematical and computer simulation for computing formulas to estimate concentration ratios. The last issue published in fiscal year 1983 discussed some field sampling designs available for deciding where and when to sample environmental media for contaminants. Some of these designs are illustrated in Figure 1.

Future topics in TRAN-STAT will include additional field sampling designs, assessments of uncertainty in dose-transport model predictions, statistical methods for identifying unusually large or suspect data, and latest results of our continuing research on methods for estimating concentration ratios.

Other accomplishments in FY 1983 included placing 1000 statistical references on a computer storage and retrieval system, expanding our knowledge of statistical methods for water and air pollution studies, and developing improved kriging techniques for estimating the spatial distribution of contaminants in soil and air.

DEVELOPING QUANTITATIVE METHODS TO STUDY POPULATION DYNAMICS OF LARGE ANIMALS

Energy developments can result in environmental impacts that affect the behavior and reproduction of animal populations such

FIGURE 1. Field sampling designs are used to locate and define the boundaries of contaminants in an ecosystem. The designs are used to make recommendations about when and where to sample for contaminants.

as bears, horses, and whales. These large animals cannot be studied in the laboratory, so accurate field techniques are needed to determine how these populations respond to stress. Studies this year indicate, for example, that the survival of a bear population may depend on the survival of one or two fully adult females per year.

This year, we evaluated indices of population size (i.e., relative rather than direct measures of population abundance), a topic that has received little quantitative attention. Elaborate mathematical and statistical procedures are available for studying populations by capture-recapture methods. Unfortunately, statistical methods are not available to analyze indices, even though index methods are much more widely used than are estimates obtained by tagging and marking approaches.

Our recent work with indices includes such diverse species as elk from Mount Rainier, and California sea otters. In particular, we have been attempting to determine how best to use indices to measure long-term trends of abundance in the presence of "noise" due to chance events, seasonal effects, and other short-term disruptions of the pattern. Results are not yet available.

We are also attempting to estimate the factors that control population size (e.g., age-specific mortality, birth rate) for several large mammals. Demographers typically use

such data in standard "population dynamics models" to study human populations.

Unfortunately, the data base for wild populations is never very complete. Thus, we have developed modified models to use the information that is available. Our goal is to project future population size and to identify the key factors which control the projected size, so that key management decisions can be made in advance. In the absence of adequate data for modeling, we have been studying ways in which various sources of data can be combined to predict the current status and future trend of a population.

Recently we have worked on models for two species, the bowhead whale off the coast of Alaska, and grizzly bears in the environs of Yellowstone National Park. Data obtained as far back as 1848 (when commercial whaling for bowheads began) were used to assess recent effects of Eskimo harvests vis-a-vis the regulations imposed by the International Whaling Commission. In the case of the much smaller grizzly bear population, we constructed a stochastic (probabilistic) model to provide projections of likely future trends of the population. This model indicates that the difference between a stable population and one slated for extinction may be as small as the survival of one or two fully adult female bears per year.

QUANTIFYING RESPONSES OF SMALL ANIMALS TO ENVIRONMENTAL PERTURBATIONS

Because small-mammal populations are often reclusive, specialized methods are needed to monitor how these animals respond to energy developments. At present, field study designs and statistical methods for assessing mobile populations do not exist. We are developing both field designs and statistical methods that allow accurate, efficient prediction of impacts from energy developments and operations.

For example, we found that when censusing methods and designs are tailored to population assessment, impacts can be detected two to 20 times more efficiently than with standard techniques. Use of statistically sound data to assess impacts ensures that biological costs of alternative resource policies can be evaluated objectively.

Our statistical research for the past two years shows that the success of population experiments depends upon five factors:

1. numbers of replicate population levels
2. magnitude of the population levels
3. variability in population numbers
4. capture probabilities during the censuses
5. trap response of the animals.

This year, we devised analytical procedures that incorporate these limiting factors into numerical expressions for determining the probable success of experiments on mobile species. As a result, we can devise a field experiment that has a high a priori chance of success (power) for detecting an impact.

We also developed new statistical tests that incorporate the unique statistical properties of census data when the goal is to evaluate the effect of treatments. For example, we found that the proper data transformation can increase the power of statistical tests for treatment effects by as much as 20%, with no change in the field study and with no added expense.

When the design of a field study eliminates replication, restricts the randomization of control and treatment sites, or both, valid statistical inferences about environmental effects cannot be made. We devised a pseudo-design, which we call an odd's ratio, to assess environmental impacts when a treatment

is repeatedly applied in a non-random fashion across the landscape. An example is the study of secondary poisoning from pesticide spraying in areas of insect infestation. Classical analyses are inappropriate since all infested areas receive the treatment.

The pseudo-experimental field design incorporates a control plot near each of several planned treatment sites. These pairs of sites are then censused immediately before and after the application of the pesticide, resulting in more field effort compared to the usual, but invalid, design.

Analytical procedures developed during fiscal year 1983 have permitted us to evaluate the pseudo-design. Power curves (Figure 2) indicate that the use of prespraying data improves the power of an odd's ratio test over that of a paired experiment, when equal numbers of site pairs are used ($n = 4$). However, the odd's ratio design achieves this increase in power by using twice as many wildlife censuses.

FIGURE 2. PNL scientists can objectively select the most efficient experimental designs for wildlife studies. A randomized odd's ratio design, for example, detects environmental impacts with more power than a paired design. If a field study cannot be randomized, a paired design has more power (see shaded area) than a non-randomized odd's ratio design for equal field effort.

When costs are considered, the odd's ratio design ($n = 4$ control-treatment pairs) results in the same number of censuses compared to a paired design (with $n = 8$ replicates); but the paired design has superior power of detection (Figure 1). The loss in statistical power at fixed costs is a measure of the cost of field designs that cannot be randomized at the onset of an experiment.

From studies such as these, we can provide an objective basis for selecting the most efficient experimental designs for wildlife studies.

ACKNOWLEDGMENTS

This program consists of research projects 80184/003386, 80244/003913, and 82011/002011, which are described in Field Task Proposal/Agreements (Form 5120.2). Principal investigators for these projects are L. L. Eberhardt, J. M. Thomas, R. O. Gilbert, and J. R. Skalski. Consultation on the mobile species research was provided by D. S. Robson, Biometrics Unit, Cornell University, Ithaca, New York.

PUBLICATIONS

Skalski, J. R., D. S. Robson and M. A. Simmons. 1983. "Comparative Census

Procedures Using Single Mark-Recapture Methods." Ecology 64:752-760.

Skalski, J. R. 1983. "Towards the Use of Faunal Populations as Cost-Effective Biomonitors." In Symposium on Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute, Steamboat Springs, Colorado.

Skalski, J. R., D. S. Robson and C. L. Matsuzaki. "Competing Probabilistic Models for Catch-Effort Relationships in Wildlife Censuses." Ecol. Modeling (In press).

Skalski, J. R., M. A. Simmons and D. S. Robson. "The Use of Removal Sampling in Comparative Censuses." Ecology (In press).

MANUSCRIPTS SUBMITTED FOR PUBLICATION

Eberhardt, L. L., J. M. Breiwick and H. W. Braham. "Population Dynamics of Western Arctic Bowhead Whales." Canadian J. Fish. Aquatic Sci. (Accepted).

Knight, R. L., and L. L. Eberhardt. "Population Dynamics of the Yellowstone Grizzly Bear." Ecology (Submitted).

Skalski, J. R. "A Variable Effort Technique for Estimating the Areal Mean Abundance of Animals." Am. Naturalist (Submitted).

Interagency Research

Environmental and energy assessment, to be effective, requires the cooperation of many governmental agencies and sponsors. The research topics identified in this section are complementary to work discussed in other sections of this report, but do not duplicate our DOE work.

ARMY CORPS OF ENGINEERS

Analyze Samples of Dredged Material and Assess Bioavailability of Polynuclear Aromatic Hydrocarbons (Principal Investigator: J. W. Anderson)

BONNEVILLE POWER ADMINISTRATION

Environmental Information Gathering and Evaluation Relating Water Levels to River Operations (Principal Investigator: D. H. Fickeisen)

Biological Studies at the Site of BPA's 1200-kV Prototype Transmission Line near Lyons, Oregon (Principal Investigator: L. E. Rogers)

ELECTRIC POWER RESEARCH INSTITUTE

Develop a Test Protocol for Using Soil-Core Microcosms to Measure Potential Ecological Effects, Fate, and Transport of Chemicals in Terrestrial Ecosystems (Principal Investigator: P. Van Voris)

Monitoring Ecosystem Stress Through Remote Sensing (Principal Investigator: P. Van Voris)

ENVIRONMENTAL PROTECTION AGENCY

Fate and Effects of Toxic Substances on Marine Ecosystem Processes (Principal Investigator: J. W. Anderson)

Acute Effects of New Coal Conversion Technologies on Aquatic Systems (Principal Investigator: D. H. Fickeisen)

Statistical and Biomathematical Assistance on Network Biomonitoring Using Honey Bees (Principal Investigator: J. M. Thomas)

Field Evaluation of Hazardous Waste Site Bioassessment Protocols (Principal Investigator: J. M. Thomas)

Collection of Sediment Samples in Commencement Bay, Washington (Principal Investigator: E. A. Crecelius)

Management of Cold-Climate Environmental Research Programs (Principal Investigator: J. B. States)

Prioritization of EPA Superfund Research Projects Using DAPC Workshops (Principal Investigator: D. A. Neitzel)

User's Guide to Effectiveness of Selected Chemical Dispersants (Principal Investigator: J. W. Anderson)

Technical Support for International Activities Related to Sea Disposal of Radioactive Wastes (Principal Investigator: W. L. Templeton)

Technical and Management Analysis to Support the Puget Sound Water Quality Management Program (Principal Investigator: J. A. Strand)

GOVERNMENT ACCOUNTING OFFICE

Analytical Report on Salmon Fisheries in the Pacific Northwest (Principal Investigator: D. H. McKenzie)

DOE/RICHLAND OPERATIONS OFFICE

N Reactor Support: 316(a) Demonstration (Principal Investigator: D. A. Neitzel)

KNOLLS ATOMIC POWER LABORATORY

Food Chain Transfer of Corrosion Products from Radioactive Stainless Steel in a One-Step Marine Foodchain (Principal Investigator: J. S. Young)

Support for Environmental Impact Statement on Disposal of Decommissioned Naval Nuclear Reactor Plants (Principal Investigator: W. L. Templeton)

NATIONAL INSTITUTE OF ENVIRONMENTAL HEALTH SCIENCES

Fate of Heavy Metals and Heavy Metal Complexes in Soils and Plants (Principal Investigator: R. E. Wildung)

NATIONAL OCEANIC AND ATMOSPHERIC
ADMINISTRATION

Effects of Oil-Contaminated Sediment on the
Behavior of Sandworms and Clams (Principal
Investigator: W. H. Pearson)

Significance of Metal-Binding Proteins in
Lysosome-Like Vesicles in Mussels in a Metal-
Contaminated Environment: An Experimental
Field Study (Principal Investigator: G.
Roesijadi)

Feeding Ecology of Juvenile King and Tanner
Crabs in Southeastern Bering Sea (Principal
Investigator: W. H. Pearson)

Chemical Contaminants in Sediments and Marine
Bird Populations of Central and Southern
Puget Sound (Principal Investigator: R. G.
Riley)

Collect Sediment Cores and Analyze for Lead-
210 and Cesium-137 (Principal Investigator:
E. A. Crecelius)

Isolate and Select Hydrocarbon Components
Associated with Environmental Reference
Materials (Principal Investigator: R. G.
Riley)

Perform Chemical Analysis for a Study of the
Effects of Oil-Contaminated Sediment on Sand
Worm Behavior (Principal Investigator: W. H.
Pearson)

Determine Trace Metal Accumulation Rates in
Age-Dated Sediment Cores (Principal Investi-
gator: E. A. Crecelius)

History of Contamination of Sediments in
Commencement Bay, Tacoma, Washington (Prin-
cipal Investigator: E. A. Crecelius)

NUCLEAR REGULATORY COMMISSION

Environmental Standard Review Plans (Princi-
pal Investigator: D. G. Watson)

Quantitative Assessment of Aquatic Impacts of
Power Plants (Principal Investigator: D. H.
McKenzie)

Biocide By-Products in Aquatic Environments
(Principal Investigator: R. M. Bean)

Relevance of Biotic Pathways to the Regula-
tion of Nuclear Waste Disposal (Principal
Investigator: D. H. McKenzie)

Changes in the Bioavailability of Low-Level
Radioactive Effluents after Passage Through
Soil (Principal Investigator: W. H. Rickard)

Application of Statistics in Siting and Man-
aging Commercial Low-Level Radioactive Waste
Disposal Sites (Principal Investigator:
J. M. Thomas)

Safety Implications of Auxiliary System Bio-
fouling at Nuclear Power Plants (Principal
Investigator: T. L. Page)

UNC NUCLEAR INDUSTRIES, INC.

Thermal Plume Characterization Studies (Prin-
cipal Investigator: D. A. Neitzel)

Other Highlights

OTHER HIGHLIGHTS

FACILITIES

Battelle's expanded Marine Research Laboratory at Sequim, Washington, was dedicated early in FY-1983. The new facility adds 23,400 sq. ft. to pre-existing laboratory, office, and conference space, and it houses modern chemistry laboratories along with 35 new offices and support facilities. Other improvements were made to the older beach facilities, including upgrading the sea water systems to 250 gal/min capacity with backup. On the beach, a variety of experimental systems can now be maintained, such as isolated rooms for behavioral studies and high-capacity flow-through tanks, in appropriate arrays to do statistical verification studies. Exposure systems can support selected marine organism communities for long periods of time.

Since identifying and preventing disease in marine species is a major concern in the Northwest, Battelle is also developing, with corporate resources, a Disease Diagnostic Center at the Sequim laboratory. Facilities for the center include a complete immunochemistry laboratory, where animal colonies are maintained for producing immune sera used in fish and shellfish testing. Disease control has an important bearing on all sponsored studies at the laboratory. Apart from DOE work at Sequim (described in an earlier section of this report), PNL continues projects for several agencies on coastal ecosystems research, bioassay chemistry, fate of oil and dispersant chemicals, and sediment biogeochemistry.

Construction of our new toxic/hazardous aerosol exposure facility was completed early in FY-1983, and efforts to complete the instrumentation continued through the year. In recent years, scientists have come to realize that airborne contaminants, which enter foodstuffs directly through deposition and retention on edible plants, may sometimes present a more serious problem than has been previously acknowledged. Also, several field investigations have identified unexpected contaminant sources at industrial sites believed to be operating under acceptable environmental conditions.

The new facility greatly augments capabilities for evaluating aerosol contamination and allows for controlled environmental modeling of aerosols and gases, singly and in combination. Included are a wind tunnel and a system of instruments and equipment for particle generation and analysis. The wind tunnel is used to simulate aerosol transport and deposition at variable conditions of wind velocity, turbulence, temperature, pressure, and humidity. It is equipped with NBS standard pitot tubes and hot-wire and hot-film anemometers for measuring mean velocities, velocity, profiles, and turbulence characteristics. Wind speeds of 1 to 65 mph can be achieved in the 20-ft-long, 80-ft³ test section, with assured laminar flow from 0 to 25 mph. Turbulent flow can be produced at all speeds. The apparatus has a closed-loop design, HEPA filters, and a test section with eight 2 x 2-ft ports. It provides full containment and internal washdown for hazardous materials applications.

Completion of the new hilltop addition, shown here, makes the Marine Research Laboratory at Sequim, Washington, a major West Coast facility. Laboratory, office and conference space total 40,000 sq. ft., with fully equipped sea water facilities and holding tanks.

A 50-foot-long wind tunnel is one of the specially designed facilities used to study airborne contaminants.

A wide array of standard particle generation systems are readily available for aerosol studies. These include an evaporative-condensation generator for 0.03 to 1.3 μm monodispersed particles, a vibrating orifice generator for 0.5 to 30 μm monodispersed particles, and nebulization generators for labelled monodispersed and polydispersed particles. In addition, special particle generation systems or accessory devices can be developed as needed.

Characterization equipment includes a remote laser particle spectral analyzer for measuring aerosol size distribution, concentration, and velocity in ranges from 1 to 200 μm and 1 to 50 m/s; a 16-channel, high-resolution optical particle counter that counts and sizes particles from 0.3 to 20 μm (concentration limit of 2×10^6 particles/ ft^3); an electrical analyzer for measuring size distribution from 0.0032 to 1.0 μm ; and a mass monitor. Infrared laser spectrometry or gas chromatographic-mass spectrometry are used to analyze gaseous and organic pollutants and to characterize their molecular form in real time. Supporting the facility is a major aerosol physics laboratory where basic research related to sampling and generation of experimental aerosols is carried out. Scanning electron microscopy and energy dispersive x-ray analysis with automated particle sizing are available in the laboratory.

STAFF

Several PNL staff members serve on national committees or commissions or hold editorships on important journals. Staff activities at the national and international level include the following:

American Chemical Society (ACS)

E. A. Jenne: Symposium Chairman, Geochemistry of Nuclear Waste Disposal, 1985 Annual Meeting

American Fisheries Society (AFS)

D. H. Fickeisen: Board of Professional Certification (International level)

American Society for Testing and Materials (ASTM)

T. M. Poston: Committee E-47, Biological Fate and Effects Testing, member; chairman, IX Annual Symposium on Aquatic Toxicology to be held in New Orleans, April 1985

The center for marine disease control, a component of MRL, Sequim, is equipped for diagnosis and research on aquatic animal diseases. Shown is a typical apparatus for retinal diagnostic observation of fish.

Department of Energy

R. E. Wildung: Oil Shale Task Force, Office of Energy Research (member, Executive Committee and Coordinator, Solid Waste Management)

Environmental Protection Agency (EPA)

W. E. Fallon: EPA Dioxin Task Force, member

Federal Marine Mammal Commission

L. L. Eberhardt: Marine Mammal Committee of Scientific Advisors, member

International Atomic Energy Agency

W. L. Templeton: Advisory Group on "The Definition of de Minimis Quantities of Radioactive Waste Exempted from Special Permits Under the London Dumping Convention," chairman

National Academy of Sciences

L. L. Eberhardt: Committee on Wild Horses and Burros, member

E. A. Jenne: Committee for Geochemistry, member

R. E. Wildung: Committee on Soil as a Resource in Relation to Surface Mining for Coal (co-chairman, soils panel; Rapporteur, Planning Group); Committee on Onshore Energy Mineral Development

National Council on Radiation Protection and Measurements

W. L. Templeton: Scientific Committee 64, Task Group Chairman

National Science Foundation

C. E. Cushing: External Advisory Committee for Long-Term Ecological Research (Illinois-Mississippi River Project)

North American Benthological Society

C. E. Cushing: Executive Committee, member

Nuclear Energy Agency/Organization for Economic Cooperation and Development

W. L. Templeton: United Nations Interagency Group on Scientific Review of Dumping of Low-Level Radioactive Wastes in the Oceans, consultant; Executive Group for Research on Low-Level Dumping in the Sea, chairman

Society of Environmental Geochemistry and Health

E. A. Jenne: Ad Hoc Committee on Finances, chairman

University of Chicago

R. E. Wildung: Review Committee for Environmental and Radiological Research (Argonne National Laboratory)

U.S. - Japan Fusion Cooperation Program

J. A. Strand, participant (1982-1984)

Editorial Positions

C. E. Cushing, member, Board of Editors, Ecological Society of America

C. D. Becker, Coordinator, Fisheries Laboratory Series, Fisheries

G. Roesijadi, U.S. Region Editor, Marine Environmental Research

**Presentations
and
Distribution**

PRESENTATIONS

Bloom, N. S., and E. A. Crecelius. 1983. "Silver in the Marine Environment: A Preliminary Budget for Puget Sound." Presented at the 25th Rocky Mountain Conference for the Society for Applied Spectroscopy, August 14-19, 1983, Denver, Colorado.

Carlile, D. W., and R. E. Fitzner. 1983. "Use of Fauna as Biomonitors." Presented at Renewable Resource Inventories for Monitoring Changes and Trends Conference, August 15-19, 1983, Corvallis, Oregon.

Cataldo, D. A., T. R. Garland and R. E. Wildung. 1983. "Physiological Responses of Plants to Oil Shale Retort Water and its Constituents." Presented at the Plant Uptake and Soil-Plant Processes Meeting, May 9-10, 1983, Gaithersburg, Maryland.

Cataldo, D. A., T. R. Garland and R. E. Wildung. 1983. "Plant Processes Controlling Uptake and Behavior of Plutonium and Neptunium." Presented at the Plant Uptake and Soil-Plant Processes Meeting, May 9-10, 1983, Gaithersburg, Maryland.

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Creceius, E. A., N. S. Bloom, E. A. Jenne and C. E. Cowan. 1983. "Silver Speciation and Adsorption in Coastal Water." Presented at the International Symposium on Complexation of Trace Metals in Natural Waters, May 2-6, 1983, Den Burg, The Netherlands.

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Gilbert, R. O. 1983. "Estimating the Spatial Pattern of Radionuclides in the Environment Using Kriging." Invited paper at the American Statistical Association Annual Meeting, August 15-18, 1983, Toronto, Canada.

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Hinds, W. T., and M. C. McShane. 1983. "Food Habits and Monitoring Strategies: Some Lessons from Field Experience." Presented at the International Conference on Renewable Resource Inventories for Monitoring Changes and Trends, August 15-19, 1983, Corvallis, Oregon.

Jenne, E. A. 1982. "Solubility Controls on Weathering and Trace Element Mobilization." Presented at the Symposium on Weathering and Mobilization of Trace Elements in Energy Impacted Arid Environments, November 22-24, 1982, Denver, Colorado.

Jenne, E. A. 1982. "Geochemical Modeling: Opportunities and Limitations." Presented at Regional American Chemical Society Meeting, December 3-5, 1982, El Paso, Texas.

Rickard, W. H. 1983. "Causes and Consequences of Invasions of Alien Plants in Western North America." Presented at the 64th Annual Meeting of the American Association for the Advancement of Science, June 19-23, 1983, Logan, Utah.

Roesijadi, G., and J. E. Morris. 1983. "Development of Immunological Procedures for the Study of Mercury-Binding Proteins of Mytilus Edulis." Presented at the Second International Symposium on Pollutant Responses in Marine Organisms, April 27, 1983, Woods Hole, Massachusetts.

Roesijadi, G. 1983. "Enhanced Mercury Tolerance in Mytilus edulis: Influence of Cu, Zn, and Cd Pre-exposure and Relationship to Metal-Binding Proteins." Presented at the Fifth Conference of the European Society for Comparative Physiology and Biochemistry, September 5-8, 1983, Taormina, Sicily, Italy.

Rogers, J. E., S. W. Li, L. J. Felice and J. M. Zachara. 1983. "Microbiological Transformations of Substituted Anilines in Soil-Water Suspensions." Presented at the 83rd Annual Meeting of American Society of Microbiology, March 6, 1983, New Orleans, Louisiana.

Thomas, J. M. 1983. "Quantitative Methods for Extrapolation of Animal Dose Response Curves to Low-Dose Regions and Procedures for Comparing These Estimates to Human Data Bases." Mathematical Colloquium, April 7, 1983, University of Montana, Missoula, Montana.

Thomas, J. M., and J. F. Cline. 1983. "Statistical Designs for Plant Concentration

Ratio Studies: A Serendipitous Result." Presented at the Plant Uptake and Soil-Plant Processes Meeting, May 9-10, 1983, Gaithersburg, Maryland.

Thompson-Hanson, P. A. 1982. "Winter Communal Roosting and Roost Characteristics of Marsh Hawks on the Hanford Site." Presented at the Raptor Research Foundation 1982 Meeting, November 18-21, 1982, Salt Lake City, Utah.

Thompson-Hanson, P. A. 1983. Computer Generated Movies for Radio-Telemetry Analysis Using Northern Harrier Data." Presented at the Annual Meeting of the Northwest Section of the Wildlife Society, April 13-15, 1983, Spokane, Washington.

Thompson-Hanson, P. A. 1983. "Reproductive Success of Northern Harriers in Dissimilar Habitats on the Hanford Site." Presented at the Annual Meeting of the Cooper Ornithological Society, May 19-22, 1983, Albuquerque, New Mexico.

Vaughan, B. E., J. K. Soldat, R. G. Schreckhise, E. C. Watson and D. H. McKenzie. 1982. "Problems in Evaluating Radiation Dose for Effective Environmental Assessment." Presented at Fourth Department of Energy Environmental Protection Information Meeting, December 7-9, 1982, Denver, Colorado.

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