PNL-3700 PT2
UC-11

Pacific Northwest Laboratory Annual Report for 1980 to the DOE Assistant Secretary for Environment

Part 2 Ecological Sciences February 1981

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

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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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

Pacific Northwest Laboratory's (PNL) 1980 Annual Report to the Department of Energy (DOE) Assistant Secretary for Environment describes research in environment, health, and safety conducted during fiscal year 1980. 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. Part 5 reports progress on all other research performed for the Assistant Secretary for Environment, including the Office of Environmental Assessment and the Office of Environmental Compliance and Overview. Each part consists of project reports authored by scientists from several PNL research departments, reflecting the interdisciplinary nature of the research effort. Parts 1 to 4 are organized primarily by energy technology.

The parts of the 1980 Annual Report are:

Part 1:	Biomedical Sciences Program Manager - H. Drucker	D. L. Felton, 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	R. L. Drake, Report Coordinator M. F. Johnson, Editor
Part 4:	Physical Sciences Program Manager - J. M. Nielsen	J. M. Nielsen, Report Coordinator I. D. Hays, J. L. Baer, Editors
Part 5:	Environmental Assessment, Control, Health and Safety Program Managers - D. L. Hessel S. Marks W. A .Glass	W. J. Bair, Report Coordinator R. W. Baalman, I. D. Hays, Editors

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 and Irene D. Hays, editors 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, VNWL-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

FOREWORD

This volume of the Annual Report describes all of PNL's work in the ecological sciences funded by the Office of Health and Environmental Research (OHER) in the following budget activity categories:

H - Environment

A- Multi-Resource

HA-02-03-01	Identification Transport and Conversion of Energy-Related Pollutants in the Environment
HA-02-03-02	Environmental Effects of Energy-Related Processes and Pollutants in the Environment
HA-02-03-03	Energy-Related Supporting Research
HA-02-03-04	Environmental Operations and DOE Support Activities

For convenience, organization charts for the several participating departments and sections of PNL can be found at the back of the report.

Where appropriate, we have grouped the individual research projects (Field Task Proposals) (Form 5120) according to the energy technology they primarily support. With the abstracts that follow, principal investigators are listed who may be contacted for further information about individual projects. We hope this format makes the report useful, not only to OHER but to managers of technology programs as well. The reader should note that for several large programs, research on biomedical effects, atmospheric dispersal and chemical characterization are reported in separate volumes of this Annual Report (see Preface). Such projects are, principally, the Synfuels (Section 4), Nuclear Fission (Section 5), Nuclear Fusion (Section 7), Electromagnetic Field (Section 10), and Pathways Modelling (Section 9) research efforts.

PNL's industrial experience with the oil, synfuels and shale developments, and with other agencies concerned with energy installations, has contributed in a particularly pertinent way to the understanding of environmental problems requiring timely assistance. However, not all such work is reported herein. Projects funded specifically on the basis of contract with Battelle, or by interagency agreement with DOE, are listed for reference in Section 11 of this report. Descriptions of the major projects will be found in a separate annual report [a]. Bibliographic listing of all published studies will be found in the Ecological Sciences Department bibliography[b]. The bibliography, published biennially in previous years, now will be published annually commencing with the February 1981 issue.

The ecological data used for DOE purposes seem frequently to be misunderstood. Basically, the ecological programs are designed to assist DOE technologies in anticipating problems in meeting the intent of the National Environmental Policy Act. Problems "around-the-corner" need to be systematically evaluated before major capital investment is committed by a developing technology. Also, the theoretical studies described in Sections 1 and 9 of this report are needed for improving the basis for measuring environmental effects. Many current estimates of ecological processes are quantitatively provisional, without statistical basis and suited only as order-of-magnitude estimates. In these areas, it is in the interest of technologists that a groundwork be laid for quantitatively meaningful data, especially where any data are likely to be used by agencies responsible for setting standards.

During 1980, design was approved for the construction of a new Battelle laboratory. Construction is scheduled for 1981. The six-million-dollar expansion will approximately double the size of the present office, laboratory, and wet laboratory facilities used by PNL's Marine Sciences Section. With the Northern Tier Pipeline and other new energy developments in the Pacific Northwest, the decision to expand the Marine Research Laboratory reflects our confidence that regional research needs will continue to be met.

During 1980, Dr. Everett A. Jenne joined PNL staff after eighteen years with the U.S. Geological Survey. He assumes laboratory-wide responsibility for coordinating efforts in geochemical modelling. Also during 1980, Dr. Richard F. Foster retired from PNL after more than thirty years of service largely devoted to radiological protection at the Hanford site. Staff scientific activities at a national level included the following:

National Academy of Sciences

L. Lee Eberhardt: Com. Free-Roaming Wild Horses & Burros
Everett A. Jenne: Member, Com. on Geochemistry
Burton E. Vaughan: Consult., FREIR
Raymond E. Wildung: Com. Accessory (Trace Elements), Oil Shale Panel; Com. Soil as Mineral Resource (Bd. of Mineral Resources)
Colbert E. Cushing: Consult., FREIR

National Council on Radiation Protection

David A. Baker: Member, Task Group 3, Sci. Com. 64
William L. Templeton: Chairman, Task Group 2, Sci. Com. 64
Edwin C. Watson: Member, SC-38, Task Group on TMI Accident-Generated Waste Water

Federal Marine Mammal Commission

L. Lee Eberhardt: Com. Scientific Advisors

International Standards Organization

Edwin C. Watson: Working Group 7, Tech. Com. 85/5

National Oceanographic & Atmospheric Administration

Jack W. Anderson: Panel Member, Interagency Com. Ocean Pollution Research, Development & Monitoring

Standard Methods of Analysis of Atmospheric Transport of Routine/Accidental Release of Nuclear Reactor Effluent

Edwin C. Watson: Member, American Nuclear Standards Committee Working Group 2.15-2.16

In addition, several staff members served as editors or associate editors of various learned journals (Colbert E. Cushing, *Ecology*; C. Dale Becker, *Trans. Amer. Fish. Soc.*; and Jack W. Anderson, *J. Marine Environ. Res.*).

Burton E. Vaughan
Subprogram Manager
Ecological Sciences

(a)*Annual Report for 1980 on Interagency/Contract Research, Ecological Sciences, Department;* Battelle, Pacific Northwest Laboratories, Richland, WA 99352

(b)*A Bibliography of Environmental Research* PNL-SA-4655, Rev. No. 5 Ecological Sciences Department Pacific Northwest Laboratory Richland, WA 99352

CONTENTS

1 National Environmental Research Park and Land Use

NATIONAL ENVIRONMENTAL RESEARCH PARK AND LAND USE

- **Hanford National Environmental Research Park**
- **Terrestrial Ecology (ALE Administration)**
- **Dynamics of Wild Populations**
- **Restoration of Surface-Mined Lands**
- **Long-Term Ecological Monitoring**
- **Application of Long-Term Chemical Biobarriers for U-Tailings**
- **Revegetation of Inactive U-Tailings Sites**

In connection with its nuclear energy activities, the U.S. Department of Energy manages large land holdings in the arid and semi-arid regions of the western United States. One of the most strategically situated of these is the Hanford Site in the state of Washington. The Hanford Site currently contains the obsolete facilities developed for wartime plutonium production, and it also safely stores large amounts of radioactive waste materials. As a health and safety measure, these facilities are isolated by large land areas unoccupied by people. Today, these buffer zones provide some of the least disturbed and, therefore, most useful land for long- and short-term terrestrial ecological research. In recognition, the Arid Lands Ecology (ALE) Reserve and the Hanford National Environmental Research Park (NERP) were established to promote the use of the Hanford Site for ecological research, especially studies related to developing energy technologies and their potential for ecological impacts in arid regions.

The terrestrial ecology studies being conducted on the Hanford Site are concerned with short- and long-term impacts of construction and operation of energy facilities. These studies provide the kind of information needed to comply with the intent of the National Environmental Policy Act (NEPA) and various congressional acts pertaining to wildlife, apart from advancing the state of ecological knowledge in the scientific community at large. For example, land restoration studies of areas located in Washington, Colorado and Arizona, are aimed at testing more cost effective ways to successfully revegetate surface-mined lands in arid climates. Also, for example, some airborne and liquid effluents of energy facilities are not confined to the land holdings of any particular state, federal or private ownership and are dispersed widely over regional landscapes. Air pollution is one example where impact may be more directly assessed by damage to vegetation. Methods are under investigation to develop quantitative tools for monitoring the long-term damaging effects of air pollution. The Pacific Northwest is one of the most ecologically diverse regions in North America, so numerous methods are under development.

For locations as large as the Hanford Site, wild animal populations often cause serious problems associated with construction and operation of energy facilities. Quantitative ecological methods are needed for assessing or mitigating impacts, especially for populations of large mammals.

Finally, the disposal of tailings and chemically toxic materials requires prudent environmental consideration. Public Law 95-604, enacted by the 95th Congress of the United States, requires that every reasonable effort be made to provide for safe and environmentally sound disposal and control of uranium mill tailings. Revegetation is one among several methods that seem promising in meeting these objectives. In keeping with that Act, a number of approaches are being considered to contain radon and other toxic materials in inactive uranium mill tailings piles. Programs underway in the Ecological Sciences Department on uranium mill tailings remedial action include research on long-term biobarriers for U-tailings and on potentials for revegetating tailings disposal sites.

Many of the field methods and sampling techniques developed in these studies also have been applied to studies being conducted for the Bonneville Power Administration (high voltage transmission lines) and for the Environmental Protection Agency (acid precipitation) and the Nuclear Regulatory Commission (migration of radionuclides from shallow-land burial sites). Detailed research findings on these studies are reported in our *Annual Report for 1980 on Interagency/Contract Research, Ecological Sciences Department.*

• National Environmental Research Park

Principal Investigator: W. H. Rickard

The National Environmental Research Park (NERP) at Hanford is an outdoor laboratory dedicated to research and education leading to the better understanding of ecological systems and the impact of energy technology development upon them. The Hanford NERP is one of five designated research parks in the United States. It supports ecosystems representative of semi-arid shrub steppe, some of which are believed to be in near-pristine condition. These ecosystems serve as baseline cases suitable for objectively judging the magnitude and direction of ecosystem-level changes induced by time and by man's manipulations in the shrub steppe region. Few studies have been made of vegetal changes that occur as a result of agricultural, urban, or industrial development. The studies that are concerned with the use of revegetated land by birds and small mammals in the shrub steppe region are described.

Characterizing the Shrub-Steppe Region

Land Use

Three general kinds of land use are widely imposed by people in the shrub steppe region of the northwestern United States. Agricultural use includes irrigated land, dry land cultivation and livestock grazing which is practiced on almost all of the available land area. Urban use includes cities, airports, highways and railroads which occupy relatively small areas because the region is not highly populated. Industrial use is devoted to energy research and production activities. Two sites devoted to the development of nuclear energy are the Idaho National Engineering Laboratory (INEL) and the Hanford site in Washington (Figure 1.1). These are Federal lands operated by the Department of Energy and have large land areas with some relatively undisturbed ecosystems. Other Federal land holdings that are administered by the Bureau of Land Management for the U.S. Department of Interior have energy-rich deposits of uranium, coal and oil shale. These deposits will need to be developed in an environmentally acceptable manner to comply with the National Environment Policy Act (NEPA).

Almost any energy development disturbs the land. Surface mining results in the most severe land disturbances. The capacity for revegetation of disturbed land depends upon the climate, rooting substrate, persistence of the planted species, and mankind's mitigative actions designed to enhance the long-term success of revegetation.

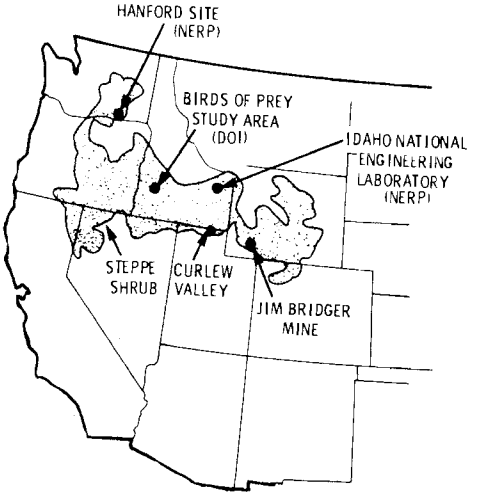

Figure 1.1. The Shrub Steppe Region in the Northwestern United States Showing the Location of Sites Where Data Were Gathered

Long-lasting, man-induced vegetal changes in the shrub steppe region (Figure 1.1) range from complete vegetal replacement as in dryland wheat farming and irrigated crops to partial replacement of the native plants by plantings of alien, perennial grasses such as crested wheatgrass (*Agropyron cristatum*). The invasion of badly overgrazed shrub steppe rangelands by alien weeds such as cheatgrass brome (*Bromus tectorum*) is common. There are only a few places in the shrub steppe region that do not show the effects of 150 years of man-induced vegetal

changes; nevertheless, only a few studies have been focused on determining the effect of these changes upon nongame vertebrate populations.

Small Mammals

Information concerning pocket mouse (Perognathus parvus) populations on the Hanford Site (Figure 1.2) is assembled and synthesized in respect to man-induced vegetal changes other than those created by agricultural land use. This information provides insight into what to expect when vegetal structure is changed by man-induced perturbations and state-of-the-art mitigation practices involving semi-arid, shrub steppe lands.

The Hanford site supports some plant communities that have been altered by livestock grazing and some that have been severly disturbed by the shallow land burial of low level radioactive wastes. Other plant communities have been burned by wildfires and some remain in a relatively undisturbed condition. None of these plant communities have been grazed by livestock since 1943 when the land was designated for special use by the government.

Small-mammal populations in plant communities were investigated using 100 livetraps placed in a square ten by ten meter grid pattern. Trapping was done for three consecutive days. All captured animals were identified as to species, sex, and age; toe clipped, weighed to the nearest 0.5 g on a spring tension scale and released at the site of capture. Data sets were proofed and stored in a computer-retrievable format.

Five study areas were used. Two were dominated by cheatgrass; one (A) was located on a group of retired low-level radioactive waste burial trenches that had become self-revegetated with cheatgrass brome, and the other (B) was a bitterbrush-cheatgrass community that had been burned by wildifre in 1970 and mostly supported cheatgrass brome. Three other areas were shrub-dominated plant communities that had not been burned for many years; one (C) was dominated by bitterbrush (Purshia tridentata) and the others (D,E) by big sagebrush (Artemisia tridentata). The understory was mostly cheatgrass brome.

Because year to year variations occur in populations of pocket mice (Perognathus parvus) in response to variable precipitation

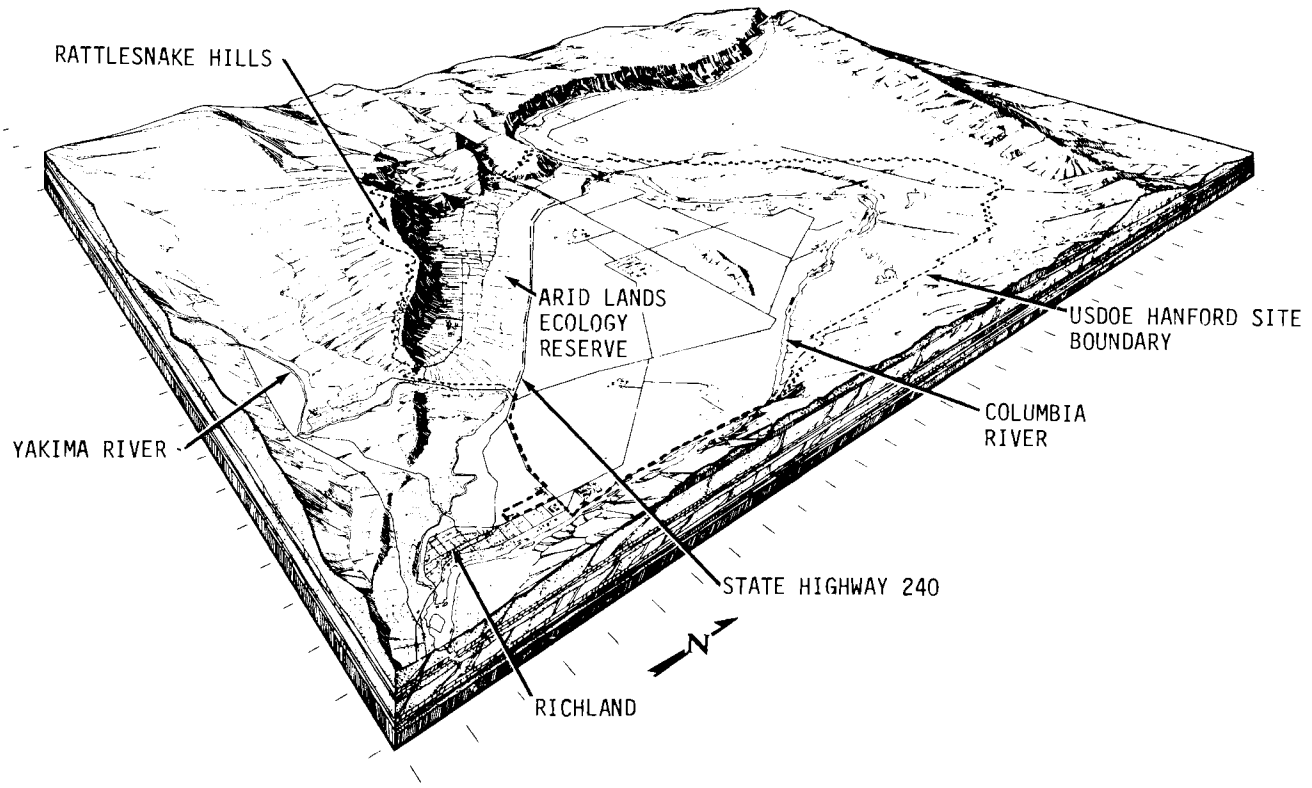

Figure 1.2. Hanford National Environmental Research Park (NERP) Showing the Arid Lands Ecology Reserve and the General Features of the Columbia River Basin

regimes, site comparisons were made only for the years 1974 and 1975 when data were collected at all sites. Pocket mouse catches were highest in the spring and summer months and lowest in winter when the pocket mouse population had mostly retired to burrows (Figure 1.3). In 1975, the mouse catches on the retired burial trenches (A) and the burned site (B) were lower than those from shrub sites (C,D,E). This can be attributed to at least two factors: 1) the plant cover on the retired burial trenches was sparse and consisted mostly of cheatgrass brome, and 2) the soil substrate consisted of a heterogeneous mixture of cobbles and sand resulting from trench excavation, backfilling, and land leveling using heavy machinery. Although cobbles and sand are a part of the native earth, the soil stratification differed from the surroundings, which may in some way have restricted the burrowing activities of pocket mice. The burned area (B) which was dominated by cheatgrass brome also had a small mouse catch. This community also had a relatively rich mixture of native plant species, especially Sandberg bluegrass (Poa sandbergii), but the bitterbrush shrubs had been totally destroyed by burning. The soil substrate was not affected by burning.

Since the three shrub-dominated plant communities had higher catches of pocket mice than the two grass-dominated plant communities, the shrub component of the community appears to be important to pocket mouse populations. The relationship between mouse populations and shrubs has not been completely studied. Seed production by bitterbrush is erratic with no seed production at all in some years; sagebrush seeds ripen and fall to the ground in late autumn when pocket mice are less active aboveground, which indicates that there may be some other way that shrubs can influence pocket-mouse populations.

Pocket mice populations were also higher in native shrub plant communities at Curlew Valley, Utah (Table 1.1) than they were non-shrub dominated communities. Population levels were low in a native plant community consisting of annual forbs and in a community consisting mostly of alien forbs. Populations were intermediate in a community dominated by an alien, perennial bunchgrass (Agropyron desertorum). These data also suggest that the shrub component of plant communities is important to pocket-mouse populations.

Studies conducted at the INEL in southeastern Idaho showed deer mice (Permyscus maniculatus) as the most abundant small mammal on native sagebrush and in plant communities dominated by crested wheatgrass.

Table 1.1. August Catch of Pocket Mice in Plant Communities in Curlew Valley, Utah

Community	1972	1973	1974	Average
Native shrub(a)	32	62	30	41.0
Native annuals(b)	11	21	5	12.3
Alien grass(c)				
hectare 62	23	20	29	24.0
hectare 17	17	19	11	15.7
Alien forb(d)	11	10	6	9.0

(a) *Artemisia tridentata* and *Atriplex confertifolia* with an understory of *Sitanion hystrix* a native perennial bunchgrass.
(b) *Descurainea pinnata* and other annual forbs.
(c) *Agropyron desertorum*, an alien, perennial bunchgrass.
(d) *Halogeton glomeratus*, an alien, annual forb.

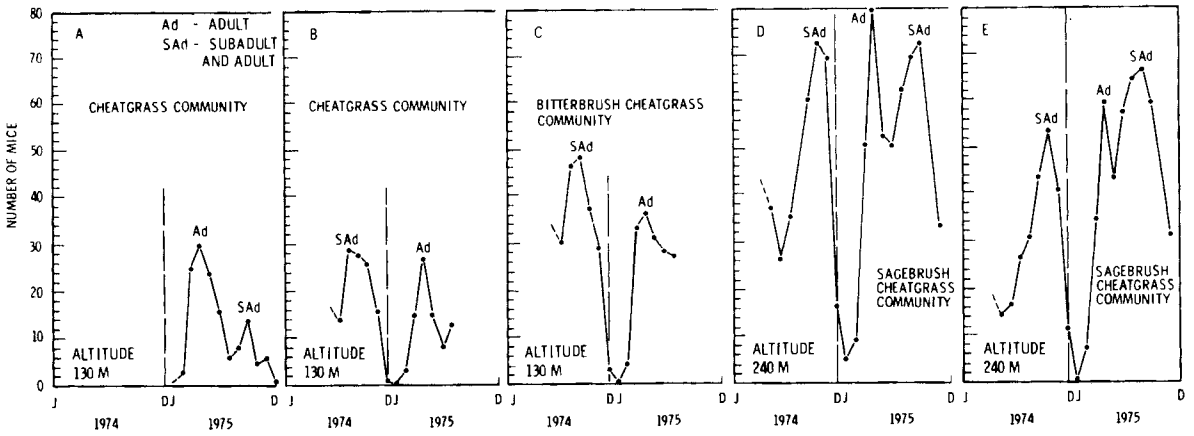

Figure 1.3. Seasonal Catches of Pocket Mice Populations

Pocket mice occurred in small numbers. Studies on the Hanford Site showed that as elevations increased, the number of pocket mice declined while the abundance of deer mice increased (Figure 1.4). The changes were attributed to the cooler climatic regime associated with increasing elevations which ranged from a low of 160 m to a high of 1130 m.

On the Birds of Prey Study Area in southwestern Idaho, deer mice were much more abundant than pocket mice in sagebrush communities at elevations of 920 m. At the Jim Bridger coal mine, deer mice were the dominant small mammal caught in sagebrush communities; pocket mice were seldom trapped. According to International Biological Program Desert Biome studies deer mice were more abundant in Curlew Valley than were pocket mice.

Information concerning the abundance of pocket mice and deer mice in shrub steppe plant communities before vegetal disturbances by neo-European man is not available. However, there are a few extensive areas in the shrub steppe region that have not been greatly changed by man's activities. One of these is the Arid Lands Ecology (ALE) Reserve located on the Hanford Site. Trapping done in a stand of the big sagebrush/bluebunch wheatgrass community (which essentially contained no cheatgrass brome) showed mouse populations here more much like those of the shrub-dominated communities having cheatgrass brome as the understory. Caryopses of cheatgrass brome and native bluebunch wheatgrass (Agropyron spicatum) were observed to be important dietary items of pocket mice. Cheatgrass brome is a more prolific seed producer than bluebunch wheatgrass; the caryopses also ripen earlier in the spring. In this respect, cheatgrass brome may have some beneficial aspects for pocket-mouse populations by providing food.

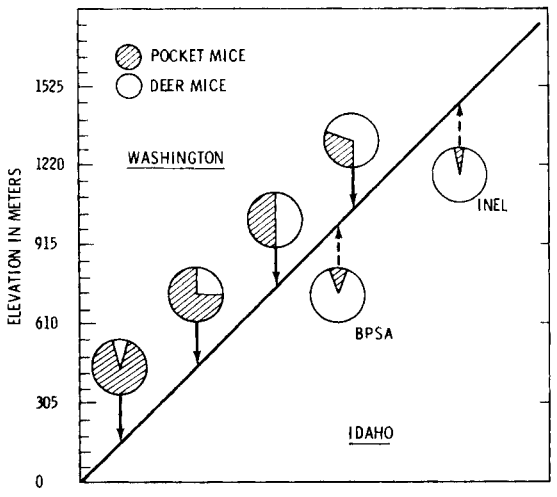

Figure 1.4. Composition of Pocket and Deer Mice Populations in Relation to Increasing Elevation

Breeding Birds

Throughout the shrub steppe region raptorial bird populations have tended to decline as more land is exploited and diverted for man's use. The Hanford Site is one of only a few places in the shrub steppe region that has been allowed to undergo the process of secondary plant succession on purposely bared ground over several decades. Productive dryland wheatfields were abandoned in the early 1940's and allowed to undergo a self-revegetation process without any intentional human interferences such as selective plantings or managed livestock grazing. After 30 years these abandoned dryland wheatfields are still dominated by an early invading alien grass: cheatgrass brome. The land immediately surrounding these fields is representative of native shrub-steppe communities in a relatively pristine condition that have been unaffected by plowing and plantings and supports only a few alien weeds.

Periodically throughout a full year (1978 to 1979), a bird census was taken on two different cheatgrass fields on two different places in the surrounding native vegetation. Data summarized in Figure 1.5 show that horned larks and meadowlarks were the most abundant birds in the native and in the cheatgrass brome communities. These are year round residents. Sage sparrows, savannah sparrows, Brewer sparrows, and vesper sparrows are spring and summer nesting residents and seldom were observed in the adjacent cheatgrass communities.

Chukar and gray partridges are game birds that prospered after being introduced from Eurasia in the early 1900's. They now provide recreational hunting in the shrub-steppe region and are an accepted part of the avifauna. These birds were more abundant in the native shrub steppe than in the adjacent cheatgrass-brome community, but they used the cheatgrass brome community in winter. Cheatgrass brome seeds were especially important in the diets of chukars in winter while bluebunch wheatgrass seeds were taken in the fall and grasshoppers were taken in the summer.

Crested wheatgrass, a perennial grass introduced to the area about 20 years ago, has been seeded upon thousands of hectares of shrub steppe land at the INEL. It has replaced the native bluebunch wheatgrass and sagebrush (Figure 1.5). Sage thrashers, sage sparrows, Brewer sparrows, vesper sparrows, sagegrouse, western meadowlarks,

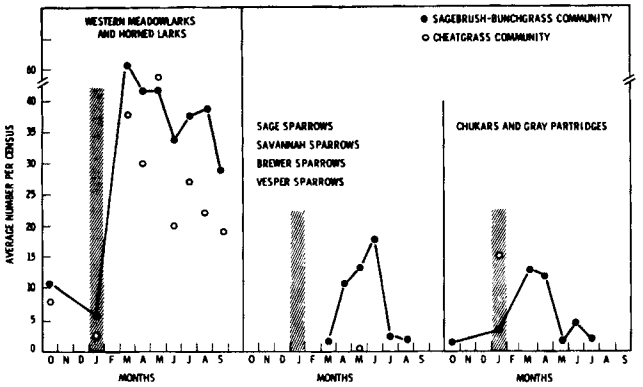

Figure 1.5. Average Numbers of Birds Counted Along Paired Census Lines in Native Sagebrush-Bunchgrass and Cheatgrass Communities

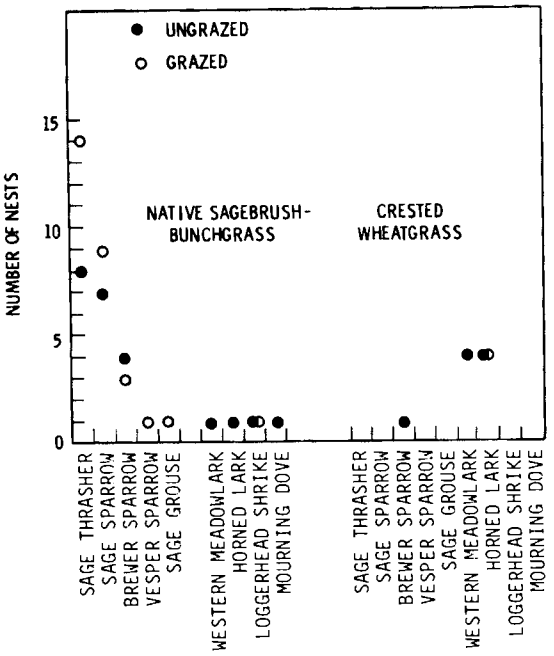

Figure 1.6. Bird Nests Found in Native Sagebrush-Bunchgrass and Crested Wheatgrass Communities in Southeastern Idaho

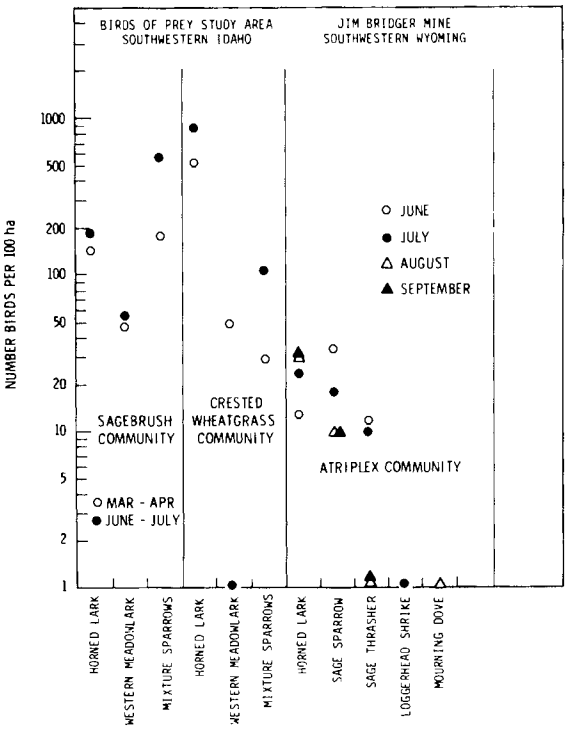

Figure 1.7. Density of Birds in Shrub Steppe Study Areas

horned larks, loggerhead shrikes and mourning doves all nested in the native sagebrush-bunchgrass communities (Figure 1.6). Only western meadowlarks, horned larks and vesper sparrows nested in the planted, crested-wheatgrass communities.

Bird census' were conducted on the Birds of Prey Study area in sagebrush and in crested-wheatgrass communities. The crested-wheatgrass communities harbored horned larks in greater abundance than did sagebrush dominated communities (Figure 1.7). On the average, however, western meadowlarks and sparrows were more abundant in communities that supported sagebrush. In shadscale shrub (Atriplex spp.) communities in southwestern Wyoming, horned larks and sage sparrows were the most abundant birds. Western meadowlarks were not observed in the shrub community even though vegetal profiles were not greatly different from those of Idaho shrub communities.

Historically, revegetation practice in the shrub steppe region has centered upon livestock grazing, removal of sagebrush, suppression of cheatgrass brome by chemical spraying, and the seeding of introduced perennial bunchgrasses. Early invading plants such as cheatgrass brome are purposefully discouraged because they are regarded as inferior livestock forage and because of the competition they foster provide for the more desirable alien grasses planted as livestock forage. Self-established cheatgrass brome communities, like crested-wheatgrass communities, are essentially botanical monocultures, and both kinds of communities seem to provide acceptable habitat to horned larks and western meadowlarks. If livestock grazing is not to be an important consideration in land use, cheatgrass brome swards are probably as effective as crested wheatgrass as far as use by meadowlarks and horned larks is concerned. Cheatgrass brome stands are also self-perpetuating over several decades of time, but crested wheatgrass stands are probably not so long lasting. There are also financial and energy costs associated with planting crested wheatgrass, but this is not the case with cheatgrass brome. Crested-wheatgrass seeds are considerably smaller than seeds of either cheatgrass brome or bluebunch wheatgrass, and whether or not these smaller seeds are consumed by birds is not known. Nevertheless, cheatgrass brome is an important food source for chukar partridges, one of the most important upland game birds in the uncultivated parts of the shrub steppe region.

When horned larks, western meadowlarks and sage sparrows co-existed in the same native sagebrush bunchgrass community, their diets consisted mostly of insects (Figure 1.8). There are no data available to permit a comparison of the diets of

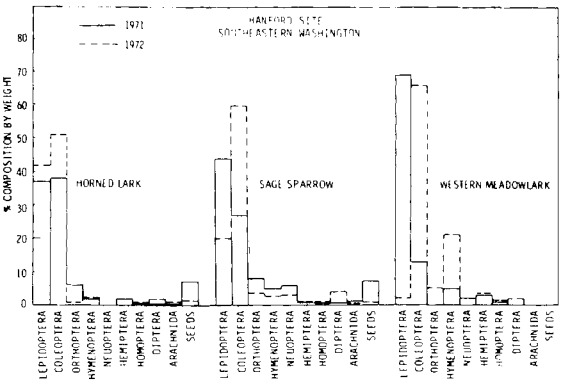

Figure 1.8. Composition of Bird Diets from Native Sagebrush-Bunchgrass Communities

horned larks and meadowlarks nesting in cheatgrass brome communities with birds nesting in the adjacent sagebrush-bunchgrass communities.

The native sagebrush bunchgrass communities support a more diverse passerine avifauna than do the revegetated communities dominated by cheatgrass brome and crested wheatgrass. If avifaunal diversity is to be one of the aims of revegetation practice in the shrub steppe, then xeric shrubs need to be considered in the revegetation plans, otherwise grass swards would probably support bird populations that were comprised mostly of western meadowlarks and horned larks.

The austere vegetal structure and food base provided by shrub steppe plant communities in conjunction with a highly variable and harsh climate suggests that shrub steppe communities are among the most difficult of all broad scale, regional vegetal types for passerine birds to colonize. Bird populations in shrub steppe communities are not as diverse in species composition as are populations inhabiting streamside cottonwood-willow communities.

Shrub-steppe plant communities in pristine condition (pre-European man) are a rapidly diminishing natural resource in the northwestern United States. Crop plants, self-sustaining populations of alien annual grasses, and extensive plantings of introduced perennial grasses have replaced native communities on thousands of km^2. These vegetal changes have affected avifaunal populations by creating plant communities that are less acceptable to several species of sparrows.

Graduate Student Research

Two students have completed research projects for advanced degrees in Botany and Wildlife Management. Field and laboratory facilities were provided through the Northwest Organization of Colleges and Universities for Science (NORCUS) and the Joint Center for Graduate Studies, Richland, Washington. Both students are enrolled at Washington State University, Pullman.

Faculty Research

Two university professors continue to use the field facilities of the Hanford NERP to pursue ecological studies supported by the National Science Foundation. These professors are from the University of Washington in Seattle, and Washington State University in Pullman.

InterNERP Research

Litterfall collections from common desert shrub species at Idaho National Engineering Laboratory, Los Alamos National Scientific Laboratory and the Hanford Site were continued. Collections were archived for chemical analyses, especially trace minerals.

Hanford Site

Stray livestock were excluded from the ALE reserve during the past year. A free-roaming herd of 15 stray horses continue to reside elsewhere on the Hanford Site, west of the Columbia River.

A few small rangefires occurred in mid-summer along both sides of state highway 240. Damage was minimal.

On May 18, 1980, the Hanford Site and vicinity was dusted with volcanic ash from the eruption of Mt. St. Helens. All vegetal surfaces received some ash fall, which caused no apparent damage.

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• Terrestrial Ecology

Principal Investigator: L. E. Rogers

Other Investigators: R. E. Fitzner, K. A. Gano and J. L. Warren

Technical Assistance: M. A. Combs, C. A. Lee and L. F. Nelson

The Terrestrial Ecology Program is dedicated to long-term ecological studies conducted on the Arid Lands Ecology (ALE) Reserve. The focus of the studies concerns the response of western arid-land ecosystems to man-induced and natural perturbations. Wildlife utilization studies of disturbed plant communities have been emphasized during the past two years and are included in detail in this report.

Wildlife Utilization of Self-Revegetated Plant Communities

Previous studies have shown that self-established annual-grass communities are able to maintain themselves over long periods of time. Some communities have experienced little change in species composition in over 30 years. This study was designed to ascertain the response of wildlife to these communities. Gathering data about vegetation, small mammals, birds, and ground-dwelling beetles is now complete. The study plots were subsets of two large agricultural fields now dominated by cheatgrass and portions of surrounding, larger areas of nearby, relatively pristine vegetation. We hypothesize that the self-establishment of persistent annual-grass communities has not affected the abundance of wildlife, vegetal cover or net primary production. The data gathered to test this hypothesis include plant cover and standing-crop values, ground-dwelling beetle abundance, bird abundance, and small-mammal population estimates. Sampling methodologies were reported last year and are not repeated here.

Vegetation

A two-year summary of peak primary productivity between two study plots representing native vegetation in near-pristine condition and old-field plots invaded by alien vegetation was made. Plots 1 and 3 are characterized by a plant community in which 85% to 95% of the total phytomass is comprised of annual-grass species. Plot 1 supports a dense stand of rye, which is a remnant from cultivation 37 years earlier. Rye comprised nearly half of the total phytomass on the plot. Cheatgrass brome is a co-dominant with rye on plot 1, but cheatgrass brome is exclusively dominant on plot 3. Dense litter mats form a continuous ground cover on both of the old field plots. Plots 2 and 4 consist of native plants that are typical of the study area in general. These plots contain a high diversity of native plant species. The litter component on pristine plots consists mostly of standing dead-plant material. The ground between ground clumps and shrubs is mostly bare.

Phytomass estimates show the large productive ability of the self-revegetated sites. These sites (plots 1 and 3) produced three-to-four times more litter than did the native habitats in 1979 and 1980 (Table 1.2). Although the self-revegated plots produced more phytomass than the native plots, (except for plot 3 in 1980), plant canopy cover on the self-revegated plots was less than on the native plots. Estimates of canopy coverage on these annual-grass-dominated areas probably do not accurately reflect productivity relative to coverage estimates of other plant community types. At the time of peak production, the lower leaves of annual grasses have died back; therefore, much of the plant's weight is distributed in the seed head. On the native habitats, plant weight is more evenly spread through the canopy of the various species. Comparisons in the phytomass data reveal that 1980 was a more productive year than 1979 for all four plots. The increased growth in 1980 may be partially explained by the dramatic difference in rainfall

Table 1.2. Primary Production in 1979 and 1980 on Native Plots and Self-Revegetated Plots

		Phytomass ($g/m^2 \pm$ S.E.)[a]				Total Cover [b]			
		1979		1980		1979		1980	
Study Area	Plot	Total Live	Litter	Total Live	Litter	%	Species	%	Species
Self-Revegative	1	195.3 ± 43.2	673.7 ± 62.4	365.7 ± 45.6	168.5 ± 40.5	42.7	5	45.5	7
	3	166.8 ± 18.0	522.2 ± 62.9	272.7 ± 22.9	137.1 ± 17.9	38.6	5	77.9	7
Native	2	51.4 ± 9.8	Not Taken	111.4 ± 20.4	51.4 ± 10.3	74.9	19	66.4	20
	4	40.4 ± 9.4	Not Taken	126.9 ± 15.6	64.8 ± 12.5	60.6	14	62.9	16

[a] Samples taken in mid-April of both years.
[b] Samples taken in mid-May of both years.

between the two years. Rainfall in the 1979 growing season (November through May) totaled 7.33 in. In the 1980 growing season, rainfall totaled 16.14 in. The winter of the 1979 growing season was unusually cold, and snow and ice remained on the ground for a much longer time than in the 1980 season. This factor also may have contributed to lower plant production in 1979. Pristine plots were slightly more affected by year-to-year variations in the physical environment than were the old-field plots.

Small Mammals

The relative abundance and species composition of small-mammal populations that inhabit native and self-revegetated plots were compared. Four trapping sessions were conducted during the year on five consecutive nights each. Live traps were used on the first two nights and snap traps were used on the following three nights. Live-trapping provided mark-recapture information, while the use of snap traps provided an estimate of relative abundance. Snap traps enabled us to capture animals that would otherwise be missed due to lack of trap sensitivity or trap shyness.

A total of six small-mammal species were captured during the four trapping sessions (Table 1.3). The animals captured during the 1980 trapping effort were, in order of abundance, the Great Basin pocket mouse (*Perognathus parvus*), deer mouse (*peromyscus maniculatus*), western harvest mouse (*Reithrodontomys megalotis*), Merriam shrew (*Sorex merriami*), pocket gopher (*Thomomys talpoides*), and the montane vole (*Microtus montanus*). The merriam shrews, pocket gophers, and most of the harvest mice were captured in snap traps. The other species were captured in both types of traps.

Table 1.3. Number of Small-Mammals Captured in Native Plots (N) and in Self-Revegetated Plots (SR)[a]

Species	Nov. 1979		March 1980		June 1980		Aug. 1980	
Trapped	SR	N	SR	N	SR	N	SR	N
Pocket Mouse	6	4	31	32	2	19	4	49
Deer Mouse		4	1	12				
Harvest Mouse	5	2	6	1		1	2	
Merriam Shrew	1	3						
Montane Vole		1		1				
Pocket Gopher	1			1		1		

[a] Each study site is comprised of two replicates. The totals shown are for five-day collection periods.

Combining the capture data for the two old-field plots and the two undisturbed sites, estimates of the proportional abundance of *P. parvus* were computed to compare the two habitats. Using the single mark-recapture method, a Chi-square statistical test showed no significant difference in the capture probabilities of *P. parvus* in the two habitats ($X_2 = 4.25$, $\alpha = 0.104$). The homogeneity in capture probabilities permits the use of the estimator of proportional abundance, $K_1 = r_2/r_1$ where r_2 and r_1 are the number of *P. parvus* captured on the undisturbed and old field sites, respectively. For the fall (November 6 through 10, 1979) and winter (March 25 through 29, 1980) sampling periods, no significant difference ($\alpha > 0.05$) in *P. parvus* abundance was observed. Proportional abundance on June 9 to 13, 1980, was estimated to be $K = 9.5$ with a confidence interval of $(3.7 \leq K \leq 15.7) = 0.95$. Proportional abundance on August 19 to 23, 1980, was computed to be $K = 16.0$ with a confidence interval of $(3.7 \leq K \leq 36.9) = 0.95$. Hence, abundance of pocket mice appears to be approximately

equal on old-field and undisturbed sites during late fall and winter months, but many times greater on undisturbed sites during the summer. Deer mice were only caught in the cooler months of November and March, and were most often caught on the native plots. Conversely, harvest mice were more often trapped on the self-revegetated plots. The other three species were caught too infrequently to show any patterns.

Birds

The old-field study plots were dominated by two passerine bird species--the horned lark and the meadowlark. Two additional species, the Savannah sparrow and mourning dove, each were sighted only once in old-field plot 1 in 1979. The native plots both had a maximum of eight breeding-bird species. Three sparrow species (Brewer's, vesper, and sage) were regular components of the native plots. The Savannah sparrow was recorded as a breeding species on native plot 1 in 1979 but was not recorded in that plot on 1980 or in plot 2 in 1979 or 1980. The mourning dove, black-billed magpie, and robin probably all nested in the native habitats, but only on an irregular basis. Three game-bird species were observed as breeding birds in native habits. The chukar and gray partridge were observed with broods, and a single male ring-necked pheasant was heard crowing, although it was not sighted.

The greater number of species and individuals regularly observed in the native study plots reveals that the old-field plant community does not support the diversity and biomass of birds that the native plant communities do. The absence of sagebrush on the old-field plots is probably one main reason for the observed difference. The native communities have a well-developed assemblage of plants and animals which have evolved together over long periods of time and have formed an interdependence with one another. The Brewer's, vesper and sage sparrows seem to be so closely dependent on the native habitats that they were never observed even visiting the old-field communities. The exotic gamebirds did not evolve in North-American shrub-steppe regions but in regions of Eurasia that have vegetal types similar to those in North America. However, they still exhibit a preference for native communities. This probably is due to the nesting and brood-rearing cover provided by big sagebrush and associated forbs and perennial grasses.

The key point to realize from the comparison of old-field and native communities is that old fields, being relatively monotypic in appearance, promote less bird diversity than native communities.

Beetles

Sixteen species of ground-dwelling beetles were found inhabiting invaded and self-revegetated study plots. Some species, such as Eleodes novoverrucula, Coniontis ovalis, conintis lanata, Amara sp. and Harpalus sp. clearly preferred the cheatgrass habitat during both study years. Others such as Eleodes granulata, Eleodes hispilabris and Eleodes nigrina were more common in the native area. Clearly the invasion of a native area by alien weeds favors some species of ground-dwelling beetles and discriminates against others.

• Dynamics of Wild Populations

Principal Investigator: L. L. Eberhardt

The main objectives of this project are to evaluate the available data on the population dynamics of plants and animals and to conduct research on quantitative methodology used for assessing the diversity of species in a community. A major goal is to advance our understanding of population regulation as it bears on the management of unconfined plant and animal populations.

As has been pointed out in previous project reports, the impacts of energy-related developments cannot be expected to have an effect on populations that is simply proportional to degree of "insult". Instead, the effects are non-linear and mainly depend on the population's ability to compensate for some degree of impact. In many species it appears that this resiliency is a function of the current level of the population relative to the carrying capacity of the environment.

The population level at maximum resiliency seems to coincide with the point known in population management contexts as the maximum sustainable yield (MSY) level. Estimating these levels has received a good deal of attention in the last several decades, especially from fisheries management. Virtually all of the work done during that period was based on the assumption that the MSY level was midway in the population growth curve (i.e., at about half of the maximal or carrying-capacity population level). But many scientists now agree that for many of the large mammals, the maximum yield (and maximum-resiliency) level is probably closer to the maximum (carrying capacity) population level. We have been actively involved in this recent development, and we have published several papers about management based on this new principle.

Much of the evidence thus far available has been empirical in nature and was largely based on plotting yields (or population growth increments) against a current population level. Furthermore, these data primarily dealt with single-species situations. To alleviate these shortcomings, work was begun in two areas. First, our studies were extended to include multiple-species situations, which are clearly those of crucial importance in the "real" world. Our progress along these lines has mainly involved a general formulation of a two-trophic-level assessment. Under quite general considerations of symmetry (in population growth curves), it appears that we can show that the MSY point for the second trophic level (consumers) is necessarily greater than the traditional 50% level.

In the second area, more research is needed in order to understand what mechanisms actually regulate the population. Not much can be done to ameliorate impact situations unless these mechanisms are understood. Using the fundamental equations of population dynamics, we have been studying the inter-relationships of the four main features of the dynamics of a population (early survival, age of first reproduction, reproductive rate, and adult survival). In 1977, we proposed the order of importance in which these features influence population regulation. Work of this nature is necessarily long-term; however, we expect that some of the intermediate developments will be useful in field contexts.

Part of our investigation has involved dealing with current problems that affect these species. The grizzly bear and the bowhead whale, for example, are two endangered species that we have been especially concerned with. In the first case, we are advising an interagency research team, and in the second, we are participants in a formal agency scientific advisory committee (U.S. Marine Mammal Commission). The energy-related aspects of the bowhead study are crucial issues that may affect petroleum development in the Beaufort Sea region. It appears that the grizzly bear problem may affect geothermal developments, particularly south of Yellowstone National Park.

In contrast to the endangered-species problems, we are involved in a National Academy of Sciences panel mandated by the Rangelands Improvement Act of 1978. In this

case, we are concerned with the management of wild horses and burros that, in some instances, appear to be expanding near the limits of their biological capabilities.

Other related efforts include attending an international meeting of population specialists assembled last May to provide advice for the diplomatic meeting that negotiated the Convention for Management of the Southern Ocean; providing material for a conference requested by the Congressional Office of Technology Assessment (fisheries research and management); and participating in an international workshop on population assessment that was convened by the International Whaling Commission in September.

We have also conducted field research that applies "distance" sampling methods to the assessment of plant species diversity. Work on line transect methodology is continuing. We also participated in an ad hoc "transuranic modeling committee" formed by the Office of Health and Environmental Research.

For further information on the statistical methodology for field sampling refer to our Annual Report for 1980 on Interagency/ Contract Research, Ecological Sciences Department

• Restoration of Surface-Mined Lands

Principal Investigator: R. H. Sauer

Technical Assistant: V. D. Charles

A major problem in restoring the vegetative productivity of western arid strip-mined lands is the difficulty of providing enough water to re-establish and maintain vegetation. The purpose of this program is to demonstrate the technical and economic feasibility of using the techniques of water harvesting to provide irrigation water for useful crops in arid surface-mined lands. The strategy is to use the slopes of moderately re-graded spoil material to gather rain and snow. The runoff travels downslope to the valley between the slopes where the best soil has been placed. The crops are planted in the valleys. This program is gathering information on optimum crops, slope angles, and slope treatments in an effort to reduce the costs of reclamation, reduce the consumption of valuable resources (water and soil) and establish productive, useful crops where only weeds would otherwise grow.

Three sites have been established to demonstrate this approach to restoration. The site on the Hanford Site is used to develop new techniques and run preliminary tests on promising crops and slope treatments. The Black Mesa Mine on the Navajo Indian Reservation in Arizona and the Colorado Site at Nucla are demonstration sites located at operating coal mines and are cooperative efforts between PNL, the Peabody Coal Company, and Dr. John Thames of the University of Arizona.

Black Mesa Mine, Arizona

The demonstration site at the Black Mesa Mine, which was started in the spring of 1979, consists of two slope treatments and several crop species. Water content in the topsoil between the slopes was greater for the salted and compacted slopes than for the untreated slopes, and both had more water than did areas that were restored with conventional procedures. Vegetative production was correspondingly greater in the areas irrigated with runoff water. The slope treatments appear to be more stable. Data will continue to be collected on soil water and vegetative production at this site.

A detailed economic analysis was conducted for the Black Mesa Mine to identify which slope treatments and crops would be the most economically feasible under the constraints of the climate, potential crop market, and slope treatment at the site. Analysis shows that approximately $3000 per acre would be saved in earth moving costs alone by using the Pacific Northwest Laboratory (PNL) approach to restoration. By using compaction as a slope treatment and alfalfa as the crop, the value of the harvested alfalfa would exceed the farming costs required to produce it. The proposed farming operation would therefore have a net income. On the other hand, when conventional restoration efforts are unproductive, the land is used by lower-value cattle or sheep ranching operations. This use of the land is probably not cost effective. This study has pointed out the importance of slope treatment and crops in determining the economy of PNL methods of restoration.

Nucla Mine, Colorado

In the spring of 1980, two demonstration areas were graded and prepared for spring seeding. The three slope treatments planned are 1) salted-compacted, 2) compacted, and 3) vegetated. The vegetated treatment is new and consists of planting a drought-resistant grass on the catchment slopes to reduce erosion and contribute to the productivity of the site. This treatment, however, will not significantly reduce the amount of runoff from an untreated slope. The Peabody Coal Company has been especially helpful in assisting with these demonstration sites.

Hanford Site

The demonstration site at Hanford combines slope treatments and valley directions (north-south/east-west) to identify practical means of increasing runoff and wind protection. Grapes (replanted this year after being killed by grasshoppers last year) and wheat have been planted to determine the efficiency of the slope treatments. Soil-water content has been monitored to indicate when water is available. The data for wheat production and soil water are given in Table 1.4. Soil-water content is represented as the number of days (wet days) between planting and harvesting that the mean water potential of the top 1 m of soil was greater than -5 bars. For a reference point, field capacity is usually considered to be -0.3 bars and permanent wilting, -15 bars. The trend is to associate more wet days with greater production, but the exceptions of 1 wet day with 30 bu/acre in rubber-asphalt shows the difficulty of using simple averages to express these relationships. Data on soil-water use indicate that the wheat does not effectively use water stored below 0.5 m deep in the soil; to better use this water, alfalfa may be planted next year instead of wheat.

Table 1.4. Wheat Production and Number of Days That Soil Water Potential >-5 Bars

Treatment	bu/acre x ± 95% CI	Wet Days
E-W Valleys		
Paraffin	11 ± 5	1
Bare	15 ± 6	10
Rubber-Asphalt	30 ± 10	1
N-S Valleys		
Bare	30 ± 6	24
Rubber Sheeting	46 ± 11	94

The system that was designed over the last several years for obtaining soil-water data was put into operation this year and has decreased the time required to obtain these data and increased the accuracy of individual readings. The heart of the system is an instrument that was developed at PNL to compensate for the capacitance inherent in long leads to the soil-moisture sensors. A patent is pending on this instrument.

Seasonal distribution of rainfall and the size of individual storms is an important factor in the design of a rainfall-harvesting project. To be able to systematically determine regional design characteristics, the University of Arizona is developing a technique for statistically summarizing measurements of snowfall, rainfall, storm size and seasonal rain distribution. This summary will provide information for decisions on ratios of catchment area to planted area and minimum efficiencies required for slope treatments. Data for the Hanford site are being used to develop the system. The results will be used to identify other sites in the arid west that show a high potential for reclamation with water harvesting.

• Long-Term Ecological Monitoring

Principal Investigator: W. T. Hinds

Other Investigators: R. E. Fitzner, M. C. McShane, J. R. Skalski and J. M. Thomas

Technical Assistants: M. A. Combs, C. A. Lee and L. F. Nelson

The objective of the Pacific Northwest Laboratory Long-Term Ecological Monitoring Project is to develop monitoring designs able to detect ecological changes associated with energy technologies in the Northwest. Potential causes of change can have either localized or widespread impacts. Transmission line rights-of-way construction and maintenance, oil and gas pipeline construction, or drift from cooling towers are examples of localized impacts. Widespread impacts may be caused by coal-fired generators producing NO_x, SO_x, and the potential for acid rain and trace-element contamination over large areas. The monitoring program is under way in two distinct areas: 1) development and deployment of monitoring techniques, and 2) low-level cooperative efforts with other federal agencies involved with monitoring, focused on the US Man and the Biosphere program.

Ecological monitoring of Northwest habitats is currently divided into two task areas. The Forest Monitoring Task is monitoring productivity of forest and steppe vegetation using a litterfall-analysis technique, and the vertebrate task is monitoring transfers of contaminants along food chains using biological materials incidental to reproduction of wide-ranging predatorial birds.

Forest Monitoring Task: Litterfall Sampling

Litter collected continuously since early 1979 at four forested sites has yielded data indicating that continuous monitoring of only a portion of the total litterflux is more cost-effective than monitoring total litter production. The variances for both total litterfall and species-specific needle production are relatively large. However, in these closed-canopy forest sites, the total flux of needles has thus far been found to be less variable: the median coefficient of variation (standard deviation/mean) was about 30% in three of the four sites.

Optimizing Statistical Design Parameters

Using the litterfall data described above to examine variability in both time and space, a first approximation to optimal statistical design can be made. The design probably should emphasize needle production rather than species composition, which can be monitored using auxiliary sampling procedures. Most sites can be economically and effectively monitored by analyzing only a fraction of the total number of samples. All the samples should be analyzed only where excessive variability requires significantly larger sample numbers. The optimum sampling intensity seems to be strongly site-specific, indicating a need for estimating plot-to-plot variances before a second-generation design can be specified.

Vertebrate Task: Contamination in Food Chains

Food chain contamination can often be detected most readily in long-lived avian predators. Using this observation, a terrestrial food chain leading to wide-ranging raptors of steppe lands and an aquatic food chain leading to herons are being investigated for ecological appropriateness and statistical reliability. Through cooperative work with the U.S. Bureau of Land Management (BLM) scientists in the BLM's Birds of Prey Natural Area, we were allowed access to a collection of egg shells and contents

that BLM personnel had gathered over a seven-year period. These eggs are currently being cataloged and analyzed for trace elements to provide a baseline of past contaminant loading. A similar set of collections is being started by Pacific Northwest Laboratory (PNL) scientists using Great Blue Heron nesting colonies as sources of egg fragments, prey remains, and other incidental materials accumulating near nesting areas. In addition to baseline data, analyses of trace-element contents will allow appraisal of the statistical reliability of such materials.

Differential contamination is already evident in various Heron colony habitats. For example, Herons nesting in a mining region of Idaho exhibited high background levels of lead and cadmium; others nesting near a major freeway had high background levels of lead. Both of these colonies currently exhibit higher loadings of contaminants than either agricultural- or energy-related sites in central Washington state.

Maintenance Costs for Monitoring Sites

Site maintenance and data-collection costs per unit effort are listed in Table 1.5. These data refer to both forest and vertebrate monitoring sites. Current efforts range over a variety of site-specific tasks, from intensive year-around data collection to seasonal visitations. The ratio of PNL staff labor to subcontracted assistance varies. The averages and total in Table 1.5 probably reflect the real commitment required to pursue long-term data collection in habitats of the Pacific Northwest. However, these costs do not include staff costs for publication or presentation at scientific meetings, nor costs associated with locating sites and developing a sampling design.

Table 1.5. Costs of Site Maintenance for PNL Ecomonitoring Program, 1980[a]

Cost factor	Cost per Site	
	$K per Year	%
Staff Labor	13	70
Travel	1	5
Materials and Subcontracts	1.5	8
Chemical Analyses	2.5	13
Project Administration	1	4
Total	19	100

[a]Environmental and biological heterogeneity produce plot to plot variation within communities; depending upon the variance observed, a typical monitoring effort applicable to a given landscape unit may require from 6 to 10 or more sites.

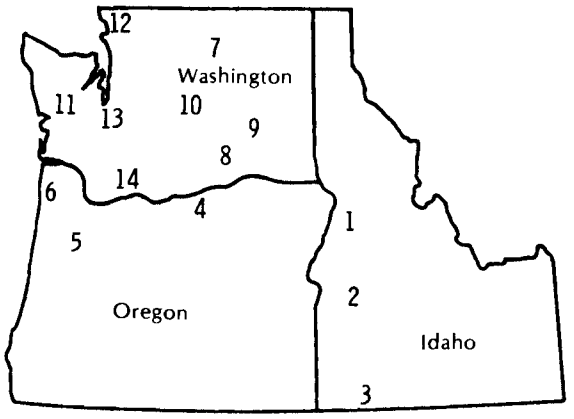
The proportion of staff labor to total cost is almost exactly the same as that proposed for a marine-monitoring program focused on toxic metals in Germany. This is a hopeful sign, because the costs documented by the PNL work to date have been incurred mainly in the "research and development" stage. It is likely that routine maintenance costs of the sites will decrease somewhat as the amount of scientific staff labor decreases.

The present distribution of sites in the Northwest is shown in Figure 1.9.

Cooperative Monitoring Efforts in the Man and the Biosphere Program

The U.S. Environmental Protection Agency's Environmental Monitoring Support Laboratory (Las Vegas, NV) and the U.S. Department of the Interior's National Park Service invited PNL scientists to help plan for the Environmental Protection Agency's (EPA) baseline-monitoring work in the Olympic National Park. Due to the difficulty of design and sample collection, the monitoring approach employed by the EPA researchers did not include sampling tree canopies. However, baseline data collected in forested ecosystems must include data from trees if the baseline is to be useful. PNL scientists requested and received a budget supplement to the Long-Term Monitoring program in order to examine the difficulty inherent in sampling tree canopies. Using replicated plots, PNL researchers collected samples of new needle growth, mature needles, and twigs supporting older but still productive needles. The samples were obtained from 5 to 40 meters above the ground in both dominant and sub-dominant tree species. These data will be crucial in determining whether tree canopies are essential for sampling in the intermittent-sampling mode used for these baseline surveys.

The PNL sampling design, by using replicated plots, also addressed an important monitoring design problem: plot-to-plot variances. This source of variability is exceedingly troublesome because it can mask important differences or emphasize insignificant differences between single plots when actually only natural variation between plots exists. Because many monitoring programs do not properly account for this source of variability, PNL's contribution to the study of plot-to-plot variation is important for the proper design and interpretation of the Department of Energy's monitoring data.



1 Birds of Prey Natural Area
2 Lake Chatcolet
3 Raft River
4 Boardman Navy Bombing Range
5 HJ Andrews Experimental Forest
6 Neskowin Crest Research Natural Area
7 Bridgeport
8 Hanford Site
9 Juniper Forest, Pasco
10 Moses Lake
11 Quinault Lake Research Natural Area
12 Samish River Delta
13 Tacoma
14 Wind River Research Natural Area

Figure 1.9. Pacific Northwest Laboratory Ecomonitoring Sites (Identified by Reserve Area or Nearby Population Center)

• Application of Long-Term Chemical Biobarriers for U-Tailings*

Principal Investigators: J. F. Cline, D. A. Cataldo, F. G. Burton and W. E. Skiens

Other Investigators: K. A. Gano and L. E. Rogers

Technical Assistants: J. L. Downs, G. E. Wilson, K. R. Hanson, R. T. Webster and J. M. McNair

The objective of this project is to develop and evaluate the effectiveness of physical and chemical barriers that are designed to prevent plant and animal breachment of uranium tailings containment systems for extended periods of time.

Development of Polymeric Carrier/Delivery (PCD) Systems

Organic polymeric materials that permit sustained and controlled release of phytotoxins at well-regulated rates are being developed to prevent plant root intrusions into sealants placed over U-tailings. Certain herbicides are available that prevent root growth in the treated zones but do not kill or harm other plant parts. Trifluralin, one of this type, was selected as the first herbicide. Polymers having properties suitable for the preliminary screening studies were two types of silicone rubber, polyethylene-vinyl acetate, polyethylene, polyetherpolyurethane, polypropylene, thermoplastic elastomeric polyester, polyamide, and polyolefin copolymer elastomer.

Trifluralin was studied with a variety of organic matrices. These included not only homogeneous mixtures of trifluralin with the polymer, but also polymer/chemical reservoirs surrounded by a polymer coating which controls the diffusion rate of the trifluralin from the reservoir.

Determination of Phytotoxin Release Rates from PCD Systems

Analysis using a continuous flow system was used to determine the release rates possible from the PCD systems. Controlled release rates are shown in Table 1.6.

Table 1.6. Release Rates of Trifluralin from Polymers

Polymer Type[a]	Release Rate, $\mu g/cm^2/day \pm SD$
Polyurethane	3.42 ± 0.95
Silastic 382 (<10% Loading)	2.70 ± 0.90
Polyester Hytrel 5525	7.32 ± 1.70
520 polypropylene	4.23 ± 0.45
Microthene F	~11
Microthene MN 710-20 polyethylene	~10
Microthene MN 710-20	~27

[a]Contains 10% Trifluralin in herbicide portion unless otherwise stated.

These rates indicate that there are a number of good polymer candidates for use in further studies that could lead to a biobarrier for uranium tailings. Both the polyethylenes and polypropylenes provide very stable, readily available, and low-cost polymers with low release rates. Polypropylene/trifluralin pellets will also be used in laboratory-scale and greenhouse lysimeters to determine phytotoxicity, and the pellets will be run in a continuous flow system to determine the release rate in vitro.

*Project funded through DOE Uranium Mill Tailings Remedial Action Project Office, Albuquerque, N.M.

Determination of Phytotoxic Concentrations and Degradation of Trifluralin in Soils

This study defines the requirements for providing a minimal level of a phytotoxin that is effective in restricting root growth beyond the biobarrier. We investigated the effects of environmental variables on chemical and microbial decomposition of the PCD system and the mobility of the phytotoxin in the soil following release from the PCD system. These data are necessary for the development of PCD systems prior to laboratory and field testing.

Toxicity screening for trifluralin to root growth is in progress using Russian thistle and Ritzville silt loam soil. The first study used trifluralin concentrations of 0, 0.1, 0.5, 2, 10 and 20 µg/g/dry soil. Longitudinal root growth was markedly inhibited at concentrations in excess of 0.5 µg/g. Under the conditions of this study, 2.0 µ/g appears to be an effective concentration. This will set the minimal release rate for the PCD systems being developed and tested for laboratory and field tests. It should be noted that these minimal phytotoxic concentrations may need to be increased depending on the rates of chemical and biological degradation. The latter will be investigated at some depth as soon as background data becomes available.

Greenhouse and Field Studies

A selected group of herbicides were tested to determine which one best prevented plant roots from growing into radon seals placed over U-tailings. The herbicides were impregnated into a polymer sheet and placed into a soil column 3 dm below the soil surface. Russian thistle was then planted. The herbicides tested and the resulting growth patterns are shown in Table 1.7.

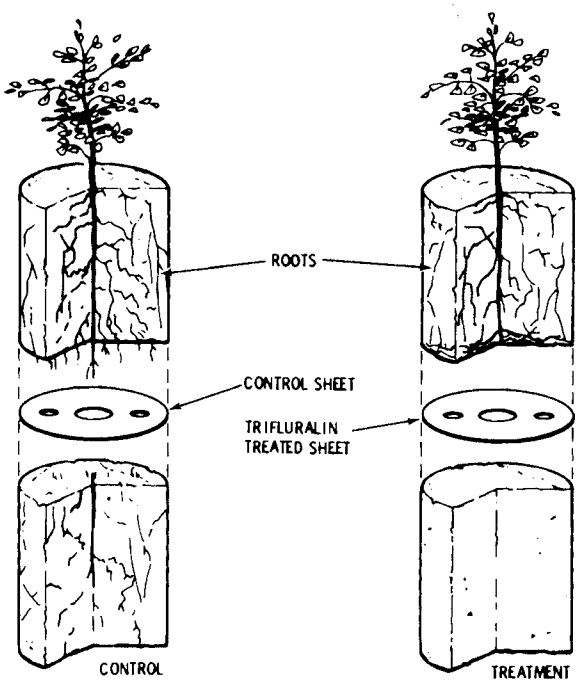


Figure 1.10. Root Growth in Control and Trifluralin-Treated Sheet-Type Polymeric Delivery Systems

Trifluralin was selected as the herbicide to be used in the development of polymeric carrier/delivery systems because it met the criteria for the prescribed root barrier. It stopped longitudinal root growth at the barrier as shown in Figure 1.10 but did not harm the remaining plant parts. Movement within the soil profile was limited to a thin layer above and below the PCD system.

Table 1.7. Results of Russian Thistle Grown in Lysimeters

	Leaves and Stems		Roots	
Herbicide	Effect	Oven Dry Wt. (g)	Penetration	Oven Dry Wt. (g)
Oryzalin	Normal green	21.1 ± 1.6	Stopped at barrier	9.2 ± 1.6
Paraquat	Normal green	25.7 ± 1.3	Grew past barrier	6.9 ± 0.4
TBA	Dead	1.4 ± 0.3	Not visible	0.4 ± 0.1
DNBP	Normal green	16.4 ± 5.0	Grew past barrier	5.9 ± 2.4
Trifluralin	Normal green	23.9 ± 2.5	Stopped at barrier	10.4 ± 1.4
Control	Normal green	25.1 ± 3.7	Throughout soil	8.1 ± 0.9

N = 3
$\bar{x}$ ± S.E.

Study of Animal Intrusion

The purpose of this study is to develop and test various barriers to burrowing rodents and invertebrates. The barriers will be designed to prevent burrowing rodents and ants from tunneling through various radon sealants used on uranium mill-tailings sites.

Eight enclosures were constructed to test the effectiveness of coarsely crushed rock as a barrier to Townsend ground squirrels (Figure 1.11). Six- and twelve-inch thicknesses of rock were tested. The asphalt sealant alone was also tested, as were controls having no barrier. Animals were placed in the enclosures and will be maintained there until February, 1981, when they again become active after the long estivation and hibernation period. At that time the enclosures will be excavated and examined for depths of tunnels and extent of penetration (if any) into the barriers.

Harvester ants also pose a threat to stabilized uranium mill-tailings and other waste management sites. Their tunnels have been excavated as deep as 8 feet (Gano 1980). The rock barriers are being tested against the tunneling abilities of this ubiquitous ant. Four complete colonies have been excavated and re-established over test barriers identical to those used for burrowing rodents.

A literature survey was conducted to investigate rodent species that may present a threat to the integrity of a radon sealant covering uranium mill tailings sites. The focus of the survey was to identify species that may be present in the vicinity of these sites and to obtain information on their burrowing strategies.

Distribution maps of small-mammal species from Hall and Kelson (1959) were used to match species with twenty priority western U-tailing sites.

This provided an initial estimate of possible species on each site. Seven small-mammal taxa, which may have to be considered in approaches to stabilizing uranium mill tailings, were identified. In order of decreasing size these taxa are 1) marmots, 2) prairies dogs, 3) ground squirrels, 4) pocket gophers, 5) kangaroo rats, 6) chipmunks, and 7) pocket mice. Although cricetid rodents (voles, deer mice and woodrats) could conceivably be important, we felt their likelihood of breaching biobarriers in a significant way is too low to warrant much attention now. Information concerning burrowing depths, habitat preference, and preferred soil types was collected and tabulated for both burrowing rodents and ants. This list is valuable in limiting the number of species of native animals that will have to be considered whenever designing barriers to protect waste management areas.

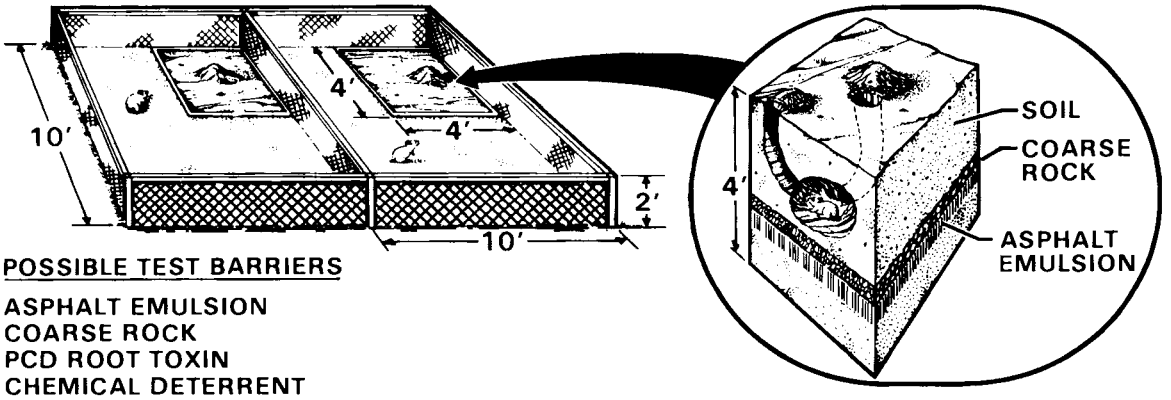


Figure 1.11. Enclosure Used to Test Burrowing Rodents Against Various Barrier Designs

• Revegetation of Inactive U-Tailing Sites *

Principal Investigators: L. L. Cadwell, N. R. Hinds,
M. C. McShane, R. H. Sauer and J. R. Skalski

Soil placed over any sealant/barrier system can provide a protective mantle if the soil is not lost by erosion. Vegetation is an attractive choice for controlling erosion because it can provide an economical self-renewing cover that serves to reduce erosion by both wind and water.

The objective of this research and development effort is to select and test vegetation strategies, including the choice of species and methods for revegetation that are compatible with sealant/barrier systems and are suited to soils and climates at inactive uranium mill tailings sites.

Test Plots

Test-plot studies initiated at Grand Junction, Colorado, will aid in the joint evaluation of selected remedial cover technologies and revegetation strategies. This inactive tailings site has been chosen for testing 1) radon sealants, 2) biological barriers for preventing animal and plant intrusion of the sealants, and 3) liners for preventing belowground migration of hazardous substances. Revegetation studies will examine the potentials for replanting on sites covered with asphalt emulsion and saturated clay sealants. Soil depth treatments over asphalt are also being investigated to determine minimum plant requirements.

The general accomplishments of this task have been to complete the experimental design for the test plot, to place contracts for constructing and planting the plot, and to initiate the earthmoving activities required for test-plot construction. Seed and soil amendments were obtained for planting the test plot. The laboratory calibration of instruments for use at the test site is also well under way.

Plant Species Selection

During FY 1980, the primary activity of the Plant Species Selection Task was to acquire data. Because many types of data are required in order to make rational decisions concerning revegetation, a computerized data retrieval system was set up to provide efficient storage and retrieval of the available information. Entries into the system are bibliographic and can be retrieved through the use of subject, author or genus keywords; dates of publication or entry on to the system; reference type (for example, report, map or article); or unique identification number. This system allows for rapid updates of the material on hand, efficient sorting and recall of all data related to the U-tailings sites, and immediate access to the amount and types of information available for each site.

Basic information on the U-tailings sites, soils surrounding the areas, and on revegetation in general have now been obtained. Contacts established with State Soil Conservation Service Offices in the vicinity of U-tailings sites provided us with soil maps as well as a list of counties for which information is presently unavailable. We are now in the process of acquiring additional sources for soils information and obtaining climatic data for the areas surrounding U-tailings sites.

One of the most useful sources of information on plant species that have revegetation potential for U-tailings sites in Colorado, Wyoming, and South Dakota has been a data base called the Plant Information Network (PIN). PIN was developed for the Western Energy and Land Use Team of the U. S. Fish and Wildlife Service by Colorado State University. It contains information on all of the vascular plant species,

*Project funded through DOE Uranium Mill Tailings Remedial Action Project Office, Albuquerque, N. M.

native or naturalized, in the states of Colorado, Wyoming, South Dakota and Montana. For many plant species, information on their geographic, taxonomic, biologic, economic and ecologic attributes has also been cataloged.

In order to use PIN, it was necessary to collect certain site-specific information. Engineering reports prepared by Ford, Bacon, and Davis for all of the U-tailings sites provided data on exact county locations and elevations for each site. This information was used by PIN to generate a preliminary list of plant species that may have revegetation potential for the U-tailings sites in Colorado, South Dakota and Wyoming. Since plant communities do not follow state boundaries, it may also be possible to use PIN to assist in choosing plants for revegetation at U-tailings sites located in other states that are in proximity to areas covered by PIN.

Climate and soils are important to consider when choosing plant species for revegetation. The Ford, Bacon and Davis engineering reports prepared for all of the sites were reviewed for specific climatic and soils data pertaining to each site. These reports provide a description of the radiological and physical characteristics of each inactive U-tailings site and a summary of the engineering alternatives available for compliance with Public Law 95-604. They are a source of useful preliminary information but are probably inadequate to characterize the inactive mill tailings sites for a specific planting selection.

Climatic and soils data will be used in conjunction with the Plant Information Network to select individual species or groups of species for revegetation trials at the U-tailings sites. At sites where PIN cannot be used, these data will be supplemented with information from available literature. At sites where existing data are minimal, field sampling will be employed when necessary prior to species selection.

2 Alaskan Resource Research

ALASKAN RESOURCE RESEARCH

- **Ecological Investigation of Alaskan Resource Development**

Ecological studies of the consequences of resource development in northern Alaska began in 1974 as part of the broader mission of the Energy Research and Development Administration. They were extensions of radiation ecology investigations initiated in 1959 for the Atomic Energy Commission and of environmental programs conducted for the petroleum industry at Prudhoe Bay from 1971 to 1973. These studies have continued under the Department of Energy to assess the true environmental cost of resource development in a previously undeveloped region of great national interest. Emphasis was initially placed on collecting baseline data on ecosystems that are or soon will be affected by petroleum resource extraction and transportation.

In our studies, we evaluated the impacts of resource development on wildlife resources and estimated that the alteration of 1.5 to 2.0 hectares of tundra habitats due to snowdrift accumulation along elevated sections of the Trans Alaska oil pipeline, plus the impoundment of surface drainage of an additional 6 hectares adjacent to buried pipeline sections, pre-empted 11 nests of 6 tundra bird species. Six of the nests would have been successful and produced 24 to 30 young birds of central importance to certain recreational activities in addition to providing future breeding stocks. The remaining five nests lost to predation would have provided 20 to 25 eggs and young birds, which are critical food items for arctic foxes and other tundra predators of significant value. This loss of 7% to 9% of the tundra-bird resource was restricted to a narrow band within the pipeline corridor. but these losses could be substantially reduced by consideration of environmental parameters defined by this research.

Quantitative information is currently being obtained on small-mammal, bird, and arctic fox populations in disturbed and control habitats to determine short-term impacts of construction, long-term impacts of operation, and mitigative procedures that may apply to future developments and to other technologies and environments.

• Ecological Investigation of Alaskan Resource Development

Principal Investigators: W. C. Hanson and L. E. Eberhardt

Technical Assistants: M. A. Combs, D. A. Garrott, R. A. Garrott, M. A. Hanson, C. J. Hohenberger, L. F. Nelson, D. P. Rudholm and M. E. Thiede

The objective of this research is to provide an integrated program for the definition of ecological consequences of resource developments in northern Alaska. The qualitative and quantitative results obtained describe the environmental costs incurred by petroleum resource extraction and transportation, including interaction of wildlife populations with industrial activities. Information is presented on affected populations of arctic foxes, small mammals, and tundra-nesting birds in the Prudhoe Bay oil field and along the Trans-Alaska Pipeline and haul road; findings from similar studies from the Colville River Delta and other affected habitats; field experiments to determine the sensitivity of lichen communities of the Brooks Range to sulfur dioxide concentrations likely to be encountered near pipeline pumping stations; and amounts of radionuclides from worldwide fallout in the lichen-caribou-Eskimo food chain.

Arctic Fox Studies

Studies were continued on arctic foxes (Alopex lagopus) in the vicinity of the Prudhoe Bay oil field. This species is the major mammalian predator of the Arctic region currently being developed for petroleum resources and represents an important source of income to resident trappers throughout the circumpolar region.

The summer diet content of arctic foxes residing in a developed area (Prudhoe Bay) were compared with those of foxes in a nearby undisturbed region (Colville River Delta). Diets were determined by analysis of prey remains found in 627 fox feces collected at Prudhoe Bay from 1975 to 1978 and 956 feces collected on the Colville River Delta from 1977 to 1978. Diets of foxes in the two areas were generally similar (Figure 2.1). As expected, a higher rate of garbage consumption by Prudhoe Bay foxes was noted. The Prudhoe Bay foxes probably ate more garbage than indicated by this method of analysis because most garbage consisted of processed food (e.g., pastries and sandwiches) that was digested completely with relatively few remains showing up in feces. University of Alaska subcontracted studies recorded a 23% occurrence of garbage in the feces of a fox family that lived under a large personnel camp at Prudhoe Bay and consumed large amounts of garbage food items.

Thirty-five arctic foxes were radio-collared and followed in the vicinity of the Prudhoe Bay oil field from October 1979 through May 1980. Arctic foxes dispersed both in the fall and in the late winter to early spring. Most juvenile foxes remained on their natal home ranges through at least January and relatively few participated in the fall dispersal. The late winter-early spring dispersal involved a larger proportion of marked animals and may be related to breeding activities. Arctic fox use of the Prudhoe Bay area and its associated garbage and handout food sources reached a peak in December, when large numbers of foxes were common around dumps and other facilities related to petroleum development. However, individual foxes appeared to use well-defined areas and did not move freely between garbage sources within the Prudhoe Bay area.

Pennsylvania State University investigators analyzed blood chemistry profiles and liver cytochemical parameters of captive arctic foxes fed protein-sufficient and protein-deficient diets. Foxes fed protein-deficient diets showed a decrease in serum

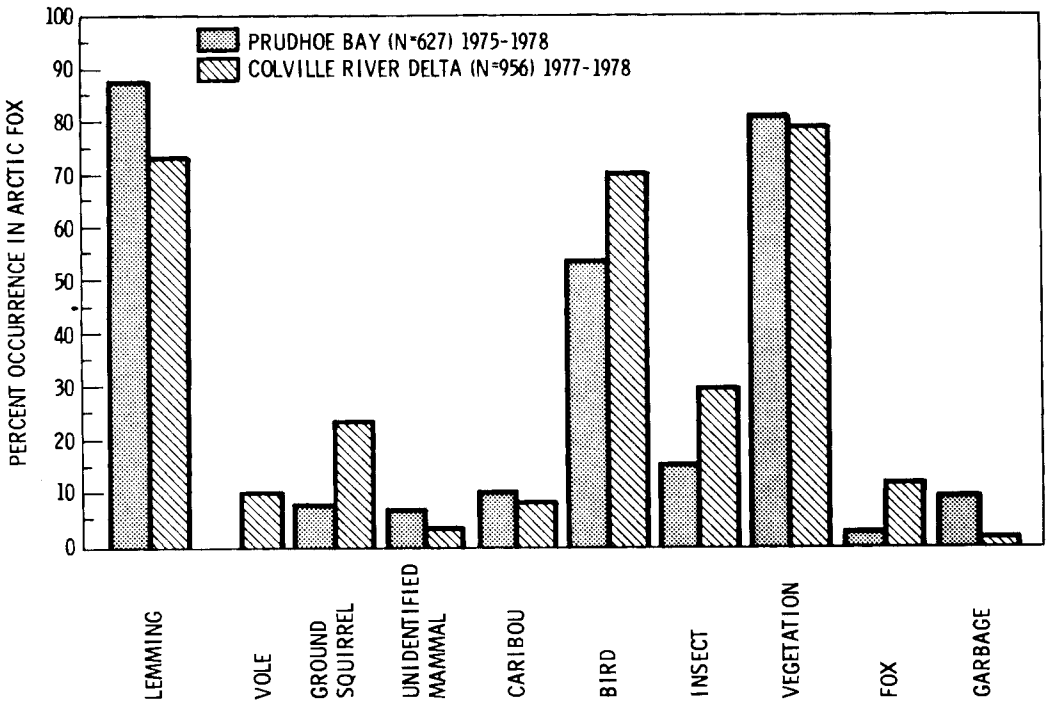


Figure 2.1. Dietary Components Recorded in Arctic Fox Feces Collected at Study Sites in Petroleum Resource Development Area (Prudhoe Bay) and Control Area (Colville River Delta)

urea nitrogen levels and in hepatocyte ribonucleic acid and protein contents. Results from this investigation demonstrate the feasibility of using blood chemical and tissue histochemical analyses to examine fox health. These studies may be expanded in the future to examine specifically some of the health effects of garbage consumption by arctic foxes.

Small-Mammal Studies

Population densities of small mammals at Franklin Bluffs and Trans-Alaska Pipeline Mile 12 were again estimated by capture-mark-recapture techniques. Totals of 5,940 and 5,580 trap-nights of effort were made at 10 grids of 0.5625-ha each at both sites. Eight small mammals were captured at Franklin Bluffs and 13 were captured at Mile 12 (Table 2.1), indicating that population densities were about the same as last year at Mile 12 and had declined at Franklin Bluffs. The low populations of these important food items for arctic and red foxes did not result in increased predation of nesting tundra birds at the Mile 12 site, as observed last year, but apparently contributed to the 50% nest mortality at Franklin Bluffs site.

Nine singing voles (Microtus miurus) were radio-tracked for periods of 5 to 11 days during August on the Franklin Bluffs study plot. The purposes of this investigation were to evaluate the effects of the Trans-Alaska Pipeline on small-mammal movements and to gather information on the ecology of small mammals in this region. The original intent was to study lemmings (Dicrostonyx groenlandicus and Lemmus trimucronatus); however, due to low population densities of these species, emphasis was switched to singing voles. Home range and activity data are being analyzed; tentative conclusions drawn are that: 1) voles extensively use the Trans-Alaska pipeline pad and service roads where revegetation efforts have produced dense stands of grasses, 2) the pipeline pad and service roads did not present an impenetrable barrier to vole movements, 3) bred females tend to have smaller home ranges than either nonbred females or males, 4) female home ranges overlap, and 5) voles tend to be active throughout the day, although periods of hot weather reduce activity.

Tundra-Nesting Bird Studies

A late spring season following heavy snowfall periods and a cool summer with persistent northeast winds, low clouds and fog combined to delay by 7 to 10 days the nesting of tundra birds in the study areas at Franklin Bluffs and Trans-Alaska Pipeline

Table 2.1. Small Mammals Captured at Franklin Bluffs and Trans-Alaska Pipeline Mile 12 from July 9 to August 24, 1980

Site	Tundra Vole[a]	Singing Vole[b]	Varying Lemming[c]	Brown Lemming[d]	Population Density (Animals/ha)
Franklin Bluffs	1	4	3	0	1.2
Mile 12	9	0	3	1	3.5

[a]*Microtus oceonomus*
[b]*Microtus miurus*
[c]*Dicrostonyx groenlandicus*
[d]*Lemmus trimucronatus*

Mile 12. Nesting densities (nests per 100 ha) of 15 species were 13% and 20% greater than in 1979 at the two sites (Table 2.2). Weather and snow cover conditions were similar to those observed during 1976 at Franklin Bluffs, but nesting densities of breeding birds were three times greater during this past season (Table 2.3).

The "snow fence effect" of the elevated portion of the oil pipeline within the Mile 12 site affected nesting densities more this year than in 1979. Deep snowdrifts persisted until late June in a band that measured 200 m wide on the west (downwind) side of the pipeline and 80 m wide on the east (upwind) side. As illustrated by the placement of the 136 nests found in the Mile 12 environs (Figure 2.2), the snow fence effect denied suitable nesting habitat to the immigrating birds. A further impact resulted from the impoundment of the snowmelt by the pipeline road and pipeline pad that extended across the natural drainage of the tundra, particularly in the northwest quadrant of the study area. The accumulation of snow and water on the east side of the buried portion of the pipeline prevented nesting birds from using about six ha of habitat available to them during 1979.

Distribution and density of nests at the Franklin Bluffs study site were similar to those of 1979; the only major change was an increase in numbers of pectoral sandpiper nests, particularly in the area west of the haul road (Figure 2.3). More nesting birds appeared to adjust to the wet habitat

Table 2.2. Comparison of Tundra-Breeding Bird Densities in Wet Coastal Tundra (Trans-Alaska Pipeline Mile 12) and Inland Coastal Tundra (Franklin Bluffs) Habitats During 1979 and 1980

	Nests per 100 ha			
	Wet Coastal Tundra		Inland Coastal Tundra	
Species	1979	1980	1979	1980
Arctic Loon	3	3	0	0
White-Fronted Goose	2	2	1	1
Willow Ptarmigan	2	1	1	4
Rock Ptarmigan	0	0	1	5
American Golden Plover	1	2	11	13
Pectoral Sandpiper	30	37	1	8
Northern Phalarope	5	10	2	2
Red Phalarope	5	3	0	0
Buff-Breasted Sandpiper	0	0	5	7
Bar-Tailed Godwit	0	0	3	3
Long-Billed Dowitcher	1	3	0	0
Semipalmated Sandpiper	22	36	2	1
Dunlin	6	4	0	0
Stilt Sandpiper	3	5	1	2
Lapland Longspur	45	44	26	25
Totals	125	150	54	71

Table 2.3. Nesting Densities of Breeding Birds During the Period 1976-1980 at Franklin Bluffs Study Site, Northern Alaska

Species	Nests per 100 ha				
	1976	1977	1978	1979	1980
American Golden Plover	5	5	7	11	13
Pectoral Sandpiper	0	8	2	1	8
Buff-Breasted Sandpiper	1	6	10	5	7
Long-Billed Dowitcher	2	2	0	0	0
Semipalmated Sandpiper	2	6	2	2	1
Redpoll	2	1	0	1	0
Lapland Longspur	8	14	18	26	25
Other	2	3	12	16	17
Totals	22	45	51	62	71

conditions imposed by the impoundment of natural drainage caused by the haul road. Several species, particularly American Golden Plovers, have now adapted to the disturbed habitat along the buried oil pipeline that traverses the Franklin Bluffs site.

Bird-banding efforts placed 670 new marked birds into the populations at Franklin Bluffs, Mile 12, and Prudhoe Bay. Of these, about 30% were adults captured on nests and 70% were fledglings from those nests. Color marks were coordinated within family groups, and family movements to feeding areas were documented. The returns of 55 birds banded in previous years provided information on pair fidelity, nest site tenacity, and population dynamics. A semipalmated sandpiper recaptured at Prudhoe Bay for the fifth time in eight years has continued to nest within a 1-ha area and has remained mated to the same bird after losing her original mate. Other band recoveries have shown that the wintering ground for these sandpipers is in northeastern South America. These data verify that the preference of tundra-nesting birds for certain critical habitats and their behavioral patterns may be affected by resource developments, and it also illustrates the appreciable geographic range of the birds affected.

Lichen Studies

Arizona State University subcontractors completed studies on photosynthetic patterns and sulfur dioxide sensitivity of Cladonia-Cetraria lichen communities at Anaktuvuk Pass and initiated new research on photosynthetic and nitrogen fixation activity of Stereocaulon alpinum, an important lichen occurring in mature and successsional upland tundra mats. Approximately 1500 nitrogen fixation samples and 1700 photosynthetic (^{14}C) samples were collected and returned to the laboratory for analysis. These studies are important because they define the critical parameters in biological nitrogen fixation in arctic ecosystems and determine the implications of an ecosystem's sensitivity to sulfur dioxide. These data will compliment past studies that have shown that atmospheric concentrations of 0.5- to 1.0-ppm SO_2 are sufficient to interdict photosynthetic capability in tundra lichens. These lichens, which are important winter foods of caribou, show no apparent recovery two years after fumigation.

Radiation Ecology Studies

Cesium-137 concentrations in Anaktuvuk Pass Eskimo adults during February were 0.80 ± 0.39 (S.D., n=59) nCi/kg, essentially the same as one year ago and 50% greater than average values measured during June, 1979. This reversal of seasonal pattern from that documented during the previous 15 years of study resulted from continued restriction of caribou meat consumption due to hunting regulations and constant employment in village construction activities. Current radiation exposures to Anaktuvuk Pass adults from worldwide ^{137}Cs fallout obtained from caribou meat in their diet average about 10 mrem above background, which is about one-fifteenth that received from the relatively high body-burdens observed during the years (1964 through 1966) of maximum fallout deposition and greater dependency upon caribou for food.

As a result of these cultural changes, the emphasis of study has changed to determination of transuranic elements in the basic elements of the arctic ecosystems. Whole-body counting of the Eskimo residents was terminated and sampling of carnivores discontinued because of the drastically reduced caribou harvest. Samples of surface soils and lichens were obtained at long-term

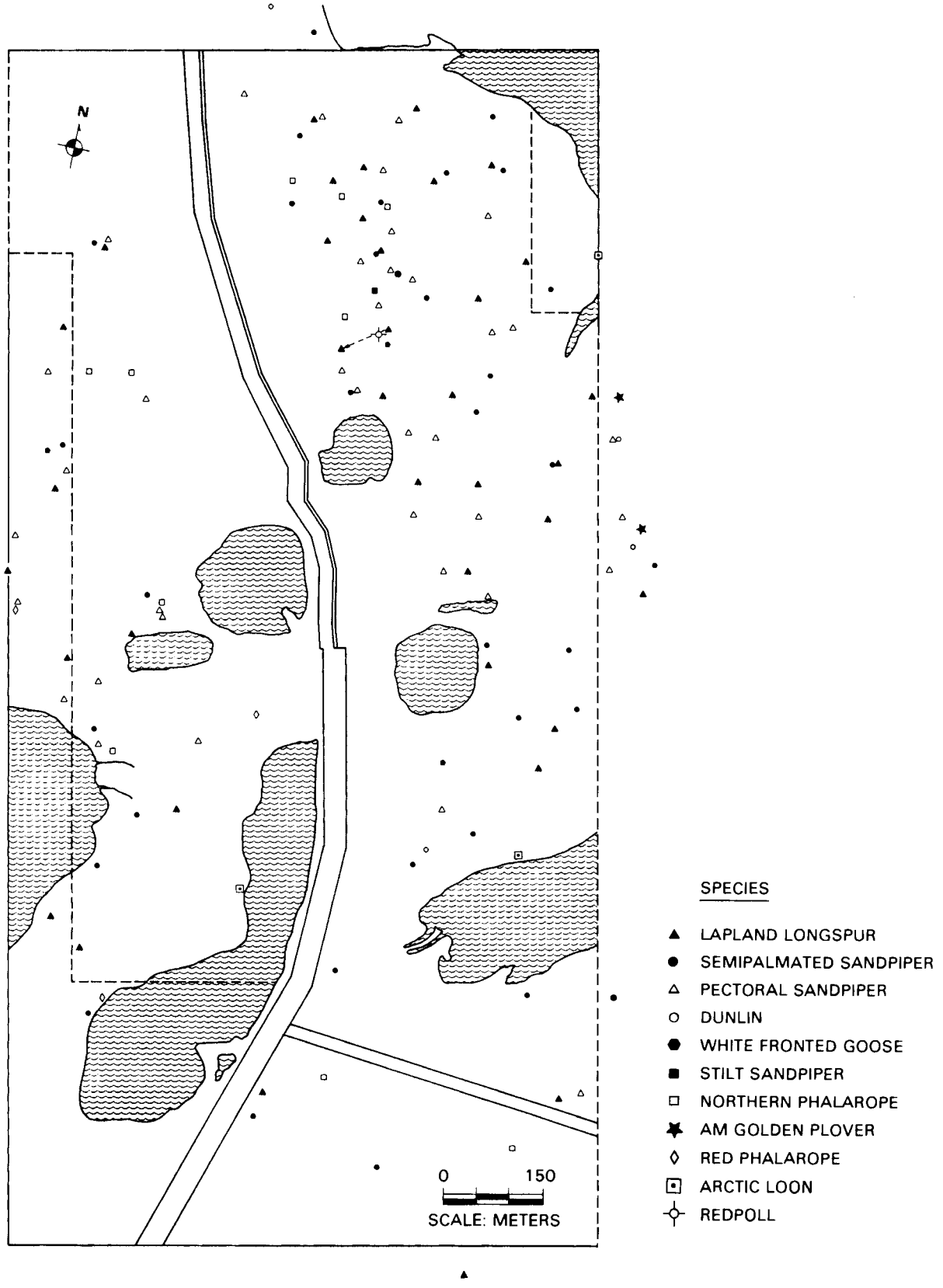


Figure 2.2. Nest Locations of Tundra Bird Species During 1980 at Trans-Alaska Pipeline Mile 12, Northern Alaska

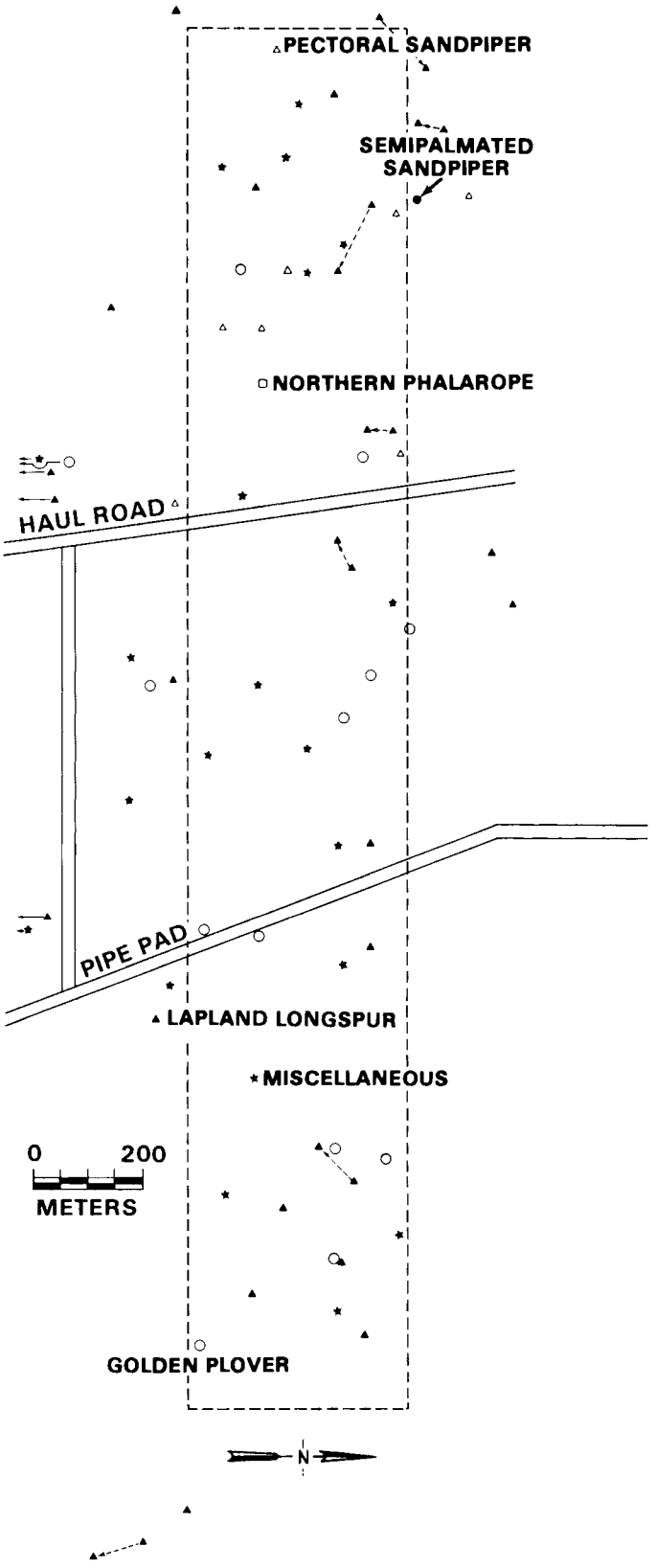


Figure 2.3. Nest Locations of Tundra Bird Species During 1980 at Franklin Bluffs, Northern Alaska

sites and returned to the laboratory for separation and radionuclide analysis. Comparable soil and lichen samples were collected at Thule, Greenland, sites during August, 1979, and processed for radiochemical analyses to describe the behavior of transuranic elements in the Alaska and Greenland environments.

3 Shale Oil

SHALE OIL

• Terrestrial Effects of Oil Shale Development

Vast domestic resources of oil shale may provide a long-term alternative to petroleum-derived fuel products. Methods proposed for obtaining shale oil from its deposits range from conventional mining and aboveground retorting technologies to *in situ* retorting. The technological and economical aspects of this wide range of options are currently under intensive study. The environmental impacts must also be assessed because questions of siting, control technology, licensing and regulation can strongly affect the best production strategy.

Three major segments of the aboveground shale oil production cycle may potentially produce environmental consequences. These include mining of the shale, extraction of the shale oil, and disposal of processed shale. In the mining process, aquifer disruption, runoff and movement of raw shale residuals through the soil and substrate to ground waters may affect streams and rivers. During the extraction cycle (crushing, retorting and refining), the major impact will result from gaseous emissions and liquid effluents containing organic, macro-ion, and trace metal residues. Disposal of retorted shale presents problems in loss of recreation land, in reclamation of land occupied by retorted shale, and in environmental and human exposure resulting from resuspension of particulates and leaching of pollutants to ground and surface waters. The nature of the shale and the use of pyrolytic methods can lead to the formation of reduced sulfur and the solubilization of other species, heterocyclic nitrogen components, which might possibly result in environmental problems not ordinarily encountered in other energy industries.

The laboratory-wide PNL program currently focuses on the chemical characterization of effluent residuals (see PNL-3700, Part 4, Physical and Technological Programs), the potential toxicity of effluent residuals (see PNL-3700, Part 1, Biomedical Sciences), and the chemical and microbiological processes governing the fate, mobilization and plant uptake of inorganic residuals (this report). Supporting research on the feasibility of revegetation in arid climates and research on the application of a water-harvesting approach are described in the Land Use section of this report. Work reported in this part of the PNL report concerns soil fate of shale oil and shale residuals.

The laboratory and field studies below concern chemical and biochemical transformations in retorted shales and soils and their relationship to water quality, viability of green plants, and human food chains. This is a multitask, interdisciplinary research approach which draws upon PNL capabilities in organic chemistry, soil science, microbiology, geochemical modeling, hydrology and plant physiology. The principal objectives of the project are to 1) develop a basic knowledge of important environmental and extraction processes influencing the form, mobility, chemical and microbiological stability, plant availability, and toxicity of trace elements and organic residuals in retort waters and retorted shales, 2) model and validate, through field

monitoring, the movement to ground water of trace elements and stable organic residuals in soil and retorted shale, and 3) develop a rational basis for the selection and subsequent laboratory and field testing of proper retort conditions/soil conditioners, irrigation waters, and native or agricultural plant species that might be used to physiochemically stabilize and revegetate retorted shales for the permanent and safe restoration of shale lands.

The studies are being closely integrated with field investigations by other federal agencies and universities. Together, these programs should provide a basis for assessment of the potential terrestrial effects of waste disposal and for viable restoration of shale lands.

• Terrestrial Effects of Oil Shale Development

Principal Investigators: R. E. Wildung, T. R. Garland, J. M. Zachara, R. G. Riley, J. E. Rogers, D. A. Cataldo, E. A. Jenne, L. L. Ames, S. W. Li, K. M. McFadden and L. Neil

The potential development of the oil shale industry requires the concomitant development of methodology to evaluate and ameliorate the environmental impact of ground disposal of wastes. Therefore, our research programs have emphasized 1) development of sampling protocols with industry, collection of samples from a range of retort processes, and physicochemical characterization of retort waters, retorted shales, retorted shale leachates, ground waters and soils of the oil shale region, 2) column and field studies to determine the chemistry and microbiology controlling the composition of leachates from retorted shale, 3) the hydrologic factors governing transport to ground waters, 4) validation and modeling of the chemical reactions and movement of inorganic and organic residuals to ground and surface waters principally at aboveground retorting sites, 5) the plant availability and effects of organic and inorganic residuals in retorted shale and retort waters, and 6) genetic selection of native plant species tolerant to effects over the long term.

Field studies of the stability and movement of trace metals and organic residuals in retorted shale have been underway since 1977 at the Department of Energy's Rifle Oil Shale Facility, operated by Development Engineering, Inc. at Anvil Points, Colorado, the Occidental Oil Shale Corporation Site at Logan Wash, Colorado and in the Piceance Creek Basin, Colorado, in conjunction with Colorado State University. Similar studies have been initiated in Tract C-a in Colorado. The results of these investigations will be used to validate laboratory models of the mobility to surface and alluvial aquifers of residuals arising from above-ground retorting and waste disposal in the oil shale region. The results of laboratory and field studies have led to new concepts of the long-term nature of leachates from retorted shales.

The program has provided technical and administrative support to current programs in integrated assessment of oil shale development, assessment by the National Academy of Sciences of redistribution of accessory minerals as a result of mining and extraction of oil shale, the Oil Shale Environmental Development Plan, Oil Shale Commercialization Environmental Readiness Document and to the DOE Task Force on Oil Shale Development.

Effects of Retorted Shale Disposal on Water Quality-Rifle Oil Shale Facility

Percolates have been collected over a four-year period from lysimeters at Anvil Points, Colorado, and in nonirrigated field plots containing Paraho retorted shale in the Piceance Creek Basin, also in Colorado. These were analyzed for major cations, anions, trace elements and dissolved organic carbon, providing definitive information on the chemical and microbiological effects of weathering on leachate composition. Hydrologic evaluations have been conducted to augment these ongoing chemical and microbiological studies and to provide a basis for evaluation of effects of disposal on surface and ground waters.

In the study area is an intermittent stream (West Sharrard Drainage) that flows at the bottom of a canyon. The retorted shale and raw shale fines have been disposed in this canyon since the research on

retorting methods was begun by the U.S. Bureau of Mines in the 1940's (Figure 3.1).

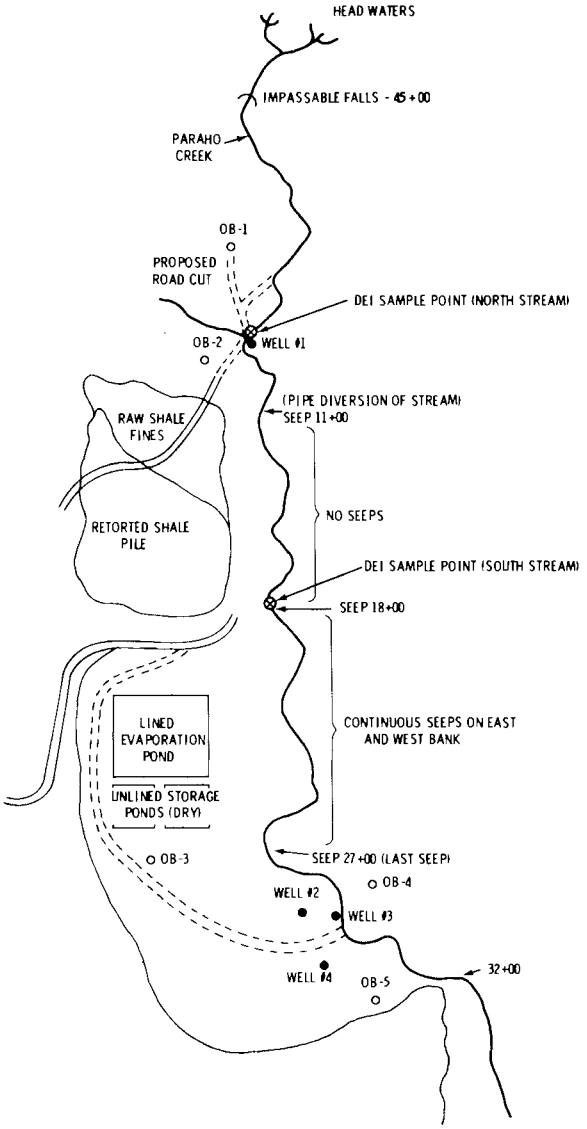


Figure 3.1. Oil Shale Field Study Area

Existing wells in the canyon above and below the disposal site were used to measure the quality of the ground water. Quarterly sampling of both the stream and the wells, and subsequent analysis of the waters, has been conducted since mid-1974 by Development Engineering, Inc. These analyses indicated that the presence of the pile had little or no effect on stream quality.

Lysimeter studies conducted by PNL indicated that chemical equilibrium between water and the disposed shale is a slow process (requiring longer than four years) and that major changes occurred in the composition of percolates as a function of the applied water volume and the water residence time in the shale.

Sodium and most of the other elements that have been measured, initially exit the retorted shale in a pulse, with subsequent releases on a more moderate scale (Figure 3.2).

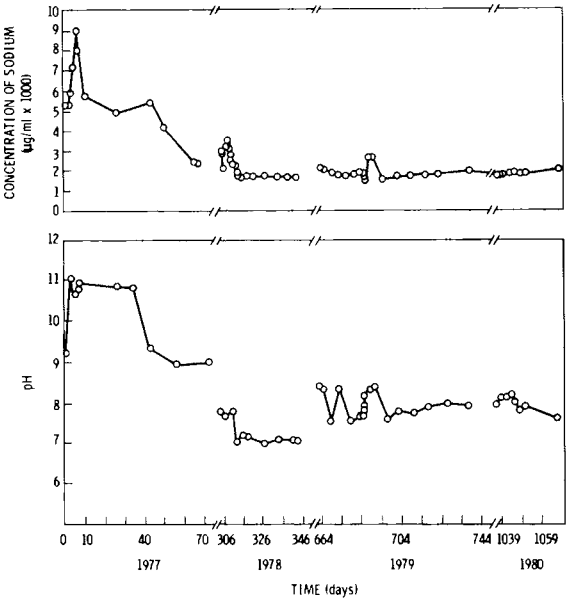


Figure 3.2. The pH and Sodium Concentration of Leachates from Retorted Shale in Field Lysimeters

The major sodium peak in the first ten days (approximately 1/4 column volume of water), results from displacement of readily soluble salts. This represents a short-term effect that may be dealt with. For example, interception and/or treatment of this material would be the first goal of a pollution-control program. The system, however is highly complex. The sodium concentration in the retorted shale decreased from 9,000 to 3,000 µg/ml through the first year (0.7 column volume of water). Over the past four years (and after approximately one column volume of water had passed through the retorted shale), the sodium concentration has been maintained at approximately 2,000 µg/ml. This is due to dissolution of minerals in the retorted shale.

The pH of the leachate (Figure 3.2) is a further example of the complexity of the

system. A relatively high pH of approximately 10-11 was maintained for most of the first year. Following the winter season, the pH had dropped to approximately 7, which, from a water-quality standpoint, is a more desirable level. The pH drop was due to weathering alone, primarily by the oxidation of reduced sulfur species, and was independent of leach-water volume. Subsequent studies in the laboratory designed to simulate the weathering reactions in soil columns attributed this change, at least in part, to oxidation of reduced S species.

Trace elements that are elevated in retorted shale leachates include Li, Mo, F, and arsenic. Macroions of Na, K, Ca, Mg, and chloride were elevated along with sulfates, thiosulfates and, at times, organic carbon. Lysimeter percolates contained markedly elevated Li contents. This was an accurate indicator that waters were leaching a zone of retorted shale. Lithium was present in concentrations that were 50 to 500 times greater than in the concentrations of Li found in leachates from the surrounding soils. These observations were verified at the field disposal site. Well waters below the pile contained higher Li concentrations than did well water above the pile, indicating that the ground water contained retorted shale leachates.

It is clear that as weathering of the pile progresses, a succession of chemical and microbiological changes will occur in response to accompanying changes in the physical and chemical environment of the pile. The long-term effects of these changes on the composition of the retorted shale leachate may be illustrated by examining sulfate and carbonate, the predominant anions in the leachates (Figure 3.3).

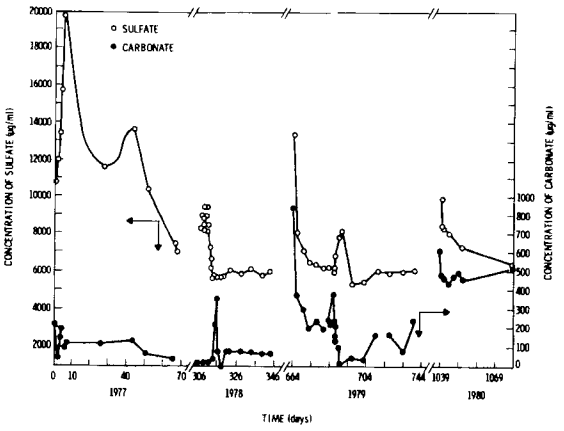


Figure 3.3. Sulfate and Carbonate Concentrations of Leachate from Retorted Shale in Field Lysimeters

In 1977, the sulfate curve (Figure 3.3) followed the sodium curve (Figure 3.2) when low levels of carbonate were present. However, in each succeeding year, the proportion of carbonate to sulfate increased. This is a strong indication that the entire chemistry of the pile is changing. Soluble sulfate and other minerals that supply sulfate to the solution are being depleted with time, whereas those supplying carbonate are beginning to dissolve. Thus, the pile, substrata, and waters beneath the pile, may not achieve steady state for many years after disposal, which highly complicates predictions of impact on water quality.

During the winter of 1978 and 1979, contact of heated retorted shale with raw shale fines resulted in a fire and initiated retorting in the fines pile at the Anvil Points Site. The heavy snowfall that winter resulted in an above-normal quantity of water in the pile as the snow melted. Water and some oil flowed from the pile into the creek. Sediment samples taken from the head-waters to the mouth of West Sharrard Drainage were found to contain significant and consistent levels of hydrocarbons. However, the major source was not the oil from the pile but the normal background of raw-shale fines that were present in the sediments from the natural weathering of the watershed. Further identification of a series of water-soluble alkyl pyridines specific to the product oil has facilitated the differentiation of product oil in the waters from background levels as a result of the fire.

A knowledge of the chemistry and geochemistry of the site can be used effectively when it is integrated with an understanding of the effect of surface hydrology on stream water quality.

In Figure 3.4, conductivity of the water in the surface stream in the West Sharrard Drainage is shown as a function of stream bed distance above and below the retorted shale pile. The shale pile is located at stream-bed distance of approximately 1800 ft.

Because of dilution, samples taken in the morning and afternoon of July 22, 1979, show major differences in conductivity. The highest conductivities were measured in the p.m. when the flow rate of the stream was 28 L/min as compared to the a.m. when the flow rate was 71 L/min; in June, the flow rate was 179 L/min.

Further hydrologic studies indicated that the stream flow at this site was governed by the transpirational demand of the vegetation in the watershed upstream from the

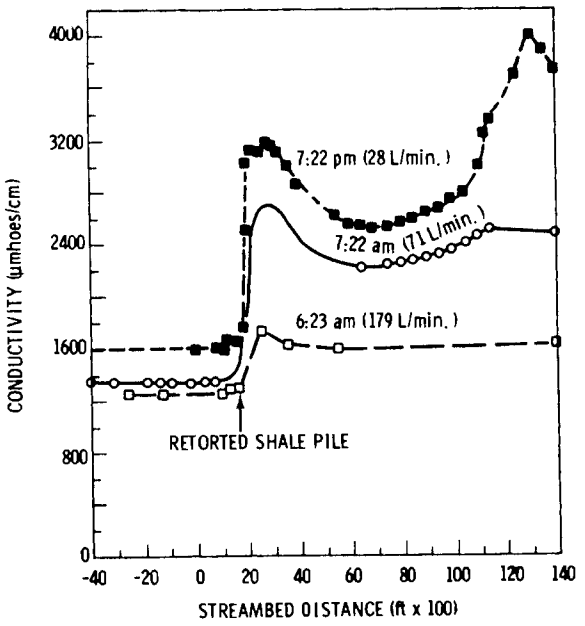


Figure 3.4. Relationship of Stream Flow to Conductivity in the West Sharrard Drainage

pile. The use of water was greatest during daylight hours when maximum vegetational growth was occurring. This markedly reduced stream flow by afternoon.

It is clear that the hydrology and geochemistry of these systems are intimately related and that a single water sample taken above and below the pile might result in a serious misjudgment of the impact that the pile has on stream water quality. Studies of this type are continuing at this site to define the effects of long-term weathering of the pile on water quality. Similar studies have been initiated at the proposed above-ground retorting site on Tract C-a.

Effect of Retorted Shale Disposal on Water Quality in Tract C-a

An integrated field-and-laboratory research program was initiated on the Rio Blanco Site (Tract C-a) in the Piceance Creek basin of Colorado. These studies are designed to evaluate the effects of raw-shale storage, mine dewatering, and future surface retorting on the chemical regime of local surface and groundwaters. The three-year project will include: 1) routine hydrologic sampling of surface waters, alluvial groundwaters, and seep waters in prominent gulches traversing the tract; 2) evaluation of chemical changes that occur as chemically-reduced groundwaters (brought to the surface by mine dewatering) are re-injected or discharged to surface waters, 3) participation in cooperative studies with the United States Geological Survey to define chemical and microbiological interactions occurring in development-scale raw-shale piles, and 4) laboratory studies designed to investigate the mechanisms governing the composition of waters which have contacted local soils, subsoil, and raw and retorted shale. Field and laboratory studies will be integrated through the use of chemical modeling techniques designed to evaluate mineralogic controls on leachate or water (ground, surface, or seep) composition and to assess later chemical changes which may occur in leachates or as a result of mixing waters of different origins.

Hydrologic field sampling efforts began in April, 1980. Preliminary results indicate that surface waters are of relatively low conductivity (≈1,100 μmhoes) for the Piceance Creek basin, and are predominantly Na/Ca/Mg - HCO_3/SO_4 systems. Surface waters show little enrichment in trace elements, contain dissolved organic carbon leads of 20 to 40 ppm, and are primarily fed by seepage from perched water or the upper oil shale aquifer. Stream flows across the tract are intermittent. Infiltration into alluvium appears to be controlled by bedrock fractures that allow direct recharge to bedrock aquifers. Chemically-reduced mine waters undergo rapid oxidation when discharged to surface waters. Dissolved sulfide (210 to 220 ppm to total S^{2-}) oxidizes to form thiosulfate (6 to 9 ppm) and elemental sulfur, thus rendering surface waters milky in appearance. No appreciable pH change was noted. These effects are not pronounced within three miles of the site as a result of continued oxidation, further dilution, and infiltration. Some reinjected mine waters return to surface waters via bedrock fractures and continuity with alluvium to create increased streamflow with higher conductivity levels (1,700 to 2,000 μmhoes) and higher levels of B, Na, and Ca (0.237, 196, and 96 ppm, respectively).

4 Synfuels

SYNFUELS

- **Ecological Effects of Coal Conversion (SRC-II)**
- **Toxicology of SRC-I Materials**

In his May 1977 environmental message, the President of the United States declared a national commitment to reducing reliance on foreign oil by increasing use of our own vast coal reserves. He admonished, however, that we were to do this in a way that protects the quality of our environment. To meet this challenge, government and industry entered into an unprecedented series of cooperative efforts to develop new energy technologies. Their purpose is to convert coal to oil substitutes and alternate fuels that burn more cleanly than their parent coals. Among these coal conversion technologies are those in which slurried coal is subjected to high heat and pressure, causing the coal to liquefy.

Of the three most promising coal liquefaction technologies, Solvent Refined Coal (SRC), H-Coal, and Donor Solvent, SRC is expected to reach the demonstration stage of development first. Design of demonstration facilities will derive partly from experience gained at a 50-ton-per-day SRC pilot plant at Fort Lewis, Washington. The demonstration plant will be located near Morgantown, West Virginia, and Newman, Kentucky, where site evaluations are in progress under the cognizance of DOE's Oak Ridge Operations Office.

The work described herein is Pacific Northwest Laboratory's (PNL) part of a larger research program on coal synfuels being implemented by DOE. To allow us to obtain maximum return on investment over the whole program, the ecological characterization task is being coordinated with complementary programs in other departments in PNL and at the Oak Ridge National Laboratory.

During FY 1979, PNL was asked by the Assistant Secretary of Environment (ASEV) to develop a comprehensive plan for research needed to assure the environmental safety of an SRC technology. The result was a six-year research plan involving four PNL research departments. The various departmental responsibilities include acquisition, characterization and disbursal of test materials (Physical Sciences Department), biomedical research (Biology Department), ecological research (Ecological Sciences Department) and atmospheric monitoring (Atmospheric Sciences Department). Research recommendations as they apply to the SRC-II process were forwarded by Dr. Harvey Drucker, PNL's program coordinator, in October, 1980, to ASEV for DOE implementation:

Solvent Refined Coal-II (SRC-II) Detailed Environmental Plan, October, 1980. PNL-3517.

A similar document describing environmental research that will aid in the development of the SRC-I process will be completed in January, 1981.

The PNL research program was expanded in FY 1979 to include evaluation of the most likely avenues of environmental change from solvent refining of coal, with particular reference to the Morgantown location. An important element of this expansion was identification of the source materials and variations of source materials needing generic ecological investigation. This required increased collaboration with technology developers and coordination through DOE's Committee on Coal Liquefaction and Commercialization. In FY 1980, the PNL program was again expanded to include consideration of the fate of SRC-I materials in the environment. Initial efforts have focused on the characterization of the physicochemical interactions that govern the fate of SRC-I materials in the terrestrial environment at the Newman site.

- **Ecological Effects of Coal Conversion (SRC-II)**

- **Toxicology of SRC-I Materials***

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Synfuels ecological research tasks are organized under aquatic, terrestrial, and chemical studies. Aquatic Studies are further subdivided into acute, chronic, and ecosystems-level studies, including an interlaboratory comparison. The rationale, methods, and results of each task are briefly described.

Acute Screening of Solvent Refined Coal Materials

Laboratory test procedures were developed and applied to measure the acute toxicity to selected aquatic organisms of water-soluble fractions (WSF) derived from a Solvent Refined Coal (SRC-II) liquid and other complex organic synfuel mixtures. Initially, we examined the effects of mixing intensity, aeration, filtration and settling time on chemical and biological characteristics of stock solutions. Aeration and filtration reduced toxicity of fast-blended solutions but not of slow-mixed solutions; the latter method was chosen as the standard for preparing stock solutions containing SRC-II WSF.

Acute tests to determine the effect of water quality (hardness, pH, temperature) on the toxicity of WSF to fathead minnow, daphnids, and midge larvae were completed. Response of test organisms were generally variable in successive tests. This complicated the task of analysis and assessment, which is still in the preliminary stage. The concepts of "lowest rejected concentration tested" and "dilution index" were developed and applied to support median lethal concentration (LC_{50}) data in statistical analysis. Studies were initiated on the effects of WSF on fathead minnow eggs during embryonic development and hatching.

Detailed research findings on acute screening are reported in our Annual Report for 1980 on Interagency/Contract Research, Ecological Sciences Department, (B. E. Vaughan, ed.).

Chronic Effects of Solvent Refined Coal Materials

This task evaluates potential sublethal and chronic effects of Solvent Refined Coal (SRC-II) liquid materials on selected life stages of representative groups of freshwater aquatic organisms. Test organisms include benthic macro-invertebrates (Chironomus tentans and Tanytarsus dissimilis), a zooplankton (Daphnia magna), a green algae (Selenastrum capricornutum) and two fish species, Pimephales promelas and Salmo gairdneri. All studies were conducted using a 2.9 to 1 middle-to-heavy blend of SRC-II distillates from the pilot plant in Fort Lewis, Washington.

*This is a separately funded work agreement sponsored by the Office of the Assistant Secretary for Energy Technology and this portion of the synfuels research project is supported by the EPA.

Because of rapid leaching and dilution of highly soluble SRC-II components, solutions used in acute toxicity tests may not be representative of those to which organisms would be chronically exposed following accidental discharge or spill. Therefore, we characterized chemical compounds in water-soluble fractions (WSF) after initial contact of SRC-II with water and also compounds that might be expected to persist in the aquatic environment over longer duration. Biological effects reflecting the change in chemical composition of the WSF were assessed by exposing test organisms to an initial-contact WSF and a WSF derived from extensively water-leached SRC-II (weathered WSF). Both WSF were complex mixtures of phenols and saturate and aromatic hydrocarbons (Table 4.1). Total phenolics accounted for about 80% of the TOC in the initial WSF and about 50% in the weathered WSF. However, the total organic carbon (TOC) in the initial WSF was about ten times that of the weathered WSF. Readily watersoluble lower molecular weight phenols predominated in the initial WSF, leaving higher molecular weight compounds with relatively lower solubility in the weathered WSF.

Our results suggest that the weathered WSF is more toxic than the initial WSF when equal concentrations of organic carbon or phenol are present (Table 4.2). The greatest difference was noted for the two benthic invertebrates Chironomus tentans and Tanytarsus disimilis. Although growth and survival of chironomids was inhibited at more dilute concentrations of the initial WSF on a total carbon or phenol basis, the weathered WSF was 3 to 9 times more toxic than the initial WSF. Toxicity trends for D. magna indicated that the initial WSF was more toxic than the weathered WSF when solutions in static tests were changed three times a week. Although initial response of algal populations to the two WSF was similar in the 5-day exposure period, the ability of algal populations to recover to normal levels was suppressed to a greater extent in weathered WSF solutions.

Table 4.1. Phenol and Aromatic Hydrocarbon Composition in "Fresh" and "Weathered" Water-Soluble Fractions Used for *Tanytarsus* Life-cycle Test

	% of TOC in WSF		% of Total Phenols in WSF	
Phenols	Initial	Weathered	Initial	Weathered
Phenol	11.7	<0.1	14.5	<0.1
Cresols	27.7	0.6	34.5	1.3
C_2 Phenols	21.9	6.6	27.3	14.2
C_3 Phenols	7.8	13.0	9.8	27.8
C_4 Phenols	2.8	11.2	3.5	23.9
Indanols	4.3	3.4	5.4	7.4
C_1 Indanols	2.9	7.9	3.6	17.0
C_5 Phenols	0.2	0.4	0.2	0.8
C_2 Indanols	0.9	3.6	1.1	7.6
Total Phenols	80.2	46.7		
	% of TOC in WSF		% of Total Aromatics in WSF	
Aromatics	Initial	Weathered	Initial	Weathered
C_2 Benzenes	0.1	<0.1	3.4	<1.9
C_3 Benzenes	0.1	<0.2	3.4	<3.8
C_4 Benzenes	0.1	0.2	6.3	5.8
Indan	0.1	0.2	3.4	3.8
Tetralin	0.1	0.4	6.3	9.6
Naphthalene	0.2	1.2	14.3	30.8
$C_{5,6}$ Benzenes / C_1 Tetralins	0.4	0.9	22.3	23.0
C_1 Naphthalenes	0.2	0.9	12.6	23.1
C_2 Naphthalenes	0.1	0.2	6.3	3.8
C_3 Naphthalenes / $C_{1,2}$ Flourenes	0.3	0.1	16.0	1.9
Phenanthrene	trace	0.1	2.9	1.9
C_1 Phenanthrenes	trace	<0.1	1.7	<1.9
Flouranthrene	trace	<0.1	0.6	<1.9
Pyrene	trace	<0.2	1.4	<5.7
Total Aromatics	1.7	4.0		

Table 4.2. Toxicity of Initial and Weathered Water-Soluble Fractions (WSF) of SRC-II on Freshwater Invertebrates and Alga[a]

Species	Parameter	Initial WSF			Weathered WSF		
		% Dilution	Total Carbon (ppm)	Phenols[b] (ppm)	% Dilution	Total Carbon (ppm)	Phenols[b] (ppm)
Chironomus tentans	growth	4.3	5.1	4.7	9.0	1.1	0.5
Tanytarsus dissimilis	life cycle	3.0	3.4	2.9	9.4	1.1	0.6
Daphnia magna	reproduction	0.2	0.2	0.2	4.3	0.9	0.3
Selenastrum capricornutum	productivity (exposure)	4.2	3.4	4.5	39.5	4.6	2.0
	productivity (recovery)	61.6	60.0	61.5	64.0	7.9	2.4

[a]Data are presented as lowest test concentration producing a significant difference in test parameter over controls.
[b]Determined photometrically.

Rapid reductions in concentrations of phenols and hydrocarbons were detected in static test solutions. About 20% of the total phenols in initial WSF (60% in weathered WSF) remained after 48 hours. These results indicate that highly specific analytical chemistry must be conducted to accurately assess potential impact from a spill or release of complex materials such as SRC-II liquids.

A series of tests was conducted to observe effects of SRC-II-contaminated sediments on Daphnia magna and Chironomus tentans. Clean sediment and SRC-II-contaminated sediment were leached to extract phenols and hydrocarbons. Preliminary results indicated that chironomid larvae were more sensitive than Daphnia to contaminated sediments. Even after ten water replacements, mean survival of chironomids after 17 days of exposure was significantly lower than controls.

A mixing and separation system was developed to produce a reproducible stock solution for exposing organisms to sublethal concentrations of SRC-II WSF under flow-through conditions. The WSF obtained in the system was similar in phenol composition to the initial batch WSF used in earlier acute and chronic tests. The mix and separation apparatus extracted a reproducible WSF while separating most dispersed and floating insoluble materials.

Newly hatched fathead minnow (Pimephales promelas) were exposed to sublethal concentrations of the SRC-II WSF in a flow-through system. Separate 14-day and 21-day exposure tests were conducted. Significant differences in mortality were noted at concentrations of 1.5 ppm total organic carbon (TOC). Significant reductions in length and weight were noted for 14-day exposures at concentrations $\geq$ 1.3 ppm TOC and for 21-day exposures at concentrations $\geq$ 0.4 ppm TOC (weight only). Dense bacterial growth occurred in the test aquaria after approximately 17 days.

Preliminary behavioral studies indicated a bias in the avoidance/attraction test apparatus when observing groups of fish. It became apparent that the fish needed a 24-hr acclimation period and that several replicates in a test series must be conducted to reduce variability in results. During FY 1981, we plan to study effects of SRC-II water-soluble fractions on fish response and evaluate the influence of motivational factors such as the spawning urge and territoriality in modifying response. During the next fiscal year, we expect to conduct additional chronic-exposure tests with other SRC-II materials. Studies involving effects of SRC-II-contaminated water and sediment on benthic invertebrate survival and behavior are also planned.

Comparative Effects of SRC-II Product, No. 2 and No. 6 Fuel Oils

If selections among competing energy technologies are to be wisely made, we need better ways of comparing risks posed by new products with those of materials they would replace in commerce. An initial series of tests compared effects of Prudhoe Bay crude oil and SRC-II liquid on growth of a freshwater algae, Selenastrum capricornutum. Once methods had been fully defined, Solvent Refined Coal liquid materials (SRC-II) were compared with No. 2 and No. 6 fuel oils by combining acute and chronic test procedures for Daphnia magna and applying them in a paired design (primary versus reference

material). Comparisons are made using a Dilution Index (DI) (DI = TOC concentration in stock solution divided by lowest test concentration causing a significant effect). The DI, therefore, is a measure of the maximum amount a stock solution can be diluted and still have a significant effect. The ratio of DI's for any two materials treated alike is thus a ratio of their different solubilities at a common level of toxicity. This serves as an estimator of a material's relative risk under the conditions of the test.

Preliminary tests were conducted using similarly derived WSF from Prudhoe Bay crude oil and SRC-II (2.9 to 1 middle-to-heavy distillate blend). Although significant depression of algal cell counts was noted in Prudhoe Bay WSF dilutions as low as 20 ppth (0.38 ppm total carbon), algae exposed to concentrations as high as 200 ppth of the WSF (3.8 ppm total carbon) recovered to normal levels after a 5-day exposure. Suppression of cell counts in SRC-II WSF occurred at $\geq$ 4.2 ppth (>3.4 ppm total carbon) during the exposure period and $\geq$ 61.6 ppth (260 ppm total carbon) for algal populations that recovered.

Toxicity of slow-mixed water-soluble fractions of SRC-II materials and two reference fuels was measured in terms of the proportion of dead (immobilized) Daphnia in eight jars; each jar contained five daphnids held at 20°C in filtered (5μ) Columbia River water at every test concentration and control. Under these conditions, no acute toxicity was observed for No. 2 fuel oil. The toxic range for No. 6 fuel oil was 0.31 ppm (which normally kills less than 8.5% Daphnia) to 3.75 ppm (which usually kills greater than 91.5% Daphnia) at the 90% level of confidence. The SRC-II material demonstrated a less severe toxic range (1.37 to 11.0 ppm), but due to its high solubility, it was judged to pose a risk 150 times greater than the risk posed by the No. 6 fuel oil. SRC-II stock solution could be diluted to 1/400th of its original strength and still show a significant toxic effect, whereas No. 6 stock solution could only be diluted to about 1/3 of its original strength and still have a significant toxic effect.

We earlier observed that the acute LRCT (the lowest concentration of toxicant that caused a statistically significant [α = 0.05] reduction in reproduction of Daphnia magna compared to controls) for SRC-II was higher (lower toxicity) than for No. 6 fuel oil. In the chronic case, the toxicity of the two oils is reversed, with SRC appearing now to be twice as toxic as No. 6 fuel oil (Table 4.3). Using the dilution indices to adjust for differences in solubility, we found that chronic risks to Daphnia from the SRC-II material were approximately 800 times greater than risks from No. 2 and 400 times greater than the risks from No. 6 fuel oil. Patterns of reproductive inhibition, which varied with WSF concentration, were highly reproducible from one test to the next if adjustments were made for inherent differences in productivity. These differences were revealed when the controls were compared. Enhanced productivity (in excess of controls) in low concentrations of the two reference fuels may be explained partly as a response to stress.

Table 4.3. Relative Chronic (21-day) Risk of Fuel Oils and SRC II Liquid to *Daphnia magna*

Test Comparison	LRCT[a] (ppm TOC)	Stock Concen. (ppm TOC)	DI[b]	RR[c]
SRC	0.68	1100	1618	404
No. 6	1.25	5	4	
SRC	0.68	1100	1618	809
No. 2	5.06	9	2	
No. 6	1.25	5	4	2
No. 2	5.06	9	2	

[a]LRCT is the lowest concentration of toxicant that caused a statistically significant (α = 0.05) reduction in reproduction of *Daphnia magna* compared to controls.
[b]The dilution index (DI) is the most the stock solution may be diluted and still achieve a statistically significant inhibition of reproduction.
[c]The relative risk (RR) represents the number of times the risk posed by one toxicant is greater than another as adjusted for differences in solubility.

Ecosystems Level Response to Solvent Refined Coal Materials

Pacific Northwest Laboratory investigators believe that aquatic effects from SRC materials would not be examined completely unless the responses of integrated ecosystems are considered. This "systems-level" approach is too frequently overlooked or avoided in hazards assessment. The fundamental objective of this task is to interpret stress in aquatic ecosystems resulting from exposure to known amounts of specific SRC materials.

Work thus far in the Systems Level Response task has included an extensive literature search, discussions with peer experts representing a variety of environmental disciplines, and the drafting of papers. The papers, primarily intended as internal working documents, communicated progress being made in the Systems Response task.

The last paper, to be finalized as a PNL document, contains the recommended strategy for the Systems Response task. This strategy will investigate systems responses to SRC materials by a gradation of inquiries escalating from small "model" ecosystems to large experimental (field) environments. Changes in biomass and complexity will be observed and parameters describing ecosystem form and function, including community structure and energetic dynamics, will be investigated.

The task will interpret changes in mass, complexity, form, and function to determine the following: 1) Is a certain SRC material potentially harmful to the environment? 2) If the material is potentially harmful, what levels are safe and what levels are unsafe? and 3) What do we risk if unsafe amounts escape into the environment?

The first series of tests will begin in April 1981 using artificial streams colonized with Columbia River biota.

Comparison of Toxicity Testing Between Two Laboratories

The objective of the comparative testing program was to determine the inter-laboratory comparability of acute toxicity tests. Pacific Northwest Laboratory and Oak Ridge National Laboratory exchanged water samples and performed a series of 48-hour acute-toxicity tests with Daphnia magna using acridine as the toxicant. This was done to determine if differences in toxicological response [median lethal concentrations (LC_{50}) and slope] to acridine were due to water quality, laboratory effects, or interactions between the two. Acridine was used as the toxicant because of its stability and inability to induce fluctuations in pH and dissolved oxygen levels in test vessels. A 2 x 2 factorial design was implemented and the data were evaluated by analysis of variance.

Analysis of the LC_{50} and the slope of the concentration-response curves (probit analysis) indicated significant main effects for laboratories ($\alpha>0.01$). No significant main effects ($\alpha<0.05$) for water quality or lab and water interactions were found, which allowed us to pool the data for both water types (Oak Ridge well water and filtered Columbia River water) and compare laboratory effects (Table 4.4). The observed differences in LC_{50} and slope were attributable to laboratory effects. Because of the extensive measures undertaken to ensure standardization of the testing protocol (using the same strain of Daphnia magna, the same source of toxicant, etc.), we attributed the observed differences to technical variability which exceeded reasonable limits of standardization. It was concluded that toxicity testing has practical and economic limitations that reduce the possibility of duplicating test procedures and conditions at independent laboratories. The best use of such tests is to provide a calibration or point of reference (positive control) for comparing test results of chemmically different and/or more complex compounds.

Table 4.4. Results of Inter-Laboratory Acridine Tests

Laboratory	LC_{50} (ppm)		Slope	
	Mean	95% CI	Mean	95% CI
PNL	3.85	3.44 - 4.26	14.18	12.14 - 16.21
ORNL	2.68	2.27 - 3.10	8.12	6.09 - 10.16

Field Studies: Growth of Barley Exposed to Solvent Refined Coal (SRC) Materials Added to Soil

Because SRC materials are new, little is known about their behavior in the environment. In normal use, SRC-I (a solid) and SRC-II (a liquid) would not come into contact with soil and water; however, if they were spilled while being handled or transported, they could contaminate surrounding soil, water, and plant life. This investigation examines the effects of SRC-I and SRC-II materials introduced to soil on barley (Hordeum vulgare) in lysimeters.

During the 1979 growing season, black, pea-sized, angular pellets of SRC-I were mixed with soil and placed in special lysimeters in two ways: a 1:1 mixture of soil and SRC-I by dry weight in a 3 dm surface layer superimposed on a 7 dm soil column, and as a 1 dm layer of SRC-I layered between a 3 dm soil over-burden and a 6 dm soil column. Each treatment was replicated four times. SRC-II liquid material (2.9 to 1 middle-to-heavy distillate) was added to lysimeters in 2, 20 and 200 mL amounts by pipetting directly onto the dry soil surface. This was then covered by a 1 dm layer of clean soil. Each treatment was replicated two times. Four lysimeters were filled with soil only and served as controls for SRC-I and SRC-II treatments. The lysimeters were seeded to barley and then placed outdoors for a 4-month period.

SRC-I material, which was added to soils and then weathered outdoors through two growing seasons, did not seem to decrease barley germination or produce visible evidence of lesions or chlorotic or necrotic tissue. This agrees with data collected from the first-year planting of barley in SRC-I material soil mixes. The length of the flowering culms and length of seed heads

of plants grown in layered SRC-I lysimeters were significantly lower (α = 0.016) than in the plants grown in the lysimeters containing control soil. The length of flowering culms and seed heads produced from barley plants grown in lysimeters with a surface layer of mixed SRC-I and soil were not significantly different (α = 0.016) from the length of plants grown in control soil (Table 4.5).

Barley plants grown in SRC-I mixed with soil produced less biomass than control plants. The barley grown in SRC-I-layered lysimeters produced less dry matter than plants grown in SRC-I-soil mixture (Table 4.6). Biomass in lysimeters containing the lower amount of SRC-II was within the range of barley plant weight for barley grown in control soil. Plants grown in lower SRC-II-to-soil concentrations produced less seed than control plants, while higher application rates greatly decreased seed production. This barley growth represents an improvement over growth in barley that was planted the previous year, which died shortly after germinating.

Barley plants grown under outdoor conditions in soil containing solvent refined coal materials showed no lesions or chlorotic or necrotic tissue when grown in SRC-I soil. Culm length, seed-head length, and grain produced were greater in plants grown in control soil than in plants grown in a soil containing a layer of SRC-I. SRC-II material inhibited plant growth at application rates of 1.5 L/m^2 and 15.0 L/m^2, but biomass increased after SRC-II soils weathered for one year.

Table 4.6. Biomass Produced in Soils Treated with SRC-I and SRC-II in 1980

Treatment	Biomass, g	n(c)
Control	35.3 ± 6.0(a)	4
SRC-I and soil (layered)	13.8 ± 4.0(a)	4
SRC-I and soil (mixed)	25.0 ± 1(a)	4
SRC-II (0.15 L/m^2)	24.0 (17-31)(b)	2
SRC-II (1.5 L/m^2)	2.5 (2.2-2.8)(b)	2
SRC-II (15.0 L/m^2)	0.4 (0-0.8)(b)	2

(a) $\bar{x}$ ± S.E.
(b) $\bar{x}$ (range)
(c) number of measurements

Environmental Fate of Solvent Refined Coal Materials

Alkyl Anilines and Phenols in SRC-II Aqueous Extracts

The water-soluble constituents of SRC-II materials are potentially the most environmentally mobile and, as such, deserve emphasis in the study of the fate of SRC products. Previous studies at Pacific Northwest Laboratory showed that alkyl phenols are a major component of an SRC-II blended distillate and that they constitute the majority of organic carbon in an aqueous extract of the distillate. Efforts to characterize the water-soluble fraction of SRC-II liquids has continued this year with emphasis on nitrogen-containing compounds.

Table 4.5. Average Length (cm) ± Standard Error of Flowering Culms and Seed Heads of Barley Plants Grown in Field Lysimeters Containing SRC-I and SRC-II

Parameter	Soil Mixture														
	SRC-I and Soil						Control Soil			SRC-II and Soil					
	Layered			Mixed						Layered (0.15 L/m^2 rate)			Layered (1.5 L/m^2 rate)			Layered (15.0 L/m^2 rate)		
	$\bar{x}$	S.E.	n	$\bar{x}$	S.E.	n	$\bar{x}$	S.E.	n	$\bar{x}$	S.E.	n	$\bar{x}$	S.E.	n	$\bar{x}$	S.E.	n
Length of Flowering Culms	56.7 ± 2.7		5	71.1 ± 1.1		11	70.8 ± 3.2		17	82.7 ± 2.5		11	40.3 ± 1.9		3	49 ±	6.9	3
	53.4 ± 3.1		10	68.6 ± 1.9		11	77.4 ± 1.5		18	66.6 ± 2.0		8	46.3 ± 0.3		2	0 ±		1
	64.9 ± 2.6		10	73.3 ± 2.1		11	79.8 ± 1.3		14									
	66.1 ± 4.9		8				73.7 ± 2.6		12									
	60.5 ± 1.9	(a)		71.0 ± 1.0	(b)		75.4 ± 1.2	(b)		75.9 ± 2.5	(b)		42.7 ± 1.8	(c)		36.8 ± 13.2	(c)	
Length of Seed Heads	6.5 ± 0.6			8.4 ± 0.3			7.6 ± 0.4			9.3 ± 0.4			4.8 ± 0.4			4.0 ±	0.6	
	5.7 ± 0.3			7.8 ± 0.3			8.3 ± 0.2			7.3 ± 0.3			4.0 ± 0.0			0		
	6.7 ± 0.3			8.1 ± 0.3			9.1 ± 0.2											
	8.4 ± 0.8						8.2 ± 0.4											
	6.7 ± 0.3	(d)		8.1 ± 0.2	(e)		8.3 ± 0.2	(e)		8.4 ± 0.3	(e)		4.5 ± 0.3	(f)		3.0 ±	1.1	(f)

(a) through (f) Means in each column followed by the same superscript are not significantly different (α = 0.016) based on Bonferroni Test.

Alkyl anilines have been identified in the SRC-II blended distillate and are found to contribute significantly to the water-soluble fraction of SRC-II. Analysis of the alkyl anilines required the development of analytical methodology that could differentiate alkyl anilines from alkyl pyridines. Although their behavior and effects in the environment may be quite different, the distinction between these two compound classes is not readily made, even by sophisticated gas chromatography/mass spectrometry (GC/MS) techniques. Derivation with acetic anhydride combined with GC and GC/MS proved to be a successful approach for identifying and quantifying alkyl anilines in the SRC-II distillate and an aqueous extract. Solvent extraction was effective in obtaining a nitrogen-rich fraction from the SRC-II or the SRC-II aqueous extract. Treatment of the nitrogen extract in aqueous media at pH 12 with acetic anhydride resulted in the acetylation of alkyl anilines. The resulting acetanilide derivatives were resolved from any alkyl pyridines by capillary GC and identified by their characteristic mass spectra. Gas chromatograms of organic nitrogen compounds extracted from an SRC-II WSF before and after acetylation are shown in Figure 4.1. Using the acetylation approach, aniline, C-1 anilines and C-2 anilines were identified and quantified. Quantities of alkyl anilines in an SRC-II blended distillate and in an aqueous extract of the distillate are presented in Table 4.7. For comparison, the corresponding concentrations of phenols are also presented in Table 4.8. Work will continue to identify other major components in the SRC-II nitrogen fraction.

Aniline Sorption and Persistence in Soils and Sediments

Since alkyl phenols and alkyl anilines have been identified as important water-soluble components of SRC-II liquids, studies were initiated to define the environmental fate of these compound types. Proposed studies involve the evaluation of the mobility and persistence of the water-soluble constituents of SRC-II liquids in both the terrestrial and aquatic environments. Batch and column studies will be used to define compound mobility and persistence in soils, and batch studies will be implemented to evaluate the persistence and microbial transformations in sediments. Initial laboratory studies have begun using batch studies with soils of the eastern coal

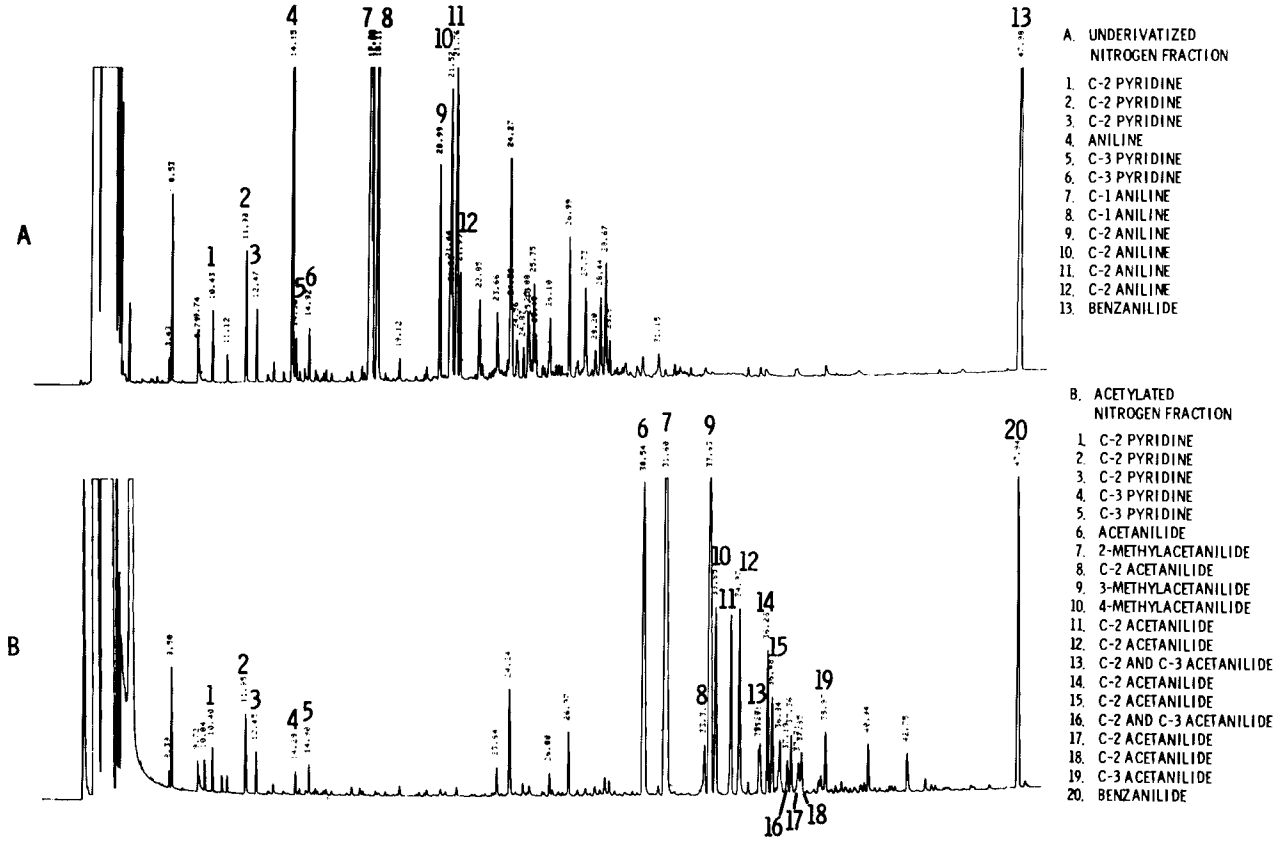

Figure 4.1. Gas Chromatograms of Organic Nitrogen Compounds from SRC-II Aqueous Extract

Table 4.7. Concentrations of Alkyl Anilines in SRC-II Blended Distillate[a] and Aqueous Extract[b] of SRC-II Distillate (duplicate analyses, conc. expressed in ppm)

	SRC-II Distillate		Aqueous Extract	
Compound	Trial I	Trial II	Trial I	Trial II
Aniline	1170	1025	11.4	14.3
2-methylaniline	2340	2545	21.0	25.1
3-methylaniline	1735	1660	14.5	16.2
4-methylaniline	400	445	4.5	4.4
C-2 anilines	2555	3350	14.5	18.9
Totals	8200	9025	65.9	78.9

[a]SRC-II blended distillate: 1 part heavy distillate, 2.9 parts middle distillate.
[b]Aqueous extract prepared by mixing 1 part SRC-II blended distillate with 100 parts water for 24 hr.

Table 4.8. Concentrations of Phenols in SRC-II Blended Distillate[a] and Aqueous Extract[b] of SRC-II Distillate

	SRC-II Distillate (ppm)	Aqueous Extract (ppm)
Phenol	20,600	169
Cresols	51,300	374
C_2-phenols	50,000	292
C_3-phenols	28,600	96
C_4-phenols	16,900	33
C_5-phenols	1,800	3
Indanols	11,000	53
C_1-indanols	13,400	29
C_2-indanols	8,600	10
Totals	202,200	1059

[a]SRC-II blended distillate: 1 part heavy distillate to 2.9 parts middle distillate.
[b]Aqueous extract prepared by mixing 1 part SRC-II blended distillate with 100 parts water for 24 hr.

region to evaluate the adsorption isotherms of alkyl phenols and alkyl anilines. Soil samples have been collected on and in proximity to the proposed Newman, SRC-I demonstration site near Owensboro, Kentucky, and at the Fort Martin SRC-II demonstration site near Morgantown, West Virginia. Soil series chosen were representative of both the site itself and the Soil Conservation Service baseline soils of the local geographic region. All soils were sampled according to genetic horizons. Chemical and physical characterization of these soils presently under way includes: pH; redox potential and conductivity; total elemental analysis; cation-exchange capacity; extractable amorphous and crystalline oxides of Al, Fe, and Mn; organic carbon; mineralogy; and particle size distribution.

Measurement of the adsorption isotherms of a series of methyl anilines with the genetic horizons (A, B1, B22t of the Elk silt loam (Kentucky, Alfisol) and the Westmoreland silt loam (West Virginia, Alfisol) has been completed. Batch studies were used, and sorption was followed by direct, high-performance liquid chromatographic analysis of the compounds remaining in aqueous solution after equilibration with the soils. Example isotherms for the adsorption of a mono and trimethyl aniline on the A and B22t horizons of the Westmoreland silt loam are presented in Figure 4.2. Adsorption was seen to differ significantly for the individual soil horizons. Sorption in the A horizons (maximum organic content) followed the Freundlich isotherm and reflected compound solubility. Sorption in the B horizons (maximum Fe, Mn, and Al oxide and clay content) was more complex, suggesting the presence of competing sorption (solvent-solute) or specific adsorption reactions. Chemical characterization of these soils must be completed before definitive interpretation of these isotherms can be made. Column studies will soon be initiated to assess the mobility and persistence of these compounds in discrete soil horizons. This approach is necessary in order to interpret

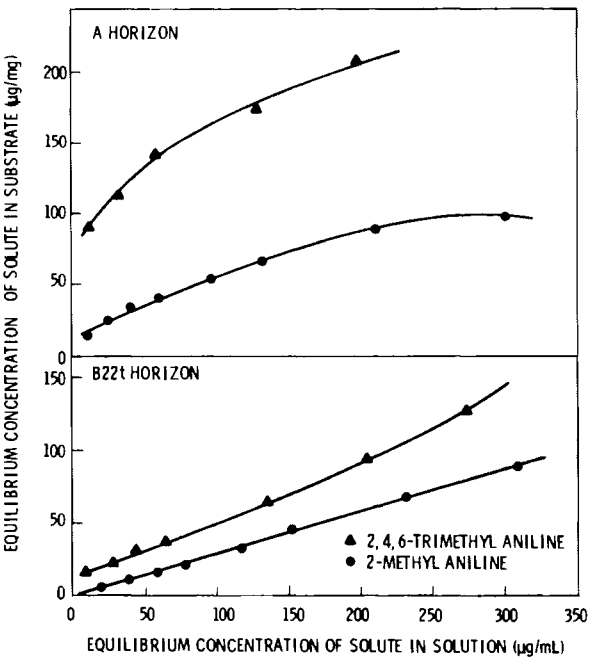

Figure 4.2. Adsorption Isotherms of Mono and Trimethyl Aniline on Westmoreland Silt Loam

the combined effects of chemical and microbiological processes and to increase its application to product spills. Bottom and suspended sediments from the Green, Ohio, and Monongahela Rivers will soon be collected for use in analogous adsorption and degradation studies for the aquatic environment.

Mineralogic and Aqueous Leaching Studies with SRC Mineral Wastes

The proposed ground disposal of solid wastes from the solvent refining of coal may create the potential for contamination of surface and ground waters through the leaching of soluble inorganic and organic compounds. Evaluation of the potential ecological and health effects which may occur requires a complete understanding of 1) the chemical and microbiological processes occurring within solid-waste landfills with time and weathering, and 2) the transport and persistence of soluble components released through soils and sediments. Laboratory studies designed to evaluate these processes include mineralogic investigations, batch equilibrations to assess the identity and total quantity of readily soluble materials present in the residue and their release with time, single phase column studies to estimate the composition of leachates potentially produced at disposal sites, and mixed-phase columns to evaluate the mobility of soluble components released from SRC solid wastes through soil, subsoil, or sub-strata.

Initial studies have included mineralogic characterization and preliminary batch and column leaching of the SRC-I mineral residue produced at the Ft. Lewis, Washington, pilot plant from a bituminous western Kentucky coal. Although this material will likely be gasified by commercial SRC-I or II operations, these studies were undertaken to evaluate methodologies applicable to the characterization of aqueous leachates from coal conversion solid wastes and to identify specific chemical and mineralogic properties of the mineral residue which may influence the physicochemical composition of the gasified mineral slag. Analagous studies dealing with the mineral slag will begin when representative materials become available.

The SRC-I mineral residue was found to be predominantly pyrrhotite, a crystallographically complex iron sulfide with an approximate formula of FeS. An X-ray diffractogram of the residue is illustrated in Figure 4.3. Major peaks at 2.07, 2.65, and 2.98 A are those of pyrrhotite; additional maxima at 3.34 and 4.25 A and at 7.13 and 3.57 A define the presence of quartz and kaolinite, respectively. Although natural-alteration products of pyrrhotite include pyrite,

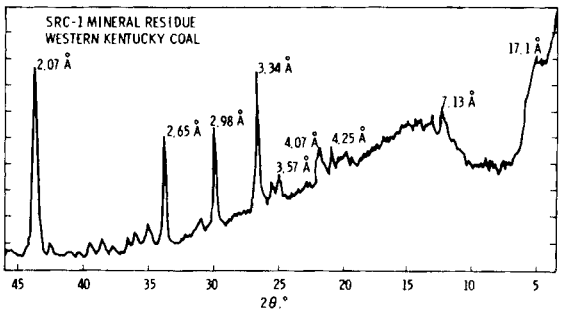

Figure 4.3. X-Ray Diffractogram of SRC-I Mineral Residue

marcasite, iron sulfate, carbonates and oxides, it is unclear whether its oxidation can be microbiologically mediated, as in the case of pyrite. Acid production will likely occur upon weathering by oxidation of ferrous iron and sulfide sulfur, which may lead to chemical conditions analogous to acid-mine drainage. The proposed gasification of the filter cake and vacuum bottoms should decompose the pyrrhotite, and thus reduce the potential for acidification upon weathering.

Batch equilibrations using a 10 to 1 solution-to-solids ratio were sampled incrementally over a 200-hr period. Leaching studies using 10 cm^3 columns with a flow rate of 0.1 mL/hr were also performed to evaluate the possible composition of solutions which could enter the environment after leaching a mineral-residue pile. An example of results obtained from these studies is presented in Table 4.9. Initial leachates (in the first pore volume $v/v_o = 1$) are slightly basic (pH 8.0 to 8.4) and contain notable quantities of soluble salts (Na^+, Ca^+, Cl^- and SO_4^{2-}), boron (70 ppm), strontium (22 ppm), flouride (23 ppm), and organic carbon (196 ppm). Additional parameters measured, but not presented because of low concentration include: Ba, Cr, Cu, Li, Ni, Pb, Zn, NO_3^{2-}, $S_2O_3^{2-}$, and SCN^{2-}. Solutions of this composition could degrade water quality if discharged directly to surface or ground waters. Significant changes will likely occur in the chemical composition of leachates with time as weathering of pyrrhotite occurs by oxidation of reduced sulfur and iron (S^{2-} and Fe^{2+}). Probable changes include lowering of pH and increased solubilization of heavy metals (Fe, Mn, Zn, and Cr) associated with sulfide mineral phases.

Chemical Studies at the SRC-II Demonstration Site: Baseline Hydrocarbon Concentrations in Monongahela River Sediments

Fine-textured sediments from the Monongahela River were sampled in October, 1979, and subjected to analysis for hydrocarbon,

Table 4.9. Chemical Composition of Batch Extracts and Column Leachates from SRC-I Mineral Residue

Chemical Composition[a]	Batch at 24 hr.	Column in $V/V_o = 1$
pH	8.40	8.07
Conductivity (m mhoes)	0.75	3.27
Inorganic C (ppm C)	4.9	13.6
Organic C (ppm C)	21.0	196
Al	1.46	0.17
B	5.07	70
Ca	360	1400
Fe	0.018	0.030
K	4.50	34.8
Na	18.3	372
Mg	1.64	27.9
Mn	0.066	0.540
Si	5.82	6.42
Sr	2.35	21.5
Mo	0.084	1.28
Cl	65.0	1360.0
F	<0.60	23.3
SO_4	742	1658

[a]All elements expressed in ppm.

phenolic, and nitrogen-containing components. The sediments were obtained from two locations: Station 1, about four miles downstream from the site of the planned SRC-II demonstration site near Morgantown, West Virginia; and Station 2, a short distance upstream from the demonstration site. The sediments at both sites were slightly alkaline (pH 7.7 at Station 1 and pH 7.4 at Station 2) and reducing (platinum electrode readings of -160 and -85 mv, respectively). Organic material was removed from 35 to 50 g subsamples by Soxhlet extraction with methanol, then with a mixture of benzene and methanol. The organic extracts were then separated over silica gel into saturate and aromatic hydrocarbons and these fractions separated into individual components using capillary gas chromatography.

A chromatogram of the aromatic components from Station 1 are shown in Figure 4.4. The complex pattern shown is significantly different from those obtained from aqueous extracts of SRC-II liquids, but the distributions and relative abundances of the naphthalene and substituted naphthalenes are very similar to those from a crude oil. In three subsamples, levels of aromatic hydrocarbons at Station 1 were 52.0 ± 32.0 mg/kg dry sediment; the corresponding saturate-hydrocarbon content was found to be 7.6 ± 1.9 mg/kg. Duplicate subsamples from Station 2 contained 32.4 and 18.8 mg/kg aromatics, and 5.6 and 3.9 mg/kg saturates. Weathering of the hydrocarbon fraction is evident from the prominence of pristane in the saturate chromatogram and the relatively high contribution of three- and four-ring aromatic components to total aromatic concentration in the sediments. The concentrations of hydrocarbons found in the Monongahela sediments are quite high, even when compared to other water bodies which are considered contaminated. Levels of aromatic hydrocarbons about one order of magnitude lower than Monongahela River sediments have been reported for Duwamish River, Washington, intertidal sediments. Individual aromatic-component concentrations such as pyrene and benzanthracene were similar.

Analysis of subsamples of sediment for phenols by caustic extraction and formation of the phenol acetates by direct aqueous derivatization did not reveal phenols to be present in concentrations >10 mg/kg wet sediment. Similarly, the Soxhlet extracts of the sediment did not give any response when chromatographed on a capillary column connected to a nitrogen-phosphorous detector. These results, taken together with the petroleum-like hydrocarbon patterns observed for the Monongahela, suggest that a number of criteria can be used for the investigation of Monongahela sediments for presence of contaminants derived from SRC-II materials. A change of aromatic hydrocarbon distributions, coupled with the appearance of significant concentrations of nitrogen bases and/or phenols, could provide evidence for the accumulation of coal-derived liquid fuels in the environment.

Solvent Refined Coal II (SRC-II) Detailed Environmental Plan

The SRC-II staff prepared the Solvent Refined Coal II (SRC-II) Detailed Environmental Plan. This document describes research to be performed which will aid in the development of an environmentally safe SRC-II process, and provide data useful for assessment of environmental impacts of the process. The document also provides a management plan involving the cognizant offices of the Department of Energy (Assistant Secretary for the Environment and Assistant Secretary for Energy Technology, Oak Ridge Operations Office), the developers of the technology, and environmental research groups. The SRC-II process is described, justification for selection of research approaches are provided, and approximate timelines and costs are presented for implementing the suggested research.

TOXICOLOGY OF SRC-I MATERIALS

In the second half of FY 1980, a program was initiated to determine the fate of SRC-I materials and solid wastes in the terrestrial and aquatic environments. Our initial efforts in this program have

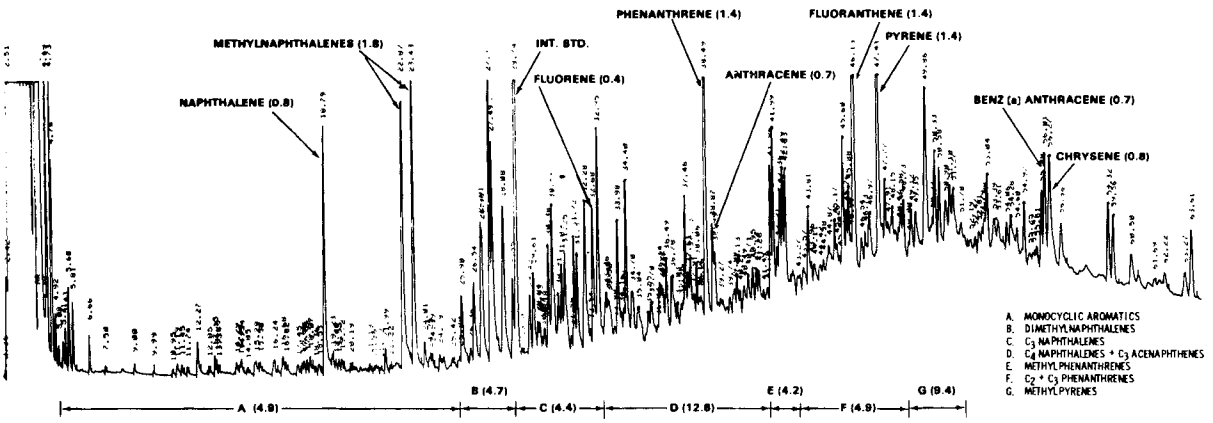

Figure 4.4. Capillary Gas Chromatogram of Aromatics Fraction from Monongahela River Sediment (Station 1). Component Concentrations are Shown in Parentheses as mg/kg Dry Sediment Weight

focused on the characterization of the physicochemical interactions that govern the fate of SRC-I materials in the terrestrial environment. We visited the proposed SRC-I demonstration site at Newman, Kentucky, and collected and characterized soils from the area for use in sorption studies. Our findings are presented in a previous section of this report. In addition to the commencement of soil-organic interaction studies, a Joint Environmental Plan for SRC-I was prepared and will be presented to DOE in January, 1981, for review.

5 Nuclear Waste: Fission

NUCLEAR WASTE: FISSION

- **Transuranic Behavior in Soils and Plants**
- **Quantitative Aspects of Transuranic Field Studies**
- **Analogs for Transuranic Elements**
- **Long-Term Plant Availability of Actinides**
- **Radioecology of Nuclear Fuel Cycles**
- **Environmental Behavior and Effects of Technetium-99 and Iodine-129**

One of the highest priorities in the continued development and use of fission as a source of energy is the resolution of questions about the long-term fate and ultimate effects of long-lived radionuclides in the biosphere. This long-term behavior generally cannot be confidently inferred from the short-lived isotopes. The individual studies described in this section range from basic investigations of the behavior and effects of long-lived nuclides at the chemical and cellular level to ecosystems studies which describe inventory, transport, and effects in waste management areas. The investigations described in this section are designed to differentiate and measure processes affecting the biological availability of the radioelement.

In terrestrial studies, investigations of transuranics in soils and plants have demonstrated the importance of valence state, complexation, competing elements, microbial processes, redistribution in the soil profile, and weathering cycles in governing the availability of selected actinide elements and fission products (^{139}I and ^{99}Tc) to plants and to the consuming animals. In the case of plutonium, it was demonstrated that ingestion of plant tissues containing plutonium may result in greater transfer across the gut compared to gavaging animals with inorganic plutonium solutions. However, technitium in plant tissues is less available to animals. This underscores the importance of detailed studies of soil, plant and animal factors influencing uptake by the ingestion pathway. The importance of the ingestion pathway was also demonstrated in studies of foliar interception of airborne transuranic elements in which plants effectively intercept and retain plutonium containing particles in the respiratory size range. Significant quantities of the intercepted plutonium were transported to roots and seeds. Similar studies on the terrestrial ingestion pathway have been initiated with other actinides, including uranium, americium, curium and neptunium.

Radioecological field studies were directed toward establishment of pertinent ingestion pathways and exposure levels through description of habitat types, population densities, and, in several instances, dosimetry, for major insects, reptiles, birds and mammalian species. These studies were extended to agricultural ecosystems.

• Transuranic Behavior in Soils and Plants

Principal Investigators: R. E. Wildung, T. R. Garland, D. A. Cataldo, J. E. Rogers, K. M. McFadden, E. A. Jenne, and R. G. Schreckhise

The principal objective of this study is to gather information about soil, plant, and foliar interaction factors that influence the availability of transuranics to agricultural plants and animals. Major areas of emphasis are: 1) soil and soil-microbial processes that influence the formation of ligands, which stabilize transuranic elements in soil solutions, and processes that influence transuranic element long-term behavior in soil and plants; 2) deposition and plant interception of airborne submicronic particles containing the transuranic elements and their susceptibility to leaching; 3) plant processes which influence transport across the plant root membrane and foliar surfaces, the form and sites of deposition of transuranic elements in mature plants; and 4) the integrated effect of soil and plant processes on transuranic element availability to, and form in, animals that consume plants.

Plant absorption of Pu from soils on an absolute (dpm) basis is relatively linear for 64 to 88 days after germination. The absorption does not appear to be related to plant dry-matter production. Studies of Pu content and concentration in plants as a function of dry-matter production indicate that Pu accumulation by plants from soils is regulated and limited by soil processes that determine the quantity of Pu available for plant uptake (Figure 5.1). This available fraction of Pu ranged from 0.4 to 3.1 pg/day for three soils to which Pu nitrate at 10 μCi/g levels had been added.

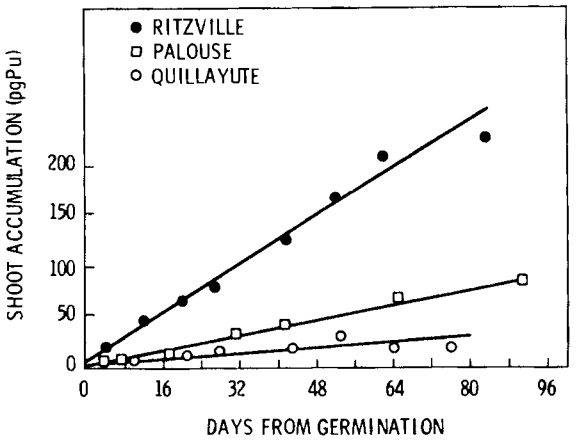

Figure 5.1. Rate at which ^{238}Pu is Absorbed from the Soil by Soybean Plants

Measurements of Pu accumulation with time for individual shoot tissues shows Pu to be relatively mobile in the plant. Evapotranspiration determines the distribution pattern. There is no indication that Pu remobilizes during senescence of plant tissues. Detailed chemical characterization of Pu form in xylem exudates indicates a substantial change in Pu form following root absorption from nutrient solutions containing Pu_2DTPA. After metabolism of Pu by roots, stems and leaves, the solubles were found to contain 28%, 54% and 67% of the Pu, respectively (Table 5.1). The Pu in the soluble fraction was primarily associated with components of >10,000 molecular weight in leaves and roots, whereas stems exhibited a distribution between components in the >10,000 and <500 molecular weight fraction. Plutonium associated with mature seeds is concentrated in the seed hull (85%) and cotyledons (14%). Fractionation of cotyledons to determine the distribution of Pu in soy products indicated that Pu was primarily associated with the insoluble residues and soluble soy whey.

Detailed study of the factors that affect plant absorption of Pu from soils, and the chemical behavior and fate of Pu following plant metabolism provide information about the behavior of Pu that affects soil-plant and plant-animal interactions. The present studies indicate that plant discrimination against actinide absorption by roots does not occur. In fact, the capacity of the

Table 5.1. Distribution and Chemical Fate of ^{238}Pu in Soybean Tissues Accumulated from Hydroponic Solutions Containing Pu_2DTPA_3

Tissue Fraction	% Distribution of Plutonium			
	Roots	Stems	Leaves	Pu_2DTPA_3
Whole tissue Fraction(a)	84.0 ± 1.3	0.6 ± 0.3	15.4 ± 1.0	—
Soluble	27.7 ± 2.9	54.4 ± 1.9	67.4 ± 3.9	—
Insoluble	72.3 ± 2.9	45.6 ± 1.9	32.6 ± 3.2	—
Fractionation of Solubles:(b)				
>10,000	90.3 ± 3.2	60.1 ± 5.1	87.2 ± 7.3	0.1
5,000 - 10,000	5.7 ± 1.1	8.4 ± 6.5	3.1 ± 1.3	0.1
500 - 5,000	2.8 ± 1.9	6.0 ± 1.8	5.8 ± 3.6	92.1
<500	1.2 ± 0.3	25.6 ± 0.4	3.9 ± 2.3	7.9

(a)Homogenized in 0.02 M NH_4OAc, insolubles (cellwalls, organelles and structural proteins) sedimented at 20,000 x G.
(b)Fractionation by ultrafiltration.

plant to accumulate Pu is not unlike that of hydrolyzable elements. The rate at which plant accumulation occurs is limited by those soil processes that result in the formation of soluble chemical species available to the plant. Measurements of Pu distribution and chemical form in soybeans show that once Pu is absorbed by the root, it is mobile within the plant. Pu solubility is maintained by the formation of Pu-complexes. In vegetative tissues such as roots and leaves, more than 85% of the Pu is associated with soluble materials having molecular weights >10,000. While ~60% of the Pu in the soluble fraction of stems is of >10,000 MW, 25% is associated <500 MW components. Previous studies have shown that gastro-intestinal absorption of Pu that was previously incorporated (metabolized) into plant tissues was ~2 orders of magnitude higher than from gavage inorganic solutions. More importantly, a consistent 2- to 5-fold increase in gut absorption of Pu was noted when the plant feed included plant stems rather than just leaves alone. The total Pu activity contributed by the stems in the composite tissue feedings was ~13 , but Pu was more soluble and 25% of the soluble activity in stems was of <500 MW. Thus, differences in Pu forms in the plant appeared to be controlling gastro-intestinal absorption. Understanding the chemical behavior of Pu in plants is critically important for re-assessing the plant-to-animal transfer factors in dose assessment models.

• Quantitative Aspects of Transuranic and Other Radionuclide Field Studies

Principal Investigators: R. O. Gilbert, J. C. Simpson and R. R. Kinnison

The purpose of this project is to identify, develop and communicate statistical methodology for environmental actinide studies. Significant accomplishments of FY 1980 were continued publication of TRAN-STAT (a periodical specializing in the statistical aspects of environmental contaminant studies), acquisition of preliminary results from our computer simulation study for evaluating estimators of average ratios (e.g., transfer coefficients, isotopic ratios), and the review of statistical estimation methods for data near detection limits. Related work under separate DOE funding includes writing the statistics portion of a radiological guide for DOE decommissioning operations, expanding our expertise in the application of Kriging in two and three-dimensions for estimating spatial patterns of contaminants in the environment to evaluate potential hazards, continuing our statistical design and analysis work for the Nevada Applied Ecology Group, and providing statistical assistance to PNL's environmental radiological monitoring effort.

TRAN-STAT: Statistics for Environmental Contaminant Studies

TRAN-STAT, a periodical distributed to DOE and DOE-contractor personnel engaged in environmental actinide studies, is a tool for communicating statistical design and analysis techniques applicable to environmental studies. This fills a need to stimulate the use of better statistical methodology in evaluating potential health hazards to man from the presence of radionuclides and other contaminants in the environment. Twelve issues have been distributed since September 1977, four of which were published during the past year. Topics discussed in Issues 9 through 12 were a description of our ratio simulation study, announcement of a new three-stage mass spectrometer developed at the Savannah River Laboratory for analysis of environmental samples, discussion of a bias problem with linear calibration lines, a statistical study to evaluate the computer pseudo-random number generator used in our ratio study, and the design of radionuclide field studies including specification of statistical criteria for deciding on the number of measurements required to meet study objectives. TRAN-STAT will continue to be published in FY 1981.

Ratio Computer Simulation Study

We are studying the statistical properties of 11 estimators of average ratios to evaluate which are best suited for estimating transfers of radionuclides from one ecosystem component to another, e.g., from soil to plants via root uptake. The rationale and methodology for this study are discussed in Issue 9 of TRAN-STAT (PNL-SA-8074). Models with additive or multiplicative errors, and statistical distributions for data believed to represent real world situations are being used. Radios are used in many areas of research and our results should be applicable to other than radionuclide studies. Preliminary results indicate several of the estimators perform poorly compared with commonly used estimators such as the familiar mean of ratios $(1/n)\sum_{i=1}^{n}(Y_i/X_i)$ and the median ratio. Our final results will be reported in TRAN-STAT and the open literature.

Data Near Detection Limits

Radionuclide concentrations at or below detection limits may be reported by analytical laboratories as zero, less-than values, or negative concentrations. We have reviewed statistical methodologies for estimating the mean and standard deviation of such data. Results have been accepted for publication in Health Physics. Details can be found in TRAN-STAT, Issue 7 (PNL-SA-7585).

Other Activities

We are writing the statistics portion of a radiological guide for DOE decommissioning operations. Statistical assistance is also being provided to DOE, CORO, on the decommissioning of the New Brunswick Laboratory

in New Brunswick, New Jersey. Expanded efforts of BNW statisticians in the application of statistics to decommissioning are expected during FY 1981.

During FY 1980 DOE purchased a three-dimensional version of BLUEPACK, a computer code for estimating spatial patterns of contaminants in environmental media (e.g., soil, air). Currently we are gaining experience in using this new code. With adequate data BLUEPACK can be used to estimate average concentrations of any spatial variable over areas or volumes. During FY 1980 we applied Kriging to estimate the spatial distribution of radionuclides and the soil tonnage removal for a hypothetical cleanup of a test area on the Nevada Test Site. This work was primarily funded by the Nevada Applied Ecology Group (NAEG).

Statistical assistance in the design and analysis of environmental radionuclide studies is supplied to NAEG, as we have done continuously since 1971. Advice is given on the type, quantity and location of environmental samples at nuclear test areas and the resulting data analyzed using Kriging and other methods to evaluate potential hazards to man.

We are also providing assistance to PNL's environmental monitoring effect regarding statistical quality control at analytical laboratories, improved statistical data display and analysis in environmental monitoring reports, and the design and analysis of various environmental sampling efforts. We continue to provide statistical input to a study of the environmental effects of a prototype 1200 kV transmission line near Lyons, Oregon; work that is funded by the Bonneville Power Administration.

• Analogs for Transuranic Elements

Principal Investigators: W. C. Weimer, J. C. Laul and J. C. Kutt

A combined theoretical and experimental approach is being used to estimate the long-term environmental and biogeochemical behaviors of selected transuranic elements. Naturally-occuring elements that have chemical properties similar to those of the selected transuranic elements are being used. Examining the environmental biogeochemistry of these natural elements enables us to estimate the ultimate geochemistry and biological availabilities of the chosen transuranics. Investigations have included elemental sorption experiments on soil-and-solution mixtures; uptake studies on plants grown in a growth chamber and under field conditions; determinations of analog element availabilities as the analogs are moved from soils by chemical extractant solutions; and examination of samples collected from natural ecosystems.

The objective of this research is to estimate the effect that long-term (hundreds of years) environmental weathering has on the behavior of the transuranic elements americium and curium. This is achieved by investigating the actual behavior of naturally occurring rare earth elements, especially neodymium, that serve as transuranic analogs. Determination of the analog element behavior provides data that can be used to estimate the ultimate availability to man of transuranic materials released into the environment.

Chemical, biological, and physical forces that bring about environmental weathering reactions act nearly equivalently on the elements with similar chemical properties. The most significant chemical properties that are used to define elemental analogs include the predicted stable environmental oxidation states and the charge-to-ionic-radius ratio. On these bases, the naturally occurring lanthanide element, neodymium, is a chemical analog for the transuranics americium and curium. The behavior of the analog neodymium has been investigated in field experiments and in a laboratory growth chamber.

The interactions of the Nd^{+3}, Am^{+3}, and Cm^{+3} with soils and solutions have been investigated in short-term (24-hr or less) experiments. The results of these studies demonstrate that the sorption characteristics of these three elements on a Ritzville silty loam soil are similar. The variations in the distribution coefficients of these elements between the soil particles and the simulated soil solutions as a function of pH show excellent correlation between the elements. These data suggest that similar or identical mechanisms may function under a variety of conditions to control the total concentration of each of these elements held in solution. The soil chemistry of each element may be controlled by the same dominant factor(s).

Controlled plant-uptake investigations were performed under both field and growth-chamber conditions. Two types of plants used in this experiment were cheatgrass and snap beans. In these studies, the same chemical forms of Nd^{+3}, Am^{+3}, Cm^{+3} were added to the soils in which the plants were grown. The uptake of these elements can be expressed as a concentration ratio (elemental concentration in plant to elemental concentration in soil). The concentration ratios for these three nonessential trace elements were indistinguishable from one another. The stems and leaves of snap beans that were grown in a growth chamber had concentration ratios of 1.1×10^{-3} (americium), 1.3×10^{-3} (curium), and 1.2×10^{-3} (neodymium). The concentration ratios for the stem and leaves of the field-grown cheatgrass were 4.8×10^{-4} (americium), 2.5×10^{-4} (curium), and 6.5×10^{-4} (neodymium). These concentration-ratio data, together with the physical and chemical data for the determination of elemental distribution coefficients in soil-and-solution studies, have confirmed that, in these short-term investigations, the rare

earth element neodymium is an adequate substitute for the transuranics americium and curium.

The principal goal of this research is to use knowledge of the biogeochemical behavior of naturally occurring (nonamended) neodymium to estimate the behavior of transuranics in the environment. These studies, which involve using added levels of the three elements, verify the similarities in the chemical and biological behaviors of americium, curium and neodymium.

Concentration ratios for the plant uptake of natural neodymium have been determined for several plant-and-soil systems. These natural soil systems contain transuranic elements from atmospheric fallout and thus afford an opportunity for comparing the concentration ratios of the naturally occurring analog with the fallout transuranics.

When comparing the concentration ratios of neodymium and americium (from natural soils) for seven different plant species, americium is from 25 to 120 times more biologically available than the neodymium, if the concentration ratios for neodymium are calculated by using the total soil-neodymium concentrations. This is due to the large fraction of soil neodymium that is geochemically bound within mineral matter and which is not available to biological systems for possible incorporation. However, when the concentrations of the chemically exchangeable neodymium in these soils are used for determining the plant concentration ratios, the concentration ratios for this "available" neodymium and for the fallout americium generally agree within a factor of two, which is an insignificant difference. These data are shown in Table 5.2.

Thus, we have been able to define, through chemical means, the apparently biologically available analog element concentration in soils and to determine representative concentration ratios from these data.

Table 5.2. Plant Uptake of Analog and Transuranic Elements

Plant	Analog Element Conc. Ratio[a]	^{241}Am Conc. Ratio
Peas	9.6×10^{-3}	6.0×10^{-3}
Potatoes	4.6×10^{-3}	6.0×10^{-3}
Corn	7.0×10^{-3}	6.1×10^{-3}
Squash	3.9×10^{-2}	9.9×10^{-3}
Rye	2.9×10^{-3}	$<3.0 \times 10^{-3}$
Rice	4.3×10^{-5}	$<7.0 \times 10^{-3}$
Wheat	1.1×10^{-3}	2.5×10^{-3}

[a]Calculated from the concentrations of isotopically-exchangeable analog element in the soils

This investigation of the transfer of analog elements from soil to plants is now being extended to include transfer to additional food products and to transfer to man. The purpose of broadening this study is to estimate the analog element "dose-to-man" that the general population receives. The data for the transfer of the analogs from soil to plant and from plant to man can be used to estimate the transfer of transuranic elements from soil to plant to man after they have achieved a state of natural environmental equilibrium.

• Long-Term Plant Availability of Actinides

Principal Investigators: R. G. Schreckhise and J. F. Cline

Technical Assistance: M. J. Harris, R. A. Peloquin, M. E. Thiede and M. G. Zimmerman

Environmental releases of actinide elements raise issues about which data are very limited. Quantitative information is required to assess the long-term behavior of actinides and their potential hazards resulting from the transport through food chains leading to man. Of special interest is the effect of time (weathering, aging and associated biological processes in soil) on the changes in the availability of actinide elements for uptake by plants from soil. This study provides valuable information on the effects of weathering and aging on the uptake of actinides from soil by range and crop plants grown under realistic field conditions.

Routine Maintenance

Work on this project during this past year primarily involved the care and maintenance of plants grown in field lysimeters. Plants are harvested at maturity and either submitted for radiochemical analysis or archived for future reference purposes. Radiochemical analyses of selected samples from the 1979 harvest have been completed and the results have been tabulated. The 1980 harvest represented the fifth year of harvest for the 20-cm subsurface layer lysimeters and the seventh year for the thin subsurface layer lysimeters. Selected samples will be analyzed to provide data for a vigorous statistical analysis to determine if the plant availability of the actinide element has changed through the five- or seven-year period.

Data-Management System

A data-management system is being developed for use on this project. An existing system, presently in use at PNL, is being modified to handle the large amount of data that is produced in this study. The system will enhance the statistical evaluation of the data by allowing more in-depth analyses. It also should reduce errors since most of the data will eventually be collected and directly entered into the system with the use of a remote computer terminal located at the ALE facilities.

Long-Term Behavior of Actinides Model

Efforts are presently under way, in cooperation with investigators from Savannah River Ecology Laboratory (SREL), Oak Ridge National Laboratory (ORNL) and DOE Headquarters, to develop a model to provide insight on the long-term environmental behavior of actinide elements. This effort is expected to identify areas requiring additional research as well as being a tool for assessing the potential risks associated with environmental releases of actinides. Efforts are presently focused on identifying existing models (e.g., geochemical and biotransport) that might be of use. Modification of these, along with the continued development of a model constructed by John Pinder of SREL during the initial stages of this effort, should provide the information necessary to put together a realistic simulation model.

• Radioecology of Nuclear Fuel Cycles

Principal Investigators: R. G. Schreckhise, L. L. Cadwell, R. M. Emery, J. F. Cline, K. A. Gano, W. T. Hinds, T. M. Poston, L. E. Rogers, R. H. Sauer, J. K. Soldat, D. A. Baker and J. R. Skalski

Technical Assistants: M. A. Combs, M. J. Harris, D. C. Klopfer, L. F. Nelson and M. E. Thiede

Radioecology of nuclear wastes was pioneered in the western United States on the Hanford Site during the early 1940's when the Columbia River provided coolant water for production reactors. Ecological studies centered on fish and waterfowl as vectors transporting radionuclides to people. After the shutdown of production reactors, the radionuclide content of Columbia River water declined. Attention was then directed toward radionuclides released into the environment as a result of chemical processing of irradiated fuel and as a result of storage of radioactive wastes.

Sites where radioactive wastes are found are solid waste burial grounds, soils below liquid storage areas, surface ditches and ponds, and the terrestrial environment around chemical processing facilities that discharge airborne radioactive debris from stacks. This study provides information to help assess the environmental impacts and certain potential human hazards associated with nuclear fuel cycles. A data base is being developed to define and quantify biological transport routes which will permit credible predictions and assessment of routine and potential large-scale releases of radionuclides and other toxic materials. These data, used in assessment models, will increase the accuracy of estimating radiation doses to man and other life forms. Information obtained from existing storage and disposal sites will provide a meaningful radioecological perspective with which to improve the effectiveness of waste management practices. Results will provide information to determine if waste management procedures on the Hanford Site have caused ecological perturbations, and if so, to determine the source, nature and magnitude of such disturbances.

Important companion studies also are underway. They are funded through local intercontractor support agreements rather than through the Office of Health and Environmental Research. These studies involve short-term assistance to Hanford plant personnel concerned with characterization of particular landscape subunits impacted by operation of nuclear facilities. They are discussed in the section entitled Hanford Project Support.

Terrestrial Radioecology of Waste Management Areas (TROWMA)

Task Management

Research activities between TROWMA and Rockwell Hanford Operations are coordinated by task management. Joint efforts have led to a study of the Hanford deer herd, compilation of data to quantify the movement of radioactive materials by biological vectors, and development of a cooperative proposal with the Idaho National Engineering Laboratory and Los Alamos Scientific National Laboratory to evaluate biotic intrusion into low-level radioactive waste burial grounds.

Waterfowl Transport

Parameters were developed to determine the quantity of radioactive materials that

waterfowl annually remove from the Hanford site. Coots (Fulica Americana), selected because they are the most prevalent nesting waterfowl on the Hanford waste ponds and because they average the highest body-burdens of any waterfowl sampled on the site, transported approximately 50 μCi ^{137}Cs offsite. The 50-year population dose from the projected harvest of coots from the site is estimated to be 0.13 person-rem.

Honeybee Study

The purposes of this study are to determine the feasibility of using honeybees as environmental monitors, to document the existence of feral colonies on the site, and to evaluate the biotic-transport potential of contaminants by wild bee colonies near waste storage facilities. Pollen and honey from colonies established in areas remote from radwaste facilities have been collected to determine background levels of radionuclides. Other colonies have been situated near Hanford waste ponds to evaluate the availability of radiocontaminants to bees. Radiochemical analyses of the pollen and honey are not yet complete. A total of 14 wild colonies have been documented; however, much of the site remains to be examined.

Wind Erosion Studies

Severe wind erosion in waste management areas may cause an unacceptable loss of soil cover and threaten to expose buried materials. Consequently, some waste management areas that are burned may require immediate restoration while others may best recover without any assistance.

This study documents soil types that are potentially susceptible to wind erosion following a wild fire and examines revegetation rates in assisted areas and areas allowed to recovery naturally.

Most waste management areas on the site are located in sagebrush/cheatgrass communities. This vegetative type is very susceptible to fire. Major wild fires occurred in 1957, 1963, 1970 and 1978 and often burned previously burned landscapes. The long-term effect of wild fires in communities dominated by perennial grasses (e.g., bluebunch wheatgrass) is much less severe than in communities dominated by cheatgrass (an annual). Since the crown/root system is not usually damaged, the perennials usually revegetate a burned area the following year. Annual-dominated areas however, take longer to recover; new seed sources are required, and in the meantime, the wind erodes the unprotected soil.

Results to date indicate that revegetation appears to be able to occur naturally in burned areas in which the total amount of erosion does not exceed 1 to 2 cm. Severe soil loss (5 cm) prevents first season restoration. This may be associated with a loss of seed reserves in the severely eroded site because the mildly eroded site (1 to 2 cm) seemed to retain as many seeds as an unburned site.

Waterfowl Movement Studies

This study is designed to determine the movement and Hanford waste-pond usage patterns of the wintering mallard duck. The Hanford Reach of the Columbia River is a major wintering area for waterfowl. This study is conducted in cooperation with the U.S. Fish and Wildlife Service (FWS), which is interested with the general well-being of waterfowl in the Mid-Columbia Basin.

To date, thirteen mallard ducks have been trapped at Gable Mountain pond and fitted with radio-transmitters and FWS leg bands. An additional 14 ducks were fitted with leg bands only. Radio frequencies from each individual radio-tagged duck were monitored periodically to determine their locations. Locations that were monitored by FWS included: Gable Mountain pond, West Lake, B-pond, Hanford Reach, and areas throughout the Mid-Columbia Basin.

Of the 13 mallards tagged, four remained on the pond; one was observed on Saddle Mountain ponds north of the Columbia River on the Hanford Site; two spent at least half their time away from the pond at the Columbia Wildlife Refuge (CWR) and the 100-F slough; and the six remaining mallards were not observed again on Gable Mountain pond but were observed to the southeast near Fishhook Park on the Snake River, to the northeast at the CWR and along the Columbia River from the Vernita Bridge to the Tri-Cities.

Additional tagging studies are planned to collect data on the use and duration-of-use patterns of the various cohorts of mallards identified during the past wintering season.

Aquatic Radioecology of Waste Management Areas

Actinide Transport

This study is designed to provide information on the potential transport of actinide elements through aquatic food chains leading to man. U-pond, a nuclear waste pond on the Hanford Site, was used as a

"worst case" situation for the potential mobilization of actinides and subsequent ingestion by man. U-pond has concentrations of ^{238}U, ^{238}Pu $^{239,240}Pu$ and ^{241}Am that are approximately three orders of magnitude greater than background levels.

Experimental work involved observing the accumulation of actinides in bluegill (Lepomis macrochirus) and bass (Microterus salmoids) inhabiting U-pond. The fish appeared to obtain most of their actinide burdens from the sediments; however, the variability in the data suggested that the results were best interpreted on an order-of-magnitude basis. The concentration of actinides in the fish fillets were no more than two orders of magnitude above background levels. Whole-fish burdens were no more than a factor of 1000 times as great as control fish.

The radiation doses to humans resulting from the consumption of U-pond fish fillets having the highest observed concentrations of actinides were calculated. If an individual consumed 0.45 kg (wet weight) of bluegill or bass fillets everyday, his 70-year total-body dose would be 0.1 rem and the bone dose 4 rem. These estimated values can be compared to the maximum permissible 70-year exposure accrual limit of 35 and 107 rem, respectively, as outlined in 10 CFR 20. Even though U-pond fish inhabit a highly contaminated environment, consumption of bluegill and bass from the pond would not result in significant radiation exposures from actinide elements.

Fate and Effects of Th and U

The proposed use of Th and U fuels as an alternative, nonproliferation fuel cycle has prompted study of the environmental behavior of Th and U in aquatic environments. The fate and effects of these actinides were examined under a "worst case" environmental condition--that is, all experiments were static and used a "soluble" form of the actinides. Organisms that were tested included daphnids, amphipods, midge larvae, trout and minnows. Studies presently being conducted or evaluated include determining Th uptake mechanisms (i.e., gut loading versus surface adsorptions); bioaccumulation of U by rainbow trout; toxicity of U on daphnids and midge larvae; and the effects of U on primary productivity. These results, along with studies planned for the future, will be used to update the parameters used in radiation-dose assessment models to quantify the movement of stable as well as radioactive contaminants associated with the entire Th/U fuel cycle.

Radioecology of the Columbia River

A document oriented to the lay person which describes the enviromental impacts of Hanford nuclear facilities on the Columbia River is being compiled from data that has been gathered over the past 30-plus years. This study is nearing completion.

Biotic Transport Parameters

Animal Feeding Studies

This study was designed to determine if there is a difference in the availability of ^{137}Cs to animals depending on whether it is incorporated in plant material or is in an aqueous solution. Some rabbits were fed lettuce that had been grown in ^{137}Cs-contaminated soil (radionuclide incorporated in the plant material), and other rabbits were administered the radionuclide by feeding them lettuce to which a solution of ^{137}Cs Cl had been applied to the surface of the vegetation. Initial results indicate that there is no difference in the assimilation or elimination rates of the two groups of rabbits. We plan to study other organisms and additional radionuclides in order to establish parameters for dose-assessment models.

Long-Term Recycling Model

A deterministic model that simulates the long-term accumulation of radiocontaminants by crop plants was completed and documented. The possible sources of contamination could be global fallout, operation of nuclear facilities, or the discharge waters from naturally occurring uranium ore bodies or geologic nuclear waste repositories. This model, termed CROPRE, was designed to include 1) the chronic input of contaminated irrigation water into both the soil compartment and directly onto the surface of the vegetation, 2) the incorporation of radiocontaminants in the soil organic matter pool and their eventual release for reuptake by subsequent crops, 3) the removal of contaminants from the system when the crops are harvested, and 4) the downward movement of radionuclides and their loss from the system by percolation.

The CORPRE model more realistically simulates the cycling of radiocontaminants in crop plants over long periods of time than do previous models. Thus, the predicted values obtained using CROPRE should be more accurate. The CROPRE model may need several modifications to increase its usefulness and precision as a predictive tool, but with or

without these modifications, it is recommended that it be incorporated into existing radiation dose-commitment models.

Soil Spiking Configuration Study

To determine how the plant root uptake of Cs and Sr is affected by the location of the contaminant in the soil profile, we are obtaining information on the vertical redistribution of the radionuclides with time in the soil profile in the presence of biological materials. A series of pots, 50 cm tall by 13.2 cm in diameter, were prepared in the following configurations: for the first four pots, a 100 g (0.5 cm) layer of soil spiked with ^{137}Cs and ^{85}Sr was placed a) on the surface of 50 cm (7900 g) of uncontaminated soil; b) 5 cm below the soil surface; c) 10 cm below the soil surface; and d) 40 cm below the soil surface. In the fifth pot, a 3500-g (20 cm) layer of spiked soil was placed above 5350 g (30 cm) of uncontaminated soil. In the last pot, the entire 8850 g (50 cm) soil column was uniformly contaminated with ^{137}Cs and ^{85}Sr.

Each pot contained 180 μCi of ^{137}Cs and 15 μCi of ^{85}Sr. Five replicates (a total of 60 pots) planted with peas and five planted with barley were prepared for each treatment. The pots are maintained in an environmental growth chamber. The crops are harvested at maturity and are presently undergoing radiochemical analyses. The pots, replanted for subsequent harvests, will eventually be cored to determine the vertical distribution patterns of the radionuclides in the soil profile after repeated harvesting.

The results of this study will be used in radiation dose-assessment models that are used to predict the potential impacts from the consumption of vegetation grown over buried radwaste. Presently, little or no information exists on plant uptake as a function of the depth at which the contaminant occurs below the soil surface.

• Environmental Behavior and Effects of Technetium 99 and Iodine 129

Investigators: T. R. Garland, D. A. Cataldo, R. E. Wildung, L. L. Cadwell, K. M. McFadden, R. G. Schreckhise, J. E. Rogers, S. W. Li and J. M. Thomas

The principal objective of this program is to define the environmental behavior of ^{99}Tc and ^{129}I, two long-lived radioactive by-products of the nuclear fuel cycle which have received little study. The specific objectives are: 1) to determine the soil physicochemical and microbiological factors and physiological parameters that govern the mobility and bioavailability of different chemical forms to ^{99}Tc and ^{129}I in the terrestrial and aquatic environments, and 2) to validate and measure food web transport in selected field locations.

Preliminary assessments using soil-to-plant transfer coefficients derived from laboratory studies in simple dose-to-man models indicate that ^{99}Tc may contribute a major fraction of the long-term radiation dose commitment from existing and future dispersement of radionuclides in the environment. The principle reasons for ^{99}Tc's significant contribution to the long-term dose commitment are that: 1) under aerobic soil conditions, Tc exists as TcO_4^- with K_d values <1 for most soils (cf Pu K_d values of 500 to 10,000); 2) soil-to-plant transfer coefficients for Tc (under lab conditions) are 200 or greater (cf Pu CR of 10^{-3} to 10^{-5}); and 3) gut transfer values for TcO_4^- in rats and guinea pigs are 100 to 1,000 times greater than Pu.

Although the research on this program has shown Tc and I to be mobile in the environment and readily taken up by plants and animals, adequate assessment of the potential hazards to man require a more thorough understanding of the mechanism that may limit their effects or reduce their long-term mobility in the environment.

Environmental Behavior of Tc

The three major sources of ^{99}Tc ($T_{1/2}$ = 2.1 x 10^5 yr) which account for nearly all of the current environmental inventory include weapons testing, nuclear fuels reprocessing and, to a much more limited extent, pharmaceutical use of ^{99m}Tc which decays to ^{99}Tc. To a large degree, the behavior of Tc in the environment is a result of its chemistry. Although known to exist in all valence states from +7 to -1, Tc behavior under aerobic conditions is principally governed by the negatively charged pertechnetate ion (TcO_4^-). The pertechnetate ion is highly soluble and mobile in soils and sediments. Under reducing conditions, TcO_4^- can become Tc^{+4}, in which case the solubility is significantly reduced by hydrolysis to $TcO_2 \cdot 2H_2O$ or reduced by precipitation reactions with sulfide ions to Tc_2S_7 or TcS_2. Reduction in apparent mobility of TcO_4^- in soil and sediment systems can also occur through uptake by microorganisms and other biota.

Studies of TcO_4^- under laboratory conditions have shown high availability from soils to plants with concentration ratios (concentration Tc in plant to concentration of Tc in soil) exceeding 200. At soil levels >0.1 μg/g, TcO_4^- is toxic to plants. Both the toxicity and high concentration ratios are related to the fact that TcO_4 appears to behave to some extent as a nutrient element.

To test whether the TcO_4^- behavior observed under short-term laboratory studies could be extrapolated for field use, soils and plants growing near a fuels reprocessing plant were collected and analyzed for ^{99}Tc (Table 5.3). Of particular significance in

Table 5.3. ^{99}Tc in Soils and Plants Near a Nuclear Fuels Reprocessing Plant (Atmospheric Input Only)

Component	Concentration, pg/g ^{99}Tc	^{137}Cs
Sagebrush (artemisia tridentata) leaves	39.2	0.023
Litter layer	13.2	0.21
Soil 0-5 cm	0.17	0.0038
6-15 cm	0.41	0.0005
16-25 cm	0.25	0.0005
26-35 cm	0.13	0.0005
Surface soil 0-20 cm (20 miles from site)	0.0159	0.0056

these studies is a lack of Tc input to the soils or vegetation for at least six years prior to sample collections. The concentration of Tc in sagebrush leaves at this site is about 175 times greater than the entire average soil concentration at depths from 0 to 35 cm. The concentration of Tc in the sagebrush leaves is due to root uptake and not foliar deposition. This conclusion is based on the ratio of Tc to Cs (if from global fallout the ratio is calculated to be 0.98 to 2.0 depending on decay time from event) and from a lack of atmospheric source of Tc to this site for at least six years. Note that the surface soil about 20 miles from the collection site has a Tc to Cs ratio of ~2.8. Since the site has not received Tc input for six years, the levels observed in the sagebrush leaves and the soil may be due to cycling from the soil to the leaves, and then from the leaves to the litter, where rainfall leaches Tc from the litterfall into the soil and the cycle begins again. If such a cycle exists, which the existing data suggest, simple models of soil to plant transfer using concentration ratios and subsequent plant-to-animal transfer coefficients will be inadequate to give accurate predictions of long-term dose commitments to man. The needed models which are suggested by this reasoning are kinetic models with associated data inputs of transfer rates (source to soil, soil to plant to soil, and plant to animal). Such model studies have been initiated and preliminary results indicate that significant differences in final output will be observed. The major limitation to more extensive and detailed kinetic models are a lack of rate data for input.

Environmental Behavior of ^{129}I

The environmental behavior of radioiodine (principally ^{131}I, but also many measurements of ^{129}I) has been studied extensively over the past 30 years. Extensive studies of iodine were conducted when early findings indicated that ^{131}I ($T_{1/2}$ = 8.0 days) was concentrated in the thyroids of animals, including man. In addition, ^{131}I was easy to measure using relatively simple instruments. No chemical separations were necessary. Iodine-131 data, however, cannot be used to predict the long-term behavior of ^{129}I because the short half-life of ^{131}I precludes studies extending beyond ~80 days.

Weapons testing and fuels reprocessing comprise most of the ^{129}I inventory currently in the environment. Most ^{129}I is deposited by atmospheric dispersion. The effect of fuels reprocessing on soil levels of ^{129}I 20 miles from the emission site is shown in Figure 5.2. Iodine-129 and cesium-137 ratios found in soils collected in Washington, Oregon, and Minnesota are plotted and arranged in ascending order. This order within the state of Washington generally follows the inverse of the distance from Hanford reprocessing facilities. Dashed lines show the calculated ratio expected from fallout that has been compared to and which coincides with values measured in Alaska lichens and the concentrations found in Columbia River sediments deposited behind McNary dam. The latter data and the relative smoothness of the data curve indicates that significant gross differences in the behavior of ^{129}I and ^{137}Cs after deposition are not occurring, i.e., one is not greatly more mobile than the other, and both are being concentrated or dispersed similarly. The fact that all soils have ^{129}I and ^{137}Cs

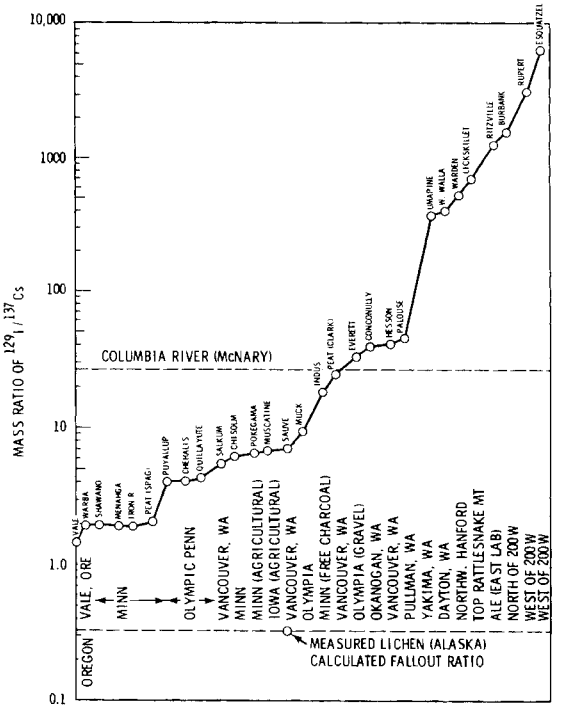

Figure 5.2. ~~Rate at Which ^{238}Pu is Absorbed from the Soil by Soybean~~ Plants
RATIO of Iodine-129 & CESium-137 in Soils collected in Oregon, Minnesota & Washington

ratios >5 times calculated fallout levels indicates that either ^{129}I is less mobile in soils than ^{137}Cs (less removed by runoff, plant uptake, volatilization, etc.), or that, when ^{129}I and ^{137}Cs have not been separated, the input of ^{129}I from fuels reprocessing is at least five times greater than from global weapons-testing fallout.

A second important aspect of the environmental behavior of ^{129}I is that it does not yet appear to be in equilibrium with endogeneous iodine pools. At a site near the nuclear reprocessing plants at Hanford, the concentrations of ^{129}I and total I reverse as the soil depths increase (Table 5.4). Input of ^{129}I from atmospheric deposition at the site over the past 35 years appears to have been retained by the surface (0 to 15 cm) of soil. The differences in the concentrations of ^{129}I in the leaves of sagebrush and in the litter (a factor of 24) versus that of total I in the same samples (a factor of 2.8), could indicate that there is either a differential behavior in the leaves of ^{129}I and total I after falling from the plant or that more ^{129}I has been deposited on the litter from the atmosphere in the past few years. Differential behavior of ^{129}I and total iodine would indicate that they are present in the sagebrush leaves in different chemical forms.

The conclusion that additional ^{129}I is deposited on the litter from the atmosphere is supported by studies that have indicated the existence of a soil-atmosphere pathway for ^{129}I after deposition. Modeling the environmental behavior of ^{129}I appears to require obtaining kinetic (time-related) data about transfer between interfaces (atmosphere-soil, soil-atmosphere, atmosphere-plant, soil-plant and plant-atmosphere). The behavior of ^{99}Tc might be explained in an analagous manner.

At this time, analytical costs prohibit making the required field measurements for Tc and I. Thus, emphasis will be placed on laboratory studies, with subsequent verification at selected field sites.

Table 5.4. ^{129}I and Total I in Soils and Plants Near a Nuclear Fuels Reprocessing Plant

Component	^{129}I, pg/g	Total I, g/g	Ratio ^{129}I to I Total x 10^6
Sagebrush (artemisia tridentata) leaves	8.5	0.46	18
twigs	6.9	0.15	46
Litter layer	205	1.3	160
Soil 0-5 cm	30.0	0.15	200
6-15 cm	16.0	0.31	52
16-25 cm	4.0	0.34	12
26-35 cm	2.5	0.58	4.3
Surface soil (20 miles from site) 0-20 cm	6.5	0.56	12
Surface soil (Olympic Peninsula 400 miles from site) 0-20 cm	0.021	5.4	0.0039

6 Marine Research Programs

MARINE RESEARCH PROGRAMS

- **Effects of Energy Systems Effluents on Coastal Ecosystems**
- **Bioavailability of Energy Effluent Materials in Coastal Ecosystems**
- **Marine Chemistry of Energy-Generated Pollutants**
- **Iron-55 Phenomenon**

The oceans and the coastal marine ecosystems have always been an integral part of the food and energy resources of the United States. In the past, however, little attention has been given to developing a basic understanding of the mechanisms and processes that are involved in the operation of the marine ecosystem or on how it is affected by mans' use. In recent years, a growing realization of the limits of land-based resources has resulted in an increased use of the ocean and in investigation of the availability of new resources. This increased activity in the oceans, and particularly the shallow coastal regions, has created conflicts between the various groups of users. The major potential conflicts appear to be similar to the traditional land-use conflicts (e.g., the industrial and aquaculture-type activities vs. the recreational, ecological preservation-type activities).

The development and expansion of existing and new energy technologies is one of the major industrial users of the marine environment. The ocean, which contains oil and gas resources, has the potential to provide new energy resources such as ocean thermal energy conversion (OTEC), tidal power, wave power, and biomass. The ocean also serves as a disposal site for effluents and byproducts such as waste heat, oil and gas well discharges, low-level nuclear wastes, and it is the ultimate sink for many materials discharged to the land, atmosphere and freshwater streams. In addition, a major portion of the transferable energy sources—oil, gas, liquefied gas, synfuels and other future energy sources—are transported either directly across or in proximity to oceans and coastal zone regions. These activities present the potential for energy technologies to have a major impact on the marine ecosystem and, in particular, the shallow coastal zone.

The research programs discussed in this section have been investigating questions about the effects of contaminants common to many energy technologies on the marine ecosystem. The multidisciplinary approach utilizes a wide range of scientific expertise to address the complex problems associated with understanding the interaction of materials discharged by energy technologies into the marine ecosystem. The studies identify the quantities and forms of contaminants entering the marine ecosystem, qualify the existing background concentrations, and determine how physical, chemical and biological factors influence the bioavailability of these materials and their effects on organisms, populations and communities.

Marine chemistry research investigates the cycling and flux rates of contaminants between the atmosphere or sediment and the water. New methods are being developed and validated to measure particular chemical species in ocean waters. Studies examine the deposition of organic combustion products in Pacific Northwest marine waters, the chemical behavior and toxicity of aerosols entering the marine environment, and the relationship between the specific activity of ^{55}Fe in salmon as compared to that of the surface ocean waters and atmosphere. Investigations of the bioavailability of contaminants and factors controlling bioaccumulation include studies on the interaction of Cd with organic and inorganic materials, Cd chemical speciation and availability to littleneck clams, the chemical speciation of Cu and Ni and their interaction with sediment, and the toxicity of aerosol particulate matter to phytoplankton. The research program on the biological effects of contaminants has centered on the mechanisms by which marine organisms are able to detoxify and adapt to metal exposure and the relationship between the activity of such mechanisms and the toxic effects of metals. Taken as a whole, these individual research programs represent an integrated effort to understand the systems and processes underlying interactions between energy-related contaminants and the marine environment.

Marine Research Programs on petroleum contamination funded by EPA and NOAA and other programs on the ecology of the Puget Sound region will be found in:

Annual Report for 1980
on Interagency/Contract Research
Ecological Sciences Department

• Effects of Energy Systems Effluents on Coastal Ecosystems

Principal Investigators: G. Roesijadi and J. S. Young

The objective of this research is to identify and evaluate effects that contaminants released by energy technologies have on the well-being of marine animals. We have been investigating the mechanisms that regulate subcellular trace metal binding and storage and their relationship to the toxicity and detoxification of metals.

Research results this past year included the following: 1) mussels (*Mytilus edulis*) exposed to mercury respond by induction of a low molecular weight, mercury-binding protein; 2) induction of the mercury-binding proteins is associated with an increased binding of mercury to the proteins; 3) previous exposure of mussels to low mercury concentrations results in an increased tolerance to toxic concentrations of mercury, whereas higher pre-exposure concentrations do not result in such a tolerance; and 4) characterizing the normal histology, histochemistry, and ultrastructure of the pinnules of the polychaete *Eudistylia vancouveri* and developing procedures for the histochemical localization of lysosomes and intracellular copper for *E. vancouveri*.

Low Molecular Weight, Mercury-Binding Proteins in the Marine Mussel

In a previous study, we demonstrated that gills are a primary organ for the incorporation of mercury and that gills respond to mercury exposure by induction of low molecular weight, mercury-binding proteins (Hg-BP). In the past year, the role of these proteins has been studied in further detail and an attempt has been made to characterize them.

Mussels were exposed to 5 µg/L of mercury for 28 days. Induction of Hg-BP during this period was determined by following the incorporation of ^{35}S-cysteine into the Hg-BP of gills, which had been excised at intervals during the exposure. Induction of two Hg-BPs was detected. One protein (Hg-BP II), whose induction was detected on the first day of exposure, eluted from Sephadex G-75 at a position similar to that of rat liver metallothionein (~10,000 daltons apparent molecular weight). The second protein (Hg-BP I), about twice as large as the first, was the significant mercury-binding protein in mussel gills. Induction of this protein was observed on day 7 of exposure. The protein's incorporation of Hg was initially slow, then increased rapidly and linearly after its induction. The relative amount of Hg in the gill associated with Hg-BP I increased up to day 15. After day 15, there was an increase in the Hg associated with high molecular weight proteins and the particulate fractions. We are testing the hypothesis that these changes may be due to the onset of toxicity.

Hg-BP I was selected for biochemical characterization. The proteins were initially separated on Sephadex G-75, then collected and applied to a column of diethylaminoethyl (DEAE)-cellulose. Although metallothionein and other cadmium-binding proteins are routinely purified by this procedure, we found that Hg-BP I in mussel gills essentially binds irreversibly to DEAE-cellulose. The physicochemical properties of Hg-BP differ from other low molecular weight, metal-binding proteins. As an alternative procedure, proteins were passed through a column of carboxymethyl (CM)-cellulose, collected in the column void, then subjected again to Sephadex G-75 chromatography. Purity was checked by high-pressure liquid chromatography. Amino acid analysis of the purified protein indicated that high levels of cysteine glycial and the carboxylic acids, glutamic and asportic, acid were present. The aromatic amino acids tyrosine and phenylalamine were also present.

Antiserum to Hg-BP I has been induced in goats as a first step toward the development of immunoassays for the protein.

Induced Tolerance to Mercury Toxicity Following Pre-Exposure of Mussels to Low Levels of Mercury

In order to determine whether preexposure of mussels to low levels of mercury and the associated Hg-BP induction can alter tolerance to mercury, mussels were exposed to 0.5 and 5 µg/L Hg for 28 days, then exposed to acutely toxic bioassay concentrations of 75 to 300 µg/L mercury. The results indicated that a highly significant increase in tolerance to mercury occurred in mussels that were pre-exposed to 0.5 µg/L, then subsequently exposed to the lower concentrations (75, 100 µg/L) of the acute bioassay. Mussels pre-exposed to 5 µg/L and subjected to all bioassay concentrations and those pre-exposed to 0.5 µg/L and subjected to the higher bioassay concentrations (150, 200, 300 µg/L) did not exhibit higher tolerance than the mussels in the control group. Pre-exposure to low mercury concentrations can result in increased tolerance to mercury; however, there were also upper limits in the pre-exposure levels that were able to induce tolerance and in the levels to which induced tolerance was effective. Subsequent work has extended the lower range of mercury concentrations which induce tolerance to 0.05 µg/L, a concentration which approaches background levels of mercury in sea water.

Field Studies: Mercury in Mussels

We previously reported that mussels in Bellingham Bay, Washington, contain slightly elevated levels of mercury. However, the levels were not serious enough to warrant continued study. Preliminary findings on mussels recently collected in the vicinity of Tacoma, Washington, indicate that these mussels contain significant quantities of mercury (~0.2 µg/g) and that they may be a suitable population for field testing of hypotheses that metal accumulation and detoxification is related to the activity of metal-binding proteins.

Effects of Copper on the Polychaete Eudistylia Vancouveri

Previous work with Eudistylia vancouveri was concentrated on copper uptake and histo- and cytological changes in the pinnules of E. vancouveri following copper exposure. In the past year, the normal histology, histochemistry, and ultrastructure of the gill pinnules of E. vancouveri were characterized in order to understand more clearly the pathologic effects of copper on these structures. The pinnules are secondary projections of the branchial crown that aid in respiration and feeding. Each pinnule consists of a cuboidal to columnar, grandular epithelium that surrounds a column of cellular cartilage; a blind-ending blood vessel; and associated musculature.

The epithelium has a transport function and possesses well-developed microvilli, folded cell-to-cell surfaces, numerous mitochondria, and pigment granules. The frontal face of the pinnule is grooved and lined with cilia that channel food particles toward the mouth. Cells forming this food groove are unpigmented and nonglandular. Another row of cilia forms a narrow band on the abfrontal face, which seems to aid in directing water and food over the gills. Two kinds of gland cells were distinguished in the pigmented, unciliated epithelium. One kind, distributed along the entire length of the lateral faces, contains fusiform bundles of secretory rods that are open to the surface. The rod formation is associated with a small amount of granular endoplasmic reticulum (GER). Histochemical tests indicated the presence of non-specific mucin or gylcogen. Other histochemical tests were negative. The other kind of gland cell was a saccate collection of secretory droplets located fronterolaterally near the ciliated groove. The droplets, possibly a glycoprotein, are formed in association with extensive GER and Golgi apparatus.

The cellular cartilage, which consists of a thin, layered, fibrous mucoprotein that adds support to the pinnule, is secreted by a single column of highly vacuolated chondrocytes. The cartilage is separated from the epithelium by a layer of collagen.

The blood vessel is an elastic tube that branches from a larger vessel in the gill rachis and extends to the pinnule tip. Bands of striated muscle that surround the vessel rhythmically constrict the lumen to facilitate blood exchange.

Longitudinal muscles lying under the epithelium and collagen run the length of each pinnule and control its movement.

Because of the interest in lysosomal sequestering of toxic metals, tests were made for the lysosomal marker enzymes, acid phosphatase and N-acetyl-B-D-glucosaminadase. Activity was localized in the epithelium and chondrocytes. Two vital stains for lysosomes, neutral red and acridine orange, showed the same localization. Cryosectioned gills from copper-exposed animals, stained for the presence of copper, showed that copper was present as granules in the same areas as lysosomes. This indicates a relationship between lysosomes and the subcellular localization of copper.

• Bioavailability of Energy Effluent Materials in Coastal Ecosystems

Principal Investigators: E. A. Crecelius, C. I. Gibson, J. T. Hardy, J. E. Rogers and R. L. Schmidt

Other Investigators: J. M. Gurtisen, C. W. Apts, and S. P. Joyce

This research program involves a multidisciplinary effort to determine the bioavailability of energy-effluent materials in the marine ecosystem. We are examining chemical speciation of contaminants in seawater, the bioavailability of different contaminant species to marine organisms, and various sediment-contaminant interactions.

During the last several years, our major goal has been to better predict the bioavailability and fate of copper in the coastal ecosystem. Recent efforts involve four main tasks: 1) bioavailability of dissolved and organically-bound Cd to the littleneck clam, *Protothaca staminea*; 2) chemical speciation of cadmium in sea water; 3) interaction of sediment with Cu and Ni; and 4) toxicity of atmospheric particulate matter to phytoplankton. We are presently comparing our previous studies on the behavior of copper with our current studies on the bioavailability of Cd and Ni.

Kinetics of Cadmium Bioaccumulation

Significant advances in our understanding of the bioavailability of metal contaminants can be made by focusing on particular metal/organism interactions. Examining such metal/organism systems will eventually help us to construct a more general quantitative model to define the variables controlling the movement of metals from seawater into marine organisms. Initial efforts have focused on the bioavailability of cadmium to the marine clam, Protothaca staminea. We have chosen this interaction system because 1) cadmium is an important and widespread toxic contaminant in the marine environment; 2) it has a radioisotope (^{109}Cd) convenient for use in tracing its bioaccumulation; 3) many factors apparently control the bioavailability of cadmium, but these are not well understood at present; 4) P. staminea, like other bivalves, filters large volumes of seawater during feeding and, thus, concentrates toxicants from seawater. This clam is easily collected and maintained in our laboratory and can be readily dissected into individual tissues and organs.

Whole Clams

We studied the effects of dissolved organics (algal exudates) on the uptake kinetics of cadmium in whole clams. Whole clams accumulated cadmium linearally over a 48-hr period at an average rate of 0.13 µg of Cd/clam hr. Adding low concentrations of algal exudate (15 and 150 µg dissolved organic carbon DOC/L) had no measurable influence on cadmium uptake in whole clams; however, at an algal exudate concentration of 3,700 DOC/L of seawater, cadmium uptake by clams was reduced to 0.05 µg Cd/clam hr, i.e., the cadmium bioaccumulation was reduced by 62% when algal exudate was present in the seawater.

The (baseline) concentration of total organic carbon in 0.45 µm filtered Sequim Bay seawater used in these experiments was 1,330 µg DOC/L. Therefore, it is obvious that only in the highest algal exudate concentration was the background level of total organic carbon in seawater appreciably enhanced, and only at this highest concentration was the bioavailability of cadmium reduced. Whether this is due to a change in Cd speciation or to a change in the physiology of the clam has not yet been determined.

Individual clam tissues accumulated cadmium at different rates. The highest rate was found in gills, then neck and mantle, visceral wall, and was lowest in adductor muscle. The percentage distribution between

different tissues exposed to 5 µg/L Cd was approximately the same after 48 hr as it was after only 4 hr of exposure.

Excised Gills

Although biochemistry has benefitted greatly from the use of Michaelis-Menten formulations to describe enzyme, substrate, and inhibitor interactions, few studies have investigated the bioaccumulation of substances by marine organisms in terms of Michaelis-Menten kinetics. The few exceptions to this trend indicate that this approach merits further investigation. We have tested the Michaelis-Menten relationship as a model to describe short-term uptake kinetics of cadmium in excised clam gills.

During a 24-hr period, the maximum bioaccumulation of cadmium occurred in the beaker containing 674 µg Cd/L. There, cadmium in the gill reached 3.99 µg Cd/gill or about 40 µg Cd/g dry wt of gill, which is, on a weight basis, a concentration 60 times greater than that of the surrounding water. Twenty-four-hour uptake in the 1020 µg Cd/L exposure was less, indicating a possible toxic effect (Figure 6.1).

Examination of the first 0 to 6 hours of exposure indicates that the initial rate of Cd bioaccumulation in excised gills increases hyperbolically with increasing Cd-seawater concentration; it eventually reaches an asymptote or apparent saturation rate. Thus, initial uptake of Cd by gills can be expressed in terms of classic Michaelis-Menten kinetics. Plotting [Cd]/v produces a straight line, and by using a least squares linear regression statistical analysis, Y = 1.57 + 0.006 X, r2 = 0.98.

$$v = \frac{V_m[Cd]}{K_m + [Cd]}$$

where v = velocity of uptake,
V_m = maximum velocity

$[Cd]$ = cadmium concentration (µg Cd/L), and

K_m = Michaelis-Menten half-saturation value, or the substrate concentration at which the velocity is half of the maximum velocity.

The extrapolated apparent maximum velocity of Cd bioaccumulation is 164 ng Cd/gill hr. The Cd concentration at which the uptake velocity is half of its maximum velocity (K_m) is 262µg Cd/L seawater (Figure 6.2).

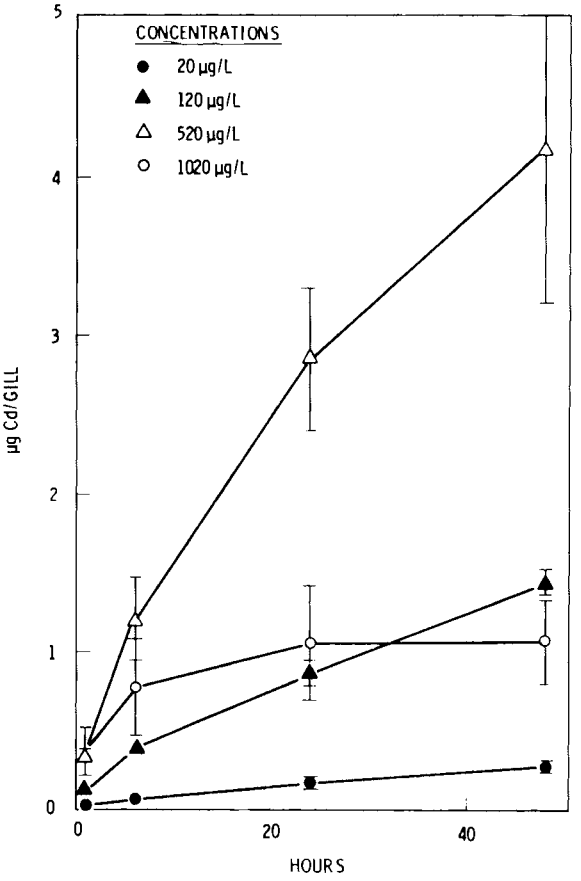

Figure 6.1. Effect of Seawater Cd Concentration on Cd Uptake in Clam Gills During a 48-hr Exposure

Excised gills held for 96 hr under the same experimental conditions (without Cd) and subsequently exposed to 20µg Cd/L, accumulated Cd at the same rate as initially exposed gills over the first 6 hr of exposure. This indicates that the gills were in a healthy physiological state during the experiment. Our previous measurements of oxygen consumption after 24 hr also indicate that excised gills remain in a healthy metabolic state for at least 24 hr.

We refer to V_m as the apparent saturation of the Cd-uptake rate. We cannot conclude from this data, however, whether V_m is a true saturation constant in which the enzymes or membrane sites for Cd uptake become saturated, or whether there is a negative feedback loop of Cd toxicity on some mechanism necessary for Cd uptake. Further experiments are planned to examine the effects that specific metabolic inhibitors and dissolved organic substances have on Cd bioaccumulation.

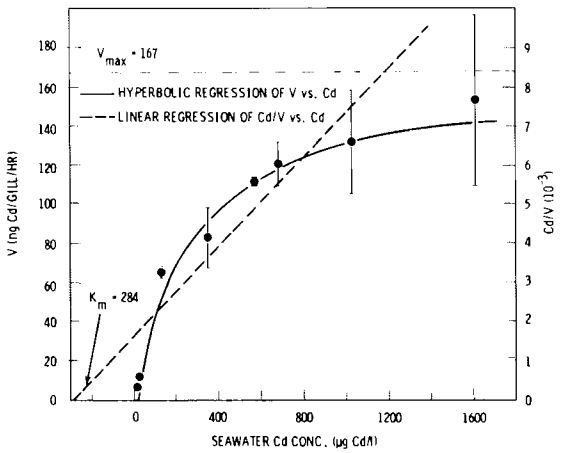

Figure 6.2. Cd Bioaccumulation in Excised Clam Gills Follows Michaelis-Menten Kinetics

Chemical Speciation, Complexation, and Bioavailability

Copper

Several researchers have suggested that organic compounds influence the chemical speciation and bioavailability of copper in the marine environment. However, the impact of organics on equilibrium models has been precluded by a shortage of appropriate chemical data. The bioavailability of copper to several marine invertebrates is related primarily to the concentration of free ionic (uncomplexed) copper in the water. We have found different rates of bioaccumulation when using aged and fresh solutions of copper and seawater.

When Cu uptake, as measured by anodic stripping voltametry (ASV), is examined in terms of free and labile copper, bioaccumulation increases linearly with increasing free-copper concentration. The stability constant (log K) and complexing capacity (C_L) of the organic fraction in seawater has been re-evaluated using ASV. Modifications to our amperometric titration procedure were made and a correction factor was applied. This will account for adsorption effects and for labile metal forms (hydroxy and carbonato species) measured by ASV. A new value for the copper-organic stability constant and complexing capacity is log K = 9.6, $C_L = 0.105 \times 10^6$ M.

Cadmium

It has been suggested that Cd^{++} is complexed by Cl^- in seawater. To test whether or not there is an inverse relationship between salinity levels and Cd^{++} uptake rates in marine organisms, previous researchers simply diluted experimental solutions with distilled water and monitored metal uptake. However, other factors besides chloride ions (e.g., dissolved organics) might have shared control of or even dominated the availability of Cd^{++}. The effects of these factors would have been diminished by dilution. Our approach was to increase salinity from a base solution of 20 ppt up to 35 ppt by adding ultrapure NaCl. The commonly accepted inverse relationship between salinity and Cd uptake was not reaffirmed by our data on clam gills.

The performance of a cationic adsorption column has been characterized for Cd^{++} in seawater and compared to a seawater-Cd^{++}-phytoplankton exudate matrix. Cadmium-109 was used as a tracer to monitor the extraction efficiency of the resin column. The extraction rate was linear, which indicates that the organic exudate had no effect on the movement of Cd^{++} through the column. This suggests that either there are no Cd-exudate interactions or that the technique may be insensitive to the interaction. The sensitivity of the technique to weak interactions is presently being investigated.

Sediment and Trace Metal Interaction

Previous research has indicated that the presence of sediments can greatly influence the bioavailability of trace metals to marine invertebrates. We are continuing investigations in this area. Measurements of soluble copper (<0.4 µm) in Sequim bay surface water indicated that a seasonal range existed from 0.3 µg/L in February, 1979, to 1.1 µg/L in September, 1979. The seasonal increase in Cu concentration was accompanied by a concomitant and significantly correlative increase in dissolved organic carbon. The source of increased soluble Cu appears to be external to Sequim Bay since the concentration of Cu in suspended form and in the sediment also exhibited similar seasonal changes.

In a series of laboratory studies, ionic copper was added to slurries consisting of 100-g Sequim Bay clayey silt suspended in 1 liter of seawater in concentrations of 1.5, 15, and 150 mg/L. Following a period of equilibrium, pH adjustments were made and samples of the slurries were centrifuged and filtered. More than 98 of the added Cu was reduced to insoluble forms (<0.4 µm). The concentration of remaining soluble Cu ranged from 30 to 950 µg/L. When the soluble Cu fractions were subjected to ultrafiltration (filter retaining proteins $>10^3$ molecular wt.), only samples having the highest addition of ionic Cu (150 mg/L) exhibited detectable (>10 µg/L) levels of Cu in the filtrate. The Cu concentration in this fraction was 600 µg/L. Apparently, Cu is

first complexed by larger organic molecules until all of their binding sites are occupied. Cu in concentrations exceeding the complexation capacity of these molecules is not retained by ultrafiltration.

Recent studies have emphasized the role of microorganisms in maintaining or altering the distribution of trace metals (especially ^{63}Ni) between interstitial water (soluble fraction) and the sediment matrix (bound fraction). The redistribution of trace metals in an incubation system is examined when the microbial community is altered by the addition of a readily metabolizable organic substrate such as glucose. These studies have been conducted using a stirred sediment-seawater (1:10) incubation system in which pH and E_h were continuously monitored.

Initial results suggest that there is a correlation between glucose use and an increase in soluble ^{63N} (Figure 6.3). The increase in soluble ^{63}Ni appears to be transitional; when maximum solubility is reached, solubility slowly decreases with time. This increase in soluble ^{63}Ni concentration may be attributed to a number of factors related to the microbiological degradation of the glucose. Of primary interest is the formation of microbial metabolites capable of forming soluble ^{63}Ni complexes. Of secondary interest, and in conjunction with the formation of metabolites, is the observed reduction in E_h because of reduced oxygen levels due to glucose use and the reduction in pH (7.0 to 5.3) from glucose metabolism. The E_h profile over the incubation period was complex and will require further study. The reduction in pH occurred within three days of glucose addition and remained at 5.3 for the duration of the incubation. Elements such as Ca, Sr, Mg and Mn for which the solubility would be expected to be pH dependent upon the pH level, were found to be more soluble as the pH was reduced. However, Fe and Al showed no appreciable change in concentration. Further characterization studies at fixed pH and E_h values will enhance our understanding of the processes involved in sediment and trace metal interactions.

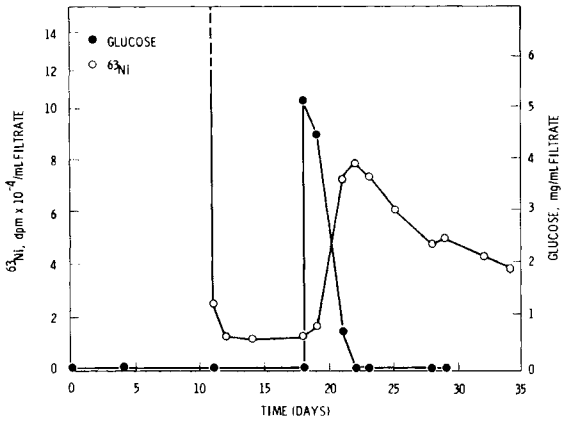

Figure 6.3. Solubilization of Sediment-Bound Nickel after Addition of a Microbial Substrate (Glucose)

Atmospheric Particulate Matter: Inhibition of Marine Primary Productivity

Using high-volume air filtration, particulate matter from the atmosphere was collected at urban and rural locations and analyzed by X-ray fluorescence. When trace elements were added to seawater, the ratios of soluble trace elements from equal amounts of urban (Seattle) to rural (Quillayute) atmospheric particles were: As 112, Br 6.4, Cr 3.4, Cu 3.7, Ni 3.0, Pb 36, V 2.7, and Zn 2.2. Air particulate matter added to sea water resulted in an exponential reduction in photosynthetic carbon-14 assimilation by natural marine phytoplankton populations. Particles collected from urban areas were six times more toxic than particles from rural areas (Figure 6.4). Existing models suggest that most of the toxicity results from concentrations of soluble Pb, V, Cd, Cu, Zn, and Ni (in that order). However, present deposition rates of atmospheric particulate matter do not appear high enough to inhibit marine primary productivity except, perhaps, at the sea-surface microlayer.

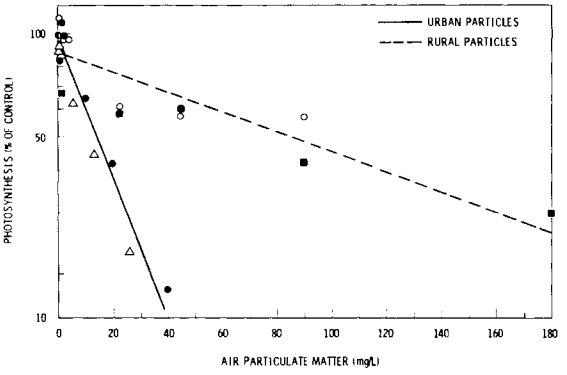

Figure 6.4. Influence of Atmospheric Particulate Matter on Photosynthesis in Natural Populations of Marine Phytoplankton

• Marine Chemistry of Energy-Related Pollutants
• Iron-55 Phenomenon

Principal Investigators: E. A. Crecelius, D. E. Robertson, and K. H. Abel

These programs are designed to increase our understanding of the biogeochemical and physical processes that control the fate of energy-generated pollutants that enter the marine environment. As the energy needs of our country increase, coastlines are being used as sites for energy-generating facilities and related industries. As a result, increasing amounts of energy-related pollutants are introduced into the oceans. This research is vital to the U. S. Department of Energy in that it provides an understanding of 1) the natural origins, distributions and concentrations in baseline data of trace metals and other contaminants in the oceans; 2) the input rates and mixing rates of pollutants introduced to the oceans; 3) the behavior and fate of the anthropogenic pollutants entering the oceans from the atmosphere and the continents; and 4) provides an assessment of the potential environmental impact of energy-generated pollutants on the marine environment.

Presently, the Marine Chemistry program is concerned primarily with concentrations and processes that affect the fate of pollutants entering the ocean. The Iron-55 Phenomenon program, closely related to the Marine Chemistry program, is examining the chemical speciation of soluble air particulate matter. Specific tasks pursued during the last year include: determining the diffusion coefficient for Hg° vapor between air and seawater; intercalibrating a mercury-analysis technique; measuring atmospheric input of combustion organics; determining the solubility of air particulates in seawater; and interpreting high ^{55}Fe-specific activities in salmon.

Experimental Determination of the Diffusivity of Hg° Vapor in Seawater

Man's mobilization of mercury by energy production and metal smelting has prompted concern regarding the movement of this pollutant through the environment. The anthropogenic flux of mercury in the environment has been estimated to exceed the flux due to natural processes. Mass balances of global mercury have suggested that the oceans are a potential sink for atmospheric mercury. In order to estimate the exchange rate of Hg° vapor between air and seawater, the diffusion coefficient must first be measured.

Experimentally, we have measured this coefficient in the laboratory using radiolabeled mercury. We used the stagnant-boundary layer model for gas and water exchange. This model assumes that mass transfer of Hg° vapor occurs by diffusion through the boundary layer. In our experiments, we used CO_2 to measure the thickness of the boundary layer, and then, knowing this number, we determined the diffusivity of mercury under identical expermental conditions. The mercury-vapor diffusion coefficient was 2.1×10^{-9} m^2/sec in seawater containing a NaCL solution and 2.7×10^{-9} m^2/sec in distilled water.

Using the mercury-vapor diffusion coefficient and the concentration of mercury vapor in the air and surface seawater, the flux of mercury vapor across the ocean can be estimated. Application of the mercury-diffusivity data is limited by lack of data on mercury vapor concentration in seawater.

International Intercalibration for Mercury Analysis in Seawater

During the last year, we participated in an international intercalibration experiment for the analysis of mercury in seawater. The exercise was organized by the International Council of the Exploration of the Sea (ICES).

Approximately 24 laboratories participated, including three other labs from the U.S. Seawater samples collected near Iceland by the Marine Research Institute were acidified, stored, and then shipped in borosilicate glass bottles. Our sample of unspiked seawater contained a mercury concentration of 7.0 ng/L. The average value that 16 other laboratories obtained was 4.4 ng/L. Our spiked-seawater sample had a mercury concentration of 25 ng/L; the average for all laboratories was 21 ng/L.

The results of the intercalibration are encouraging for two reasons: first, we have again verified that our analytical technique produces results that agree with those of other researchers, and secondly, the results help confirm that the concentration of mercury in the open ocean is in the range of a few ng/L.

Measuring Atmospheric Deposition of Organic Combustion Products

This task will estimate the types and quantities of organic pollutants that enter Pacific Northwest marine waters from atmospheric fallout. Data collection and analysis are being conducted jointly with the University of Washington. During calendar year 1979, monthly air-particulate samples were collected at Seattle, Sequim, and Quillayute.

Chemical analyses of approximately 12 polynuclear aromatic hydrocarbons (PAH) and 9 elements have been completed on the Sequim and Quillayute air filters. In the fall of 1980, we will complete analysis of the Seattle samples. As expected, the concentrations of PAH and elements are lower in rural samples than in urban samples. The PAH concentrations at Sequim and Quillayute are similar, and the concentration patterns are typical of a high-temperature combustion source.

The deposition velocity of air particles has been previously determined for the Pacific Northwest. This will enable us to calculate the annual flux of polynuclear aromatic hydrocarbons to coastal waters. The concentrations of PAH will be determined in suspended matter collected from the Washington coast in the Fall of 1980. A comparison will be made between estimated atmospheric input rates of PAH and the flux of PAH in suspended matter moving through the water column.

BEHAVIOR OF SOLUBLE AEROSOLS IN THE MARINE ECOSYSTEM

Tasks of the Iron-55 Program during the last two years were conducted to determine the solubility of air particulate matter in seawater, compare the bioavailability of soluble elements in urban and rural aerosols, and reinterpret past data that is related to high specific activity of ^{55}Fe in Northeast pacific salmon.

The solubility values for urban air particulate matter (as reported in the National Bureau of Standards Reference material) was compared with values of air particles collected from air filters in Seattle and rural areas. The solubility of most elements that we examined were similar to and independent of the ratio of particle mass to volume of seawater for the range studied. These data confirm results previously published by this laboratory that the solubility of many elements in rural and urban air particulate matter is similar.

The biological uptake of soluble elements leached by seawater from air filters was determined using clam gills and phytoplankton as the experimental species. The results of these uptake experiments indicate that the bioavailability of soluble elements that are leached from urban and rural air filters is identical. Different elements were taken up by clam gills and phytoplankton, but no significant differences were noted in the percentage of an element that was removed from air filters containing urban as opposed to rural particulate matter. The elements that the gills concentrated from the solution were Eu, Co, Zn, Se and La. The phytoplankton concentrated Eu, Sc, Fe and Cr.

The similar bioavailability of elements from urban and rural air filters suggests that the same chemical form or forms are solubilized from urban and rural aerosols. Similar conclusions were reached in other experiments that were conducted jointly with the Bioavailability of Energy Effluent program in order to determine the toxicity of air particulate matter to phytoplankton. The results of these experiments (reported in part two of this section) showed that high concentrations of air particulate matter are toxic and that the toxicity is strongly correlated with the soluble heavy-metal concentrations.

Interpretation of High ^{55}Fe-Specific Activities in Salmon

We have examined data concerning the high specific activity (SA) of ^{55}Fe (dpm ^{55}Fe/mgFe) in salmon caught along the west coast of North America from 1963 to 1974. Our interpretation of the data indicates that the ^{55}Fe SA in salmon reflects the SA in air particulate matter. In addition, the specific activity of soluble ^{55}Fe in seawater (and presumably in organisms) would be approximately ten times

higher than the SA in the air particulate matter due to the increased solubility of ^{55}Fe versus stable Fe. The differences in the solubility of ^{55}Fe and Fe associated with marine aerosols was demonstrated several years ago by Weimer and Langford of this laboratory (1978).

Salmon spend much of their life as members of a pelagic food chain on the outer continental shelf or in the open ocean. Atmospheric input is a major source of stable iron and ^{55}Fe for this food chain. Because iron has a one year residence time in the surface layer of the open ocean, the ^{55}Fe SA in salmon should reflect the SA in marine aerosols, and, in fact, there is a good correlation between these data.

Two questions that have been asked in the past are: 1) Why is the ^{55}Fe SA in salmon much higher than in seawater? and 2) Why does the ^{55}Fe SA in salmon increase with latitude? In a given year, salmon caught in Alaska had five times higher SA than those caught in the area from California to Washington.

The answer to the question of why there is higher SA in salmon than in seawater is related to the increased solubility of ^{55}Fe versus stable iron. Since ^{55}Fe is more soluble than stable Fe, ^{55}Fe will have a higher SA than particulate Fe in the ocean. Assuming that soluble iron is the more important source of iron to the marine organisms, they will have a higher SA than the water in which they live.

The explanation for the increase in ^{55}Fe SA in salmon as latitudes increase is related to the changes in aerosol chemistry with geographical location. Salmon caught from the California-Washington area grew in an area where the coastal air chemistry is influenced by the continent and, consequently, where the ^{55}Fe SA in aerosols is low because of dilution from crustal iron. Salmon caught in the Gulf of Alaska grew in an area with less continental aerosol input than the Washington area and, consequently, reflect a higher ^{55}Fe SA.

The results of the ^{55}Fe phenomenon study show that chemical form influences the bioavailability of potential contaminants to salmon. The results of both the ^{55}Fe and Marine Chemistry programs are used to guide future research tasks in the bioavailability and effects programs.

7 Nuclear Fusion

NUCLEAR FUSION

- **Sublethal Effects of Tritium on Aquatic Systems**
- **Ecological Effects of Lithium and Beryllium on Aquatic Communities**
- o **Teratological Effects of Low-Level Magnetic Fields**

It is possible that as nuclear fusion technology is applied toward the designing of advanced nuclear reactors that greater quantities of some potentially harmful radionuclides will be released to the environment. This may be particularly true for gaseous and liquid effluents containing tritium. The fusion reactor design is expected to result in significantly greater releases of tritium than result from present pressurized-water reactor or boiling-water reactor designs. Anticipating such contingencies, the research programs described herein respond to the need to measure the potential radiation effects of tritium and other radionuclide releases on individuals and ultimately on populations and biotic communities.

In previous years, research was conducted to identify the effects that chronic low-level exposures had on developing embryo and larval states. Research in FY 1980 addressed the effects of tritium compared to those of radioactive cobalt.

Construction of fusion reactors may lead to a three- to five-fold increase in the mining, refining and fabrication of materials containing lithium and beryllium. The subsequent increase in dispersion of these elements in the environment may have adverse effects. Accordingly, our fusion research in FY 1980 included efforts to determine at what levels toxicity from lithium and beryllium could be expected. The effects of lithium and beryllium on embryo and larval stages of rainbow trout (*Salmo gairdneri*) and the effects of lithium on the production of biomass of benthic microflora and macrofauna were studied.

Our fusion-related research also included experiments on the effects of low-level magnetic fields. It is conceivable that attendant personnel working in the transport and hot-cell areas of fusion reactors will encounter magnetic fields of 70 to 450 gauss. Personnel assigned to the areas immediately surrounding the reactor may be exposed for substantial durations to field strengths of 1 to 70 gauss. The current PNL program is aimed at developing different measurement and end-points for the early detection of chronic effects in developing and adult organisms. Work involving mammalian tissue and cell systems is reported in PNL-3700, Part 1, Biomedical Sciences; work involving nonmammalian animal-systems is reported here. The coordinator for the comprehensive program is Dr. Dennis Mahlum.

For these experiments we are using aquatic organisms in their embryo and larval stages. This research should provide data that can be used to assess the effects of low-level magnetic fields on the life processes of higher vertebrates.

- Field Task Proposal Agreement
- o Work Order Agreement

- **Sublethal Effects of Tritium on Aquatic Systems**
- **Ecological Effects of Lithium and Beryllium on Aquatic Communities**
- o **Teratological Effects of Low-Level Magnetic Fields**

Principal Investigators: J. A. Strand, T. M. Poston, J. R. Skalski, R. M. Emery, D. C. Klopfer and C. S. Abernethy

Other Investigators: R. G. Genoway and S. A. Barraclough

Continuing studies of the sublethal effects of tritium on biological systems emphasize the determination of relative biological effectiveness (RBE) of ^{3}H beta irradiation when compared to ^{60}Co gamma irradiation applying the relatively radiosensitive immune process of the rainbow trout, *Salmo gairdneri*. This study is of practical importance since recent research findings suggest that a higher RBE value than is now recognized by the International Commission on Radiological Protection (ICRP) may be required.

We are also studying the potential effects of beryllium and lithium on aquatic systems. Because of mining and refining subsequent to the use of these metals in the construction of fusion reactors, increased levels of each are likely to be encountered in surface waters. Studies included an evaluation of potential toxicity of lithium on embryological life of rainbow trout and an assessment of fate and effects of lithium in artificial stream habitats. Levels of lithium necessary to cause an observed effect would have to be at least three orders of magnitude above observed background.

Studies on teratogenic effects of low-level magnetic fields conducted in FY 1980 address the need to develop potentially more sensitive approaches to measure the effects of magnetic fields on biological systems. Preliminary results are presented for an approach using a secondary chemical stress in addition to the primary stress of magnetic field exposure. It is the objective of this research to assess the potential harmful effects of magnetic fields on attendant personnel working in the transport and hot cell areas of fusion reactors.

SUBLETHAL EFFECTS OF TRITIUM ON AQUATIC SYSTEMS

Studies undertaken during FY 1980 applied the relatively radiosensitive immune process of the rainbow trout, Salmo gairdneri to determine the relative biological effectiveness (RBE) for ^{3}H beta radiation as compared to ^{60}Co gamma radiation. In earlier studies, we had demonstrated that the primary immune response of juvenile (5 month) and adult (17 month) rainbow trout, as determined by serum agglutination assay, was significantly suppressed and permanently altered at ^{3}H doses as low as 4 rads when delivered over the first 20 days of embryogenesis. Of secondary interest, we collected data on the potential effects of embryonic exposure to ^{3}H and ^{60}Co on hatachability, early survival, abnormality, late mortality, and growth.

Approximately 16,000 eggs were stripped from 12 three- and four-year-old female trout and fertilized immediately with sperm collected from 12 three- and four-year-old male trout. The embryos were well mixed,

divided into eight equal groups, and immediately placed in eight recirculating, constant-temperature (10.5 ± 0.2°C) incubators. Four of the eight groups were exposed for 20 days to ^{3}HOH (biological grade) at 0, 0.03, 0.25 and 2.5 rads per day. The other four groups were exposed for 20 days to ^{60}Co radiation at 0, 0.10, 1.0, and 10.0 rads per day. The effective dose levels of embryos exposed to ^{60}Co were designed to be approximately 4 times greater than the levels resulting from ^{3}HOH exposure.(a)

After being exposed to either ^{3}HOH or ^{60}Co for 20 days, all treatment groups were transferred to a single-pass incubation system until hatching. Hatching occurred in 28 ± 1.5 days at 10.5 ± 0.2°C. At 14 days after hatch, each treatment group was subdivided into four equal groups; each group was assigned to a different circular culture pond. Each pond consisted of eight compartments, each compartment receiving one of the now eight test groups. At 6 months after hatch, all test groups were removed from their respective compartments, marked for identification (liquid nitrogen cold-brand), and released to swim freely within their respective circular ponds. At 7 months after hatch, all test groups were vaccinated with heat-killed Flexibacter columnaris antigen in Freund's incomplete adjuvant. One week prior to vaccination, three weeks after vaccination, and at 2-week intervals thereafter, at least 20 fish per test group were sampled to determine serum agglutination response. A standard microagglutination test was applied to determine the concentration (titer) of agglutinating antibodies to F. columnaris. Decreased levels of circulating antibody served to indicate the degree of immune suppression that had been achieved.

This design facilitates treatment of the resulting agglutinin through the evaluation of treatment data by analysis of variance and orthogonal contrasts. Dose-response relationships for ^{3}HOH and ^{60}Co will further be compared to establish the relative biological effectiveness (RBE) of the ^{3}H-beta radiation.

The race of experimental fish presently reared in the Hanford hatchery only breeds during winter, so efforts to determine the RBE of ^{3}HOH will continue into FY 1981. Because the test fish were too small to vaccinate until September, 1980, post-antigenic sampling will not be completed until December, 1980. Accordingly, results at the time of preparing this report are limited to observation of the potential effects that ^{3}HOH and ^{60}Co have on early life-stages of the rainbow trout in terms of hatchability and latent mortality.

Exposure to ^{3}HOH at 0, 0.03, 0.25, and 2.5 rads per day over 20 days of embryogenesis resulted in hatching percentages of 93.3, 94.1, 95.4, and 94.3, respectively. For exposure to ^{60}Co at 0, 0.10, 1.0, and 10.0 rads per day, hatching percentages of 95.0, 95.8, 94.9, and 94.5, respectively, were recorded. Fry mortality for each ^{3}HOH treatment group through 60 days was 3.8%, 5.6%, 3.4%, and 3.6%, respectively. For each ^{60}Co treatment group, the values were 6.5%, 5.2%, 4.8%, and 4.5%, respectively. Mortality from day 60 to day 110 did not exceed 11.3% for the ^{3}HOH or ^{60}Co treatment group, with the exception of the 0.25 rad per day ^{3}HOH group where a value of 19.9% was recorded. Finally, mortality for day 110 to 200 after randomly reducing the number in each treatment group from 2000 to 600 averaged 24.0%. During this time, vaccination mortality accounted for <1.0% in each treatment group.

ECOLOGICAL EFFECTS OF LITHIUM AND BERYLLIUM ON AQUATIC COMMUNITIES

The purpose of this work has been to define the hazards associated with elevated concentrations of lithium and beryllium in freshwater environments. These elements will be expansively mined and used in fusion reactors. Our main objectives are to identify the lowest concentrations of either element that produce effects on aquatic life and to provide an interpretation of the significance of those effects. This study is in its latter stages of experimentation, and the results of lithium testing are being analyzed and communicated. Tests with beryllium are in progress.

In the past three years, we have been defining the toxicity of lithium and beryllium using parameters that measure responses in rainbow trout (Salmo gairdneri) and Columbia River periphyton communities. As a test organism, rainbow trout were exposed to lithium at all stages of their life cycles except adulthood. The trout are now being exposed to beryllium. The response parameters used are: 1) egg integrity, 2) fertilization success, 3) completion of embryogenesis, 4) hatchability, 5) fry survival, and 6) juvenile survival. Also, naturally colonizing Columbia River biota (mainly algae) were continuously exposed to concentrations of lithium. These experimental periphyton communities will be used to measure beryllium toxicity. The response

(a) Recent evidence indicates an increasing RBE for ^{3}H with protracted exposure when compared with T or x-radiation. This suggests an RBE of 3 or 4 at every low doses (<20 rads).

parameters used for these tests are: biomass, primary production, and insect habitation.

Our experiments with lithium compounds are complete. Tests with beryllium compounds will be completed in FY 1981.

For both elements, we have determined that at lower concentrations, where minimal effects are observed, the associated anions, $CO_3^{=}$ and F^-, do not play toxic roles. We also have statistically verified that only the lithium and beryllium cations of these most probable compounds associated with fusion technology are of toxicological concern.

Findings of our experiments with lithium are being prepared for publication. The main results are summarized in Table 7.1. Lowest concentrations of lithium producing effects in our response parameters are shown here as LRCT (Lowest Rejected Concentration Tested) values. The LRCTs were defined statistically using analysis of variance followed by a Fisher's protected least significant difference procedure (LSD at α= 0.05).

Of the nine parameters observed, the lowest lithium concentration producing effects was 0.26 mg/L (periphyton biomass, Table 7.1). In general terms, rainbow trout and periphyton were equally sensitive to lithium. Most of the toxicologic stress occurred in a concentration range of 1 to 10 mg Li^+/L, although periphyton biomass was reduced by lithium at a concentration range of 0.1 to 1.0 mg/L. This, then, is the range at which the lowest concentrations of lithium still produced effects.

Our second major objective is to interpret the hazards of lithium to aquatic environments. Our interpretation, which will be addressed in a forthcoming publication, considers natural concentrations of lithium in a variety of aquatic environments. Available data indicate that most freshwater systems have maximal lithium concentrations in a range of 0.0001 to 0.001 mg/L. Systems with higher salinity have maximum lithium concentrations ranging from 0.001 to 0.10 mg/L. Lithium concentrations in salt lakes and hot springs can be as high as 10 mg/L.

For purposes of setting regulatory standards on lithium concentrations in most freshwater environments, we have identified a region of uncertainty. This caution zone, where normal concentrations are exceeded and toxic concentrations are approached, lies between 0.001 and 0.1 mg Li^+/L. Our conclusions on the hazards from lithium to freshwater environments are based on interpretations of the effects expected to result when concentrations increase into and beyond this region of uncertainty.

The same approach is being used to define and interpret the hazards of elevated concentrations of beryllium in freshwater environments.

Table 7.1. Lowest Concentrations of Lithium[a] Producing Effects on Experimental Response Parameters

	LRCT in mg Li^+/L				
Response Parameter	Test 1	Test 2	Test 3	Test 4	Lowest LRCT
Rainbow Trout:					
egg integrity	55 ± 4.7*	4.4 ± 0.11	4.3 ± 0.055	**	4.3
fertilization success	None	None	46 ± 1.7	**	46
completion of embryogenesis	55 ± 4.7	4.4 ± 0.11	8.7 ± 0.22	**	4.4
hatchability	10 ± 0.43	2.4 ± 0.048	4.3 ± 0.055	**	2.4
fry survival	10 ± 0.43	2.4 ± 0.048	2.3 ± 0.083	**	2.3
juvenile survival	1.0 ± 0.038	1.2 ± 0.028	1.1 ± 0.11	**	1.0
Colonizing periphyton:					
biomass	0.26 ± 0.039	1.4 ± 0.34	0.61 ± 0.17	0.44 ± 0.15	0.26
photosynthetic rate	None	3.5 ± 0.56	4.2 ± 0.63	None	3.5
insect habitation	None	None	**	**	None

[a]Identified statistically as LRCT values (α = 0.05).
*The 95 percent confidence interval about the mean.
**Not determined.

TERATOGENIC EFFECTS OF LOW-LEVEL MAGNETIC FIELDS

Results of previous studies suggested that fertilization, development, hatchability, and juvenile survival of rainbow trout were not affected by exposure to either a static (10,000 gauss) or oscillating (2,800 - 11,200 gauss) magnetic field. Accordingly, studies conducted in FY 1980 were directed to develop potentially more sensitive approaches to measure the effects of magnetic fields on representative vertebrate systems.

One approach has been to use a secondary stress in addition to the primary stress of magnetic field exposure. The reasoning is that perhaps we can not measure the effect of a magnetic field alone, but if a synergistic effect is observed (an effect greater than that predicted for either stress alone), then it may be reasonable to assume that the magnetic field does have some degree of influence.

Hatchability and Early Survival

Under flow-through conditions, equal numbers (2,500) of rainbow trout eggs were exposed from fertilization through 21 days of development to: a) a high-density, homogeneous magnetic field (10,000 gauss), b) a continuously maintained 50 ppb TRC concentration of chlorine (sodium hypochlorite), c) both the magnetic field and chlorine, or d) neither variable (control). Incubation chambers for exposed and control embryos were identical.

At 21 days (eyed stage), the embryos were transferred to standard-drip incubators where hatching occurred in 28 ± 1.5 days at 10.5 ± 0.3°C. Two weeks after hatching, the fry from each exposure group were subdivided into four equal groups and placed in four fiberglass rearing troughs. Each trough consisted of four compartments; each compartment received one test group forming a 4 x 4 Latin Square design. Survival was monitored for 3 months. A Chi-square test of homogeneity was applied to determine the potential for differences among treatment groups. Evaluation of each index was conducted "in the blind" to decrease the possibility of investigator bias.

Results of the relative influence of magnetic field exposure, chlorine exposure, or combined exposures on survival up to 6 weeks are presented in Table 7.2. Although a relatively low survival rate during hatching was observed, no significant difference ($\alpha = 0.05$) in hatchability among treatments was found. Similarly, there was no significant difference ($\alpha = 0.05$) among treatment groups or control for survival through 6 weeks. The relatively low hatching percentages might be due to using the spawn from 2-year old parental fish in the absence of older 3- or 4-year-old fish.

Table 7.2. Effect of Magnetic and Chlorine Exposure on Early Life Stages of Rainbow Trout

Condition	Number of eggs	Percent Hatched	Survival at 6 weeks[a]
Control	2355	58.64	87.69
Magnet	2447	60.37	85.95
Chlorine	2542	63.92	89.78
Magnet and Chlorine	2397	59.61	87.54

[a]Percent survival of hatched fry.

Growth and Long-Term Survival

When the fingerlings were 4 to 6 g in weight, 25 individuals from each group (4 troughs x 4 compartments = 16 groups) were selected for uniformity of size, marked for identification (liquid nitrogen cold-branded), and placed in one of two 1.5-m diameter fiberglass circular rearing ponds. An additional 10 fish from each group were sacrificed for initial weight and length measurements. Fish stocks were fed five days each week, twice daily. In one pond excess food (4% body weight per day) was provided; in the other, a subsistence level (2% body weight per day) was made available. This allowed us to study the optimal growth and survival rates of the fish and determine the competitive advantages among treatment groups. After 4 and 8 weeks of feeding were completed, individual weights and lengths of at least 10 fish from each group (160 from each pond) were recorded. Separate analyses for growth and survival rates were performed on the data from each pond. Analysis of variance was used to compare the growth in body weight of the treatment groups. The treatment sum of squares was partitioned using orthogonal contrasts. A Chi-square test of homogeneity for a 2 (alive vs. dead) x 4 (treatment) contingency table was used to compare survival rates among treatments.

Because the race of experimental fish presently reared in the Hanford hatchery only breed during winter months (December through March), studies to determine the potential for magnetic field effects on growth will carry-over to FY 1981. The test fish were not of sufficient size for "cold-branding" until August, 1980, which necessitated analyses of growth to continue through October, 1980.

8 Pumped Storage and Hydroelectric Development

PUMPED STORAGE AND HYDROELECTRIC DEVELOPMENT

• Effects of Hydroelectric Generation on Riverine Ecology

The scale and extent of hydroelectric development has expanded in recent years while at the same time competition for the use of limited water resources has also increased. Even in very large Pacific Northwest river systems, the development and use of water resources once viewed as unlimited is now approaching the capacity of the river systems. Once-flowing rivers have created impoundments that completely change the physical features and result in changes in the structure of aquatic and riparian ecosystems. Huge storage reservoirs and the ability to withdraw large volumes of water for irrigation and other offstream uses has given us the ability to control the river hydrograph and thus alter seasonal flow regimes on which riparian vegetation and anadromous fish species are dependent. Increased use of conventional and pumped-storage hydrogeneration for peaking power production imposes a daily cycle to the flow regime, particularly affecting water levels in unimpounded river reaches.

Our objective is to examine the ecological consequences that manipulation of flow regimes has had on aquatic resources and riparian communities. The project reported here is designed to address effects of short-term (daily and weekly) cycles in the river stage, particularly with respect to production of economically and aesthetically important fish species. The tasks are designed to define impacts of flow fluctuations and to suggest means of ameliorating the impacts. An understanding of these impacts is important to regional resource-use planning as well as to resource development and for use by regulatory agencies.

• Effects of Hydroelectric Generation on Riverine Ecology

Principal Investigators: C. D. Becker and D. H. Fickeisen

Other Investigators: D. C. Klopfer and D. A. Neitzel

NORCUS Appointee: D. K. Kleopfer

Hydropower generation of peaking electricity requires frequent changes in the amount of water released through dam turbines. The resultant variations in flow rate are directly related to the daily cycle of electrical demand. Changes in the amount of water released at dams affect water temperatures and cause downstream water levels to fluctuate. These fluctuating water levels cause changes in wetted habitat areas.

The objectives of this program are to examine the effects of water-level changes on downstream biota and to quantify the ecological impacts. Our field studies examined the reproductive success of smallmouth bass (*Micropterus dolomieui*) populations in the Hanford area of the Columbia River as it related to fluctuating river stage and temperature. We also conducted studies of effects of dewatering on survival and development of chinook salmon (*Oncorhynchus tshawytscha*) eggs in artificial redds under controlled laboratory conditions.

Salmon Redd Studies (DOE)

Aquatic species that are dependent on shallow water habitats during part of their life cycles are affected by hydropower generation. For example, the available spawning area for fish that build redds or nests in shallow water (e.g., salmonids and centrachids) may be limited. Draining habitats that contain incompleted fish nests may discourage spawning above the minimum water levels. Should spawning take place at higher elevations, eggs and larvae may be lost as a result of dessication or because the adults are unable to guard the nests from predators. Nursery grounds for many fish species (salmonids, centrachids, catostomids, cyprinids, ictalurids) are located in shallow water where juveniles can be trapped in ponds as the water level falls. Subsequent draining results in death to fish by dessication or predation. Shallow ponds not drained may be heated by the sun above the upper tolerance limit of entrapped fish. Shallow-water benthos may also be affected by dessication, resulting in a limited supply of food organisms and, indirectly, may lead to reduced fish growth.

Water-level fluctuations associated with variable power outputs at conventional hydroelectric facilities, pumped storage projects, and new reservoir sites in the Pacific Northwest may result in extreme low river flows. Thus, salmonid eggs and egg-sac fry overwintering in the gravel of river beds may be dewatered for periods ranging from a few hours up to several days. We initiated dewatering tests with chinook salmon (Oncorhynchus tshawytscha) eggs and fry held in simulated redds to determine the impact of various dewatering regimes.

The initial task phase involves tests with sequential developmental stages (with some overlap), which are expected to vary in susceptibility to dewatering: fertilized eggs, eyed eggs, egg-sac fry and emerging fry. The dewatering period is 20 days, and tests are run at 10°C. Twenty days at 10°C represents the number of temperature units required to pass from one developmental stage to another. The tests employ a randomized design suitable for hypothesis testing by analysis of variance, and each test requires 30 simulated redds. Experimentally, eggs or fry are buried in

test units containing gravel of representative composition, maintained at 10°C (± 1°C) and provided with an intragravel flow of river water except during treatment (dewatered periods).

Two full-scale tests were completed in the fall of 1979, one with eyed eggs and one with egg-sac fry, and the other tests were started in September, 1980. Eyed eggs were hardy, and nearly 100% survived when they were dewatered for 0, 2, 4, 8 and 12 hours daily for 20 successive days (Figure 8.1). Egg-sac fry were much more sensitive. Some loss of fry occurred under a 2-hr daily dewatering schedule, about 50% kill occurred under 4-hr daily dewatering, and near total kill occurred under 8-hr daily dewatering.

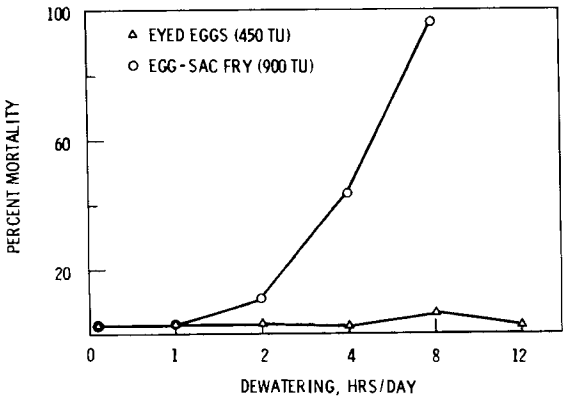

Figure 8.1. Relative Susceptibility to Dewatering for 20 Successive Days at 10°C (TU = Temperature Units Accumulated at Start of Test)

Occasional dewatering of salmonid redds may be an unavoidable consequence of full hydroelectric development. Field monitoring in different northwest rivers by other agencies indicates there is a considerable loss of redds where salmon eggs and fry remain intragravel when flows are decreased to levels too far below those that exist during redd-building and spawning. Reliability assessing the impacts and developing measures to mitigate them requires quantifying environmental conditions that cause such losses (e.g., frequency and duration of dewatering and susceptibility during various developmental stages). Our program addresses these issues.

Smallmouth Bass Studies

Smallmouth bass in the Hanford Reach of the Columbia River spawn in shallow backwater sloughs over coarse gravel substrate in late spring and early summer when water temperatures become favorable. In a system as highly regulated as the Columbia River, and where hydroelectric generation capacity is used in a load-following (peaking) mode, water flows are controlled by storage in impoundments and variable release rates at dams. Since consumer use of electrical energy is highly cyclical during each day and on weekends, gross changes in river flow and stage occur daily. The changes in water level result in alternate flooding and dewatering of shoreline areas. In sloughs used most frequently by smallmouth bass (Micropterus dolomieu) for spawning in the Hanford Reach, water levels frequently show a 2 m change in elevation daily. Due to the lag-time required for water to travel from the first upstream hydroelectric dam to the sloughs and to the daily cycle of power use, the sloughs are often flooded with cold water in the early afternoon, imparting about a 10°C change in water temperature each day.

In the spring and summer of 1980 we continued field studies of nest construction, egg deposition, and subsequent production of fry by adult smallmouth bass. Observations were hindered by higher-than-expected peak run-off and deposition of volcanic ash following eruptions of Mt. St. Helens. As in the past year, many bass nests were never observed with eggs. For those nests that contained eggs, the numbers estimated to have been deposited by adult bass were lower than is typical for the species. Only 13% of the observed nests contained eggs. The mean number of eggs in occupied nests was only 745 each.

We continuously monitored river and slough water levels and temperatures to correlate these environmental factors with bass nesting activity and to provide data required for the calibration of a predictive mathematical model of water level and temperature. These monitoring data are currently being analyzed and related to survey data on water elevations at various points near the study sloughs.

While hydroelectric peaking operations will necessarily result in water-level fluctuations, it is important to understand what their effects these operations will have on aquatic communities. The objectives of our studies are to define the effects of such fluctuations on smallmouth bass populations and suggest potential ameliorative actions (e.g., limitations on rate of fluctuation, seasonal restrictions on peaking operation, and protection of important spawning areas from severe fluctuations by diking). The study is site-specific, but the results have considerable generic application to water-level fluctuations in free-flowing streams, pumped storage reservoirs, and cooling impoundments.

9 Pathways Modelling, Assessment and Hanford Project Support

PATHWAYS MODELING, ASSESSMENT AND HANFORD PROJECT SUPPORT

- o **Assessment of Effectiveness of Geologic Isolation Systems**
- o **Hanford Defense Waste Studies**
- o **Assessment of Environmental Health and Safety Issues Associated with the Commercialization of Unconventional Gas Resources**
- o **Regional Issues Identification and Assessment**
- § **Rockwell Support Studies**
- § **Service Assessment Studies**
- o **Power Plant Fuel Conversion Environmental Impact Assessment**
- o **Environmental Dose Assessment**
- o **Technology Assessment of In Situ Uranium Mining**
- o **Technology Assessment of Advanced Isotope Separation (Uranium Enrichment)**

This section reports on related environmental studies funded by DOE and organized in support of nuclear waste management responsibilities of the Rockwell Hanford Operations (RHO), the Office of Nuclear Waste Isolation (ONWI) or the Decommissioning and Decontamination program. The studies are designed to 1) ascertain the potential for uptake and transport of waste radionuclides away from shallow low-level waste burial grounds located on the Hanford Site, 2) to develop techniques for guarding burial grounds against biotic penetration, 3) to monitor over long intervals the several most important animals likely to be impacted by industrial development of the Hanford Site and 4) to provide dose calculations for safety assessment purposes for various options under consideration in nuclear technology development.

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oDOE work performed by Ecological Sciences Department under intralaboratory work order.

§ DOE work performed by Ecological Sciences Department under intercontractor work order.

o Assessment of Effectiveness of Geologic Isolation Systems

Principal Investigators: J. K. Soldat, B. A. Napier, D. L. Strenge, R. G. Schreckhise and M. G. Zimmerman

The program for Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) is managed through PNL's Water and Land Resources Department and is funded through the Battelle Office of Nuclear Waste Isolation (ONWI). AEGIS is a continuation of the Waste Isolation Safety Assessment Program (WISAP). The Ecological Sciences Department was involved in two subtasks under AEGIS: Dose Methodology Development and Reference Site Initial Analysis (RSIA) for a Salt Dome.

Dose Methodology Development

During FY 1980, documentation was completed for three codes converted in FY 1979 to the DOE/RL 1100/44 computer--PABLM, FOOD, and ARRRG[a]. These and other previously documented codes form a comprehensive set that can be used to calculate radiation doses from most postulated mechanisms of radionuclide release from radioactive waste disposal sites. Work was begun on the principal remaining problem: long-term (tens of thousands of years) chronic leaching of radionuclides from a repository to portions of the environment accessible to humans. One aspect of this problem was addressed by R. G. Schreckhise through the development and documentation of a multi-compartment model for estimating the radionuclide concentrations in crops from long-term irrigation with contaminated water. In addition, work began on a code for the calculation of long-term, integrated (10^4 years) population doses from radionuclides reaching the biosphere from a waste disposal site. Development of this code was also funded by RL/DOE through the Hanford Defense Waste Environmental Impact Statement project.

We also published a brief description of the dose methodology in a report describing the overall AEGIS methodology (Silviera et al. 1980), and J. K. Soldat presented a lecture on internal dosimetry to the Health Physics Society Summer School of the University of Washington on July 15, 1980.

Salt Dome RSIA

The doses calculated in FY 1979 for persons consuming contaminated table salt produced by solution mining of a salt dome repository (100 years after closure) were refined and extended to include 70-year accumulated doses from salt mined at 100 years up to 30,000 years after closure. In addition, maximum potential doses to salt-solution mine workers were estimated to see if radiation-caused health effects in workers would be serious enough to indicate that the salt was contaminated enough to stop production before ingestion doses to the public became significant. The results indicated that although the upper-limit occupational cases were at least an order of magnitude above current standards, no health effects obviously attributable to salt exposure would ensue.

The dose results and a brief description of the dose methodology were included in a working document.

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[a] These three codes are listed in the Publications and Presentations sections of this report.

o Hanford Defense Waste Studies

Principal Investigators: B. A. Napier, M. G. Zimmerman, J. K. Soldat

Technical Assistant: R. A. Peloquin

PNL is assisting Rockwell Hanford Operations to prepare a programmatic environmental impact statement for the management of Hanford defense nuclear waste. The Ecological Sciences Department is leading the task of calculation of public radiation doses from a large matrix of potential routine and accidental releases of radionuclides to the environment. The FY 1980 work was organized into two phases—high-level waste and low-level waste. These phases were originally scheduled as input to two separate impact statements that have since been combined into one.

High-Level Waste Dose Assessment Task

Public radiation doses were calculated for a number of postulated radio-nuclide-release scenarios. These scenarios included transport and mining accidents at a generic site and long-term radionuclide releases at the Hanford site. Calculations for two types of waste media were performed for a Hanford deep geological repository that had been subjected to faulting and flooding. Calculations were also performed for a climate-change scenario for high-level waste left in tanks on site. A special scenario for handling of strontium and cesium capsules was investigated. A section of a topical report on the release scenario analysis was prepared.

Low-Level Waste Dose Assessment Task

Because there are a great number of sites contaminated with low-level wastes on the Hanford site, a general method was developed to analyze them. Unit-release dose factors were prepared for most of the release scenarios. These included both routine and accidental releases from the 100, 200, and 300 Areas (ground-level and elevated) for the present and for times 100, 1000, and 10,000 years in the future. Other unit dose factors were prepared for accidental, routine, and long-term release of radionuclides to the Columbia River. Individual sets of dose factors were prepared for calculating doses resulting from contaminated well water and contaminated soil. A description of the dose-calculation method was prepared, including a discussion of the relative importance of each type of environmental exposure pathway for each radionuclide-release scenario.

o Assessment of Environmental Health and Safety Issues Associated with the Commercialization of Unconventional Gas Recovery

Principal Investigators: E. F. Riedel and C. E. Cowan

The purpose of this project is to identify and evaluate known, potential, and heretofore unknown environmental and safety concerns associated with the recovery of natural gas from Unconventional Gas Resources (UGR). Results from these studies will be used by DOE to evaluate the commercialization of these important resources.

Efforts during FY 1980 resulted in the publication of two documents in which environmental health and safety issues associated with the commercialization of unconventional gas recovery from tight western sands (PNL-3391) and methane from coal seams (PNL-3413) were assessed. Other efforts were focused on the resource of Devonian (eastern) gas shales. We assessed the environmental, health, and safety problems resulting from commercialization and found them to be minimal; they will present no obstacles to the commercialization of these resources. The major environmental concerns, which differ slightly for each resource, are road construction, well pad construction, pit drilling, and exhaust from diesel engines. The most serious occupational safety problems are noise (in excess of 100 dBa at 4.5 m) and accidents that result from the use of heavy equipment.

o Regional Issues Identification and Assessment

Principal Investigators: M. L. Warner and M. C. McShane

During FY 1980 DOE's Office of Technology Impacts sponsored research involving several national laboratories aimed at identifying potential regional issues associated with two scenarios of future national energy supply mixes to the year 2000. The Pacific Northwest Laboratory is responsible for a large, diverse region comprised of the states of Alaska, Idaho, Oregon, and Washington (Federal Region X). As a part of the Laboratory's team, ecological scientists addressed potential issues and impacts in land use and ecology. Four areas of possible impacts were addressed: land use changes resulting from the location of new energy generation or transportation facilities, land use changes resulting from air quality changes and resulting impacts on sensitive crops, changes in natural ecological communities resulting from facility siting or air quality changes, and impacts on threatened and/or endangered species.

As shown in Figure 9.1, the most likely impacts identified were associated with hydroelectric or nuclear power generation, or with oil transportation through the postulated Northern Tier Pipeline. Because the postulated facilities are widely scattered throughout the region and, in most cases, sites have already been selected to minimize impacts, the impacts of projected land use or ecological changes are expected to be minor and would generally not be likely to create significant impediments to implementation of the scenarios examined.

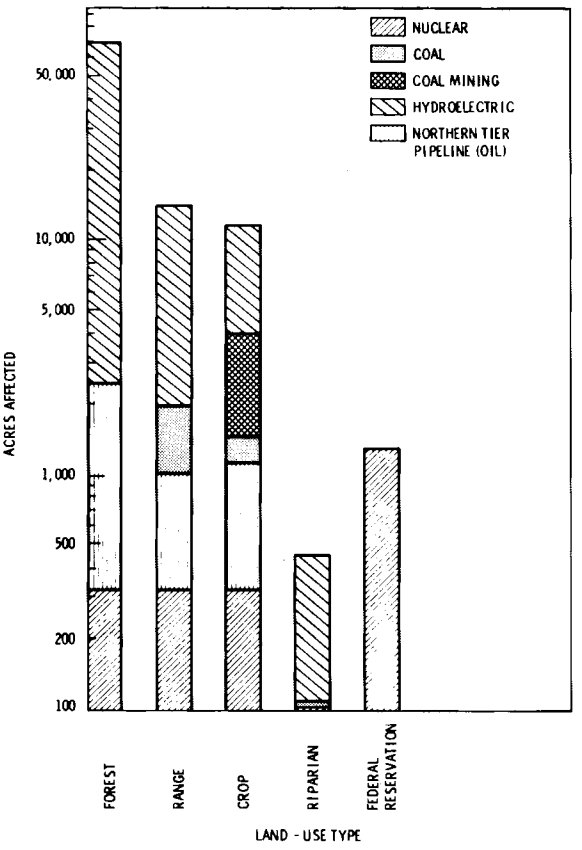

Figure 9.1. Impacts of High Oil Price Scenario on Major Land Uses in Federal Region X

For more information refer to Part 5 of Pacific Northwest Laboratory Annual Report for 1980 to the DOE Assistant Secretary for Environment. PNL-3700 PT5.

§ Rockwell Support Studies

Principal Investigators: L. L. Cadwell, J. F. Cline, K. A. Gano, J. L. Warren and L. E. Rogers

Technical Assistants: M. J. Harris and M. E. Thiede

Studies performed for the Rockwell Hanford Operations (RHO) were designed to either identify the role of biota in the uptake and transport of radionuclides from low-level waste management areas or design and/or evaluate methods for reducing biological transport of radionuclides away from waste management areas.

Investigators are continuing to complete and publish documents that describe the results of studies from the previous fiscal year.

Document and Publication Preparation

Two PNL documents reporting on research sponsored wholly or in part by RHO were published during FY 1980. One of the documents characterized the insects that inhabit the major shrubs of the 200 Area plateau. The second document contained an evaluation of several pond-management alternatives that were proposed to reduce biological transport of radionuclides from contaminated waste ponds. Two additional documents nearing completion will report on the diets of deer in the 200 Area and on the occurrence of raptors on the Hanford Site. Draft copies that report on laboratory studies designed to identify conditions that may modify concentration ratios (CR values) for Sr and Cs were completed. They are intended for open literature publication.

Pond Herbicide Study at Gable Mountain Overflow Pond

The objective of this study was to evaluate the effectiveness and ecological impact of an experimental herbicide (Sonar®) on emergent vegetation of a radioactive waste pond. The herbicide was designed to kill pond vegetation and thereby reduce the numbers of wildlife that use the pond habitat. When fewer animals inhabit the environs of a radioactive waste pond, the potential for transport of radioactive material is lower.

The herbicide, Sonar®, was applied in pellet and liquid form to the first of two overflow ponds at Gable Mountain pond on August 9, 1979.

Ecological impacts on the pond's vegetation were evaluated by 1) estimating the percentage of canopy cover and bottom cover in six representative transects in the submergent, emergent, and marginal vegetation zones; and 2) recording average height measurements and taking photographs of emergent vegetation in the transects. An avian census was also conducted during each visit to determine how many birds were using the area. These measurements were taken in September, 1980 (one month following application); in the spring of 1980; and in August, 1980 (one year after application).

The effects of the herbicide were obvious as early as September 1979. A lack of chlorophyll was indicated when cattails and rushes turned white from the roots upward. This vegetation appeared normal in an adjacent untreated pond. The manufacturer of the herbicide anticipated that algal growth in the treated pond would increase, and our experiments confirmed their expectations.

®Use of trade name does not imply Battelle endorsement.

In April, 1980, effects from the herbicide were obvious. In one transect containing only bulrushes (Scirpus sp.), all plants appeared to be dead. Although some new growth had occurred, plants in the remaining part of the pond showed deficiencies of chlorophyll in leaves and stems. By August, 1980, the general appearance of the entire pond had changed only slightly from the previous year. The treated transect containing bulrushes was the only area still showing obvious effects. Except for the influence of migration, the distribution of birds was similar before and after herbicide application.

The herbicide treatment was locally effective at killing pond vegetation, but the single late summer application failed to significantly reduce the entire stand of emergent vegetation. Factors in this test which may have compromised the herbicide effectiveness were the somewhat late season (August) application and some flushing of the pond subsequent to the herbicide application. Additional testing is required in order to determine whether the herbicide can effectively eliminate emergent vegetation in the waste pond system.

Plant-Uptake Studies

Approximately 20 years ago, ^{90}Sr and ^{137}Cs were added to soils to determine the uptake of these isotopes by plants. Recently, ^{85}Sr and ^{135}Cs were added to identical soil samples in order to compare and test the relationship between plant age and nuclide uptake.

Concentration ratios (CR) of strontium were significantly affected ($\alpha \leq 0.05$) by the age of the plant at harvest (Table 9.1). Statistical significance was determined using the Bonferroni test. Thirty-day-old plants had CR values two to three times higher than mature 90-day-old plants. Significant effects were also shown in CR values for aged versus newly added strontium. The CR for aged strontium (2.04) was significantly lower than the CR for newly added strontium (2.60). The CR for ^{85}Sr in the second harvest (1.86) was not significantly different ($\alpha \leq 0.05$) from either CR from the ^{90}Sr harvests (2.15 and 2.04). These data indicate that the availability of strontium for plant uptake does not change significantly after the radioisotope has been present in the soil complex for 60 days. Although uptake patterns of cesium were different from those of strontium; total nuclide uptake was similar for plants of all ages. Concentration ratios obtained from the sequential harvest indicate that CR values for cesium do not change as plants mature. With the exception of the CR for ^{134}Cr in 30-day-old plants (0.11), which was significantly higher than all other cesium CR values, CR values for ^{137}Cs were not significantly different from those of ^{134}Cs. This effect was probably caused by growing the plants in a nuclide-contaminated soil before equilibrium between the soil and nuclide could take place. Results indicate that cesium ions reach equilibrium with the soil complex by 30 days after mixing; availability of the nuclide for plant uptake does not change significantly thereafter.

Table 9.1. Effect of Plant Growth and Radionuclide Aging on CR Values

Growth (days)	^{90}Sr (aged 25 yr)	^{85}Sr	^{137}Cs (aged 17 yr)	^{134}Cs
1978				
20	2.04 ± 0.10[a,b]	2.60 ± 0.07*		
15[c]	2.15 ± 0.05	1.86 ± 0.09		
1979[d]				
30	1.63 ± 0.16*	2.44 ± 0.13*	0.005 ± 0.001	0.011 ± 0.001[e]
60	0.52 ± 0.04	1.96 ± 0.31	0.006 ± 0.001	0.005 ± 0.001
90 (leaf and seed)	0.67 ± 0.10	0.62 ± 0.01	0.003 ± 0.001	0.003 ± 0.004

(a) $CR = \frac{\text{pCi/g oven-dry tissue}}{\text{pCi/g oven-dry soil}}$

(b) $\bar{X} \pm SE$; n = 5

(c) planted after a 60-day fallow period

(d) sequential harvest

(e) Significantly higher ($\alpha \leq 0.05$) than comparable data from the same experiment.

§ Service Assessment Studies

Principal Investigator: D. G. Watson

Service Assessment Studies, supported through the Richland Operations Office, involve long-term ecological monitoring of animals likely to be affected by the industrial development of the Hanford site. This is a low-level effort, now in its third decade, which has provided valuable documentation of the efficacy of environmental control measures at this site.

Fall Chinook Salmon Spawning Near Hanford, 1979

Fall chinook salmon (Oncorhynchus tshawytscha) spawning surveys were conducted in the Hanford reach of the Columbia River for the thirty-third consecutive year. These studies are part of a continuing Department of Energy program to assess the effects of Hanford operations on the fish and wildlife of the area. During the period of major plutonium-producing reactor operation, the salmon surveys provided a basis for estimating the impacts that cooling effluents from reactors had on a natural fish population. Since most of the plutonium reactors have been shut down, these survey data serve as part of the baseline for evaluating the effects that nuclear power reactors and other industrial developments at Hanford have on salmon populations.

On October 7 and 27, and again on November 3 and 20 (when spawning was probably at its peak), ariel surveys were conducted on the section of the Columbia River from the City of Richland, Washington, to Priest Rapids Dam (river km 542 to 637). A total of 2983 redds (nests) were observed; however, cloudy and windy weather during much of November was generally unsuitable for aerial surveys, thus the observed number of redds is accordingly probably low.

The Hanford redd count for 1979 is about 98% of the most recent 10-year average (1970-1979) for the Hanford Reach. The passage of adult fall chinook salmon over downstream dams is compared with the Hanford counts in Table 9.2.

Table 9.2. Chinook Salmon Population Estimates for the Columbia River Compared with Adult Counts from Dams

Dam and Distance[a]	Number of Salmon	PERCENT of McNary Count
Bonneville Dam* (234)	190,627	—
McNary Dam* (470)	49,961	100
Priest Rapids Dam* (637)	6,482	13
Ice Harbor Dam*[b] (537)	2,074	4
Hanford (542-637)	20,881	42
Lesser tributaries and unaccounted for	20,524	41

*U.S. Corps of Engineers Fish Count Report 1979, Portland District, Portland, Oregon.
[a]Km from the mouth of the Columbia River.
[b]The most downstream dam on the Snake River, the major Columbia River tributary between Hanford and McNary Dam.

The Hanford Section of the Columbia River continues to support a major portion of the middle-river spawning population. The salmon surveys provide a useful baseline for estimating the environmental effects of industrial development at Hanford.

o Power Plant Fuel Conversion Environmental Impact Assessment*

Principal Investigator: D. G. Watson

The Department of Energy's Economic Regulatory Administration is responsible for administering a program that prohibits or reduces the use of petroleum and natural gas as the primary energy source in existing or new power plants. This authority is derived from the Power Plant and Industrial Fuel Use (FUA) Act of 1978 and to actions begun under the now expired Energy Supply and Environmental Coordination Act (ESECA) of 1973. The goal of both FUA and ESECA is to reduce the dependence on foreign petroleum supplies and scarce domestic energy sources by encouraging electrical generating utilities to switch to more abundant domestic fuels such as coal.

Prohibiting the burning of oil and natural gas is expected to result in the increased use of alternative fuels and a related potential for affecting the quality of the human environment. Since this prohibition is considered a major federal action under the National Environmental Policy Act of 1969 (NEPA), it requires an assessment of environmental effects. The Ecological Sciences Department, along with several other Pacific Northwest Laboratory (PNL) Departments, is assisting the DOE-ERA in the evaluation of the environmental effects of power plant fuel conversion.

In FY 1980, Ecological Sciences provided staff to evaluate the ecological impacts resulting from possible fuel conversion of eight boilers operated by the Baltimore Gas and Electric Company near the City of Baltimore, Maryland. Leadership in conducting the environmental analysis and in the preparation of an Environmental Impact Report (EIR) was also provided by this staff. The EIR will form the basis for an Environmental Impact Statement that will be issued and used by DOE in deciding if fuel conversion at these power plants is environmentally acceptable.

Also in FY 1980 we began an environmental analysis of converting two boilers from oil to an alternate fuel at the Jersey Central Power and Light Company's Sayreville Generating Station at Sayreville, New Jersey.

Coal is a logical alternative to oil for many of the boilers being considered for conversion because of its abundance in the United States and due to the fact that some of the boilers were originally designed to burn coal. Some of the more significant potential environmental impacts from coal combustion are the degradation of air quality resulting from increased emission of sulfur dioxide, particulates, and other combustion products, and the disposal of ash and solid wastes from pollution controls such as flue gas desulfurization systems. The increased air emissions may produce human health problems and add to the problem of acid precipitation.

Solid waste management requires the use of large land areas and poses a potential problem to plants, animals and water supplies through the leaching of toxic materials. Increased noise from coal handling, problems arising from the increased transport of coal and solid wastes, and the potential contamination of surface and ground waters are other potential impacts of power plant fuel conversion.

*Funded by the Economic Regulatory Administration.

o Environmental Dose Assessment

Methodology Review

Principal Investigator: M. A. Mueller

A comprehensive review is being performed on radiation dose assessment methodologies used by DOE and its contractors to access public exposure to radiation from operations at DOE facilities. This study includes investigating the methodologies now in use at DOE sites, establishing a state-of-the-art methodology, identifying discrepancies among the methods, and attempting to reach a concensus with DOE and its contractors on acceptable methodologies for assessing the exposure to the public. A workshop on dose methodology will be held for DOE and DOE contractors.

Efforts are continuing on identifying the transport and dose methodologies used in evaluating public exposure due to radiation from activities conducted on DOE sites. All of the DOE-site annual reports have been reviewed and several sites contacts were made. Information on methodologies is being collected from the DOE sites and from the open literature.

o Environmental Impact Statement Analysis

Dose Methodologies

Principal Investigators: M. A. Mueller, D. L. Strenge and B. A. Napier

Standardized sections and methodologies are being developed for use in environmental impact statements (EIS) for activities to be conducted on the Hanford Reservation. Five areas for standardization have been identified: routine operations dose methodologies, accident dose methodology, Hanford Site description, health effects methodology, and socioeconomic environment for Hanford waste management activities. Routine and accident dose methodologies were completed this year.

A computer program to calculate radiation doses from accidental releases of radioactive materials at Hanford was developed for the accident dose methodology. The program is based on existing models and subroutines. Radiation doses are calculated for both the individual and the population exposed to a plume of atmospheric contamination. A semi-infinite cloud model is used for air submersion, and inhalation doses are calculated using dose factors from the DACRIN computer code. The new program, entitled HADOC, has been programmed in ASCII FORTRAN on the UNIVAC 1100/44 computer, and has been tested and documented (Strenge 1980).

Computer programs for calculating radiation doses to the public from routine releases of radionuclides from the Hanford Site have been standardized. The inhalation dose program DACRIN was converted in order to use the same data libraries as the ingestion pathway codes ARRRG, FOOD, and PABLM. The data libraries were updated based on the most current literature.

A report describing each of the programs recommended for use in EIS analyses at Hanford has been prepared (Napier 1980). The report includes the rationale for the use of each program, required input data, definition of resulting output, and code limitations. These programs will be maintained on the BCSR UNIVAC 1100/44, which is available for use by all Hanford contractors. All programs are written in ASCII FORTRAN suitable for easy adaption to offsite computer systems.

o Technology Assessment of In Situ Uranium Mining

Principal Investigator: C. E. Cowan

The objective of the PNL portion of the Technology Assessment project is to provide a description of the current in situ uranium mining technology; to describe the physical, ecological, institutional and socio-economic environment within which the technology exists; to evaluate, based on available data, the environmental impacts and, in a limited fashion, the health effects; and to explore the impediments to development and deployment of the in situ uranium mining technology. This material, which is reported in PNL-3439, will be used as a source document for the Technology Assessment project.

For further information on the technology assessment of in situ uranium mining refer to:

Part 5 of *Pacific Northwest Laboratory Annual Report for 1980 to the DOE Assistant Secretary for Environment.* PNL-3700 PT 5.

o Technology Assessment of Advanced Isotope Separation (Uranium Enrichment)

Principal Investigator: P. J. Mellinger

Additional nuclear fuel is retrievable by recovering uranium (^{235}U) from uranium flouride (UF_6) tails. This potential has led to the establishment of the Advanced Isotope Separation (AIS) program in the Department of Energy.

For detailed information on this topic refer to:

Part 5 of *Pacific Northwest Laboratory Annual Report for 1980 to the DOE Assistant Secretary for Environment.* PNL-3700 PT 5.

10 Electric Field and Microwave Research

ELECTRIC FIELD AND MICROWAVE RESEARCH

- **Biological Studies of a 1200-kV Prototype Transmission System Located near Lyons, Oregon**

Meeting future power demands requires innovative approaches to generation and transport of electrical power. Two such approaches were studies under DOE sponsorship. One approach is to place solar collector satellites in outer space and transmit electrical power to earth via microwave beams. The second approach involves transmission of power between regional power generation centers and population centers via ultrahigh-voltage (higher than one million volts) transmission systems. While both approaches are technically feasible, questions about their environmental acceptability arise. In both cases, substantial land areas either along transmission line rights-of-way or near microwave receiving stations would be exposed to electromagnetic energy fields higher than background levels.

The space satellite collector studies were held in abeyance during the past year, and information about these exploratory studies will be found in our earlier Annual Report, PNL-3300, (Part 2).

Ecological effects possibly associated with a 1200-kV power transmission system are currently being investigated under sponsorship of the Bonneville Power Administration (DOE). This study is reported separately in the *Annual Report for 1980 on Interagency/Contract Research, Ecological Sciences Department.*

11 Energy-Related Research for Other Agencies

ENERGY-RELATED RESEARCH FOR OTHER AGENCIES

Bonneville Power Administration (DOE)*

Environmental Protection Agency

Knolls Atomic Power Laboratory

National Institute of Environmental and Health Sciences

National Oceanographic and Atmospheric Administration

National Science Foundation

Nuclear Regulatory Commission

U.S. Army Corps of Engineers

U.S. Fish and Wildlife Service
(Department of the Interior)

Washington Public Power Supply System

The purpose of this section is to identify energy research conducted for sponsors other than U.S. DOE where interagency and other mutual agreements exist to support work on a nonduplicative basis. The research topics identified in this section are complementary to work discussed in other sections of this report. The data bases being developed provide a unique long-term reference for environmental and energy assessment in the arid West.

Federal agency research that was transferred to the Environmental Protection Agency in October 1979 is identified in this section and is reported in further detail in our *Annual Report for 1980 on Interagency/Contract Research, Ecological Sciences Department.*

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*Direct contract with BPA.

Bonneville Power Administration

Biological Studies of a 1200-kV Prototype Transmission System Located Near Lyons, Oregon (Principal investigator: L. E. Rogers)

Environmental Protection Agency

Acute Screening of SRC Materials (Principal investigator: J. B. States)

Long-Term Effects of Petroleum Hydrocarbons from Water on Marine Organisms (Principal investigators: J. W. Anderson, R. G. Riley and R. M. Bean)

Long-Term Effects of Petroleum Hydrocarbons from Sediment on Marine Organisms (Principal investigators: J. W. Anderson and R. G. Riley)

Fate and Effects of Petroleum Hydrocarbons in the Coastal Marine Ecosystems (Principal investigator: W. H. Pearson)

Effects of Petroleum Hydrocarbons on the Behavior of Marine Organisms (Principal investigator: W. H. Pearson)

Methodology for Collecting and Interpreting Ecological Data (Principal investigators: L. L. Eberhardt and J. M. Thomas)

Knolls Atomic Power Laboratory

Benthic Boundary Layer Program (Principal investigator: C. I. Gibson)

National Institute of Environmental and Health Sciences

Heavy Metal and Metal Complexes in Soils and Plants (Principal investigator: R. E. Wildung)

National Oceanographic and Atmospheric Administration

Quantification of Pollutants in Suspended Matter from Puget Sound Waters (Principal investigators: R. G. Riley, E. A. Crecelius, D. C. Mann, K. H. Abel, B. L. Thomas and R. M. Bean)

Effects of Petroleum Hydrocarbons on Chemoreception in Marine Organisms: I. Dungeness crabs (Principal investigator: W. H. Pearson)

Effects of Single or Multiple Pollutants on Benthic Organisms (Principal investigator: J. W. Anderson)

Determination of the Biological Availability/Absorption of Cadmium (Principal investigator: J. T. Hardy)

Effects of Experimental Contamination with Prudhoe Bay Crude Oil on Faunal Recovery in the Strait of Juan de Fuca (Principal investigator: J. R. Vanderhorst)

National Science Foundation

The River Continuum: Strategies of Biological Systems for Maintaining A Quasi-Equilibrium of Energy Flow (Principal investigator: C. E. Cushing)

Immediate Effects of Mt. St. Helens Ash Fallout on Streams Draining Mt. Adams (Principal investigator: C. E. Cushing)

Nuclear Regulatory Commission

Biocide By-Products in Aquatic Environments (Principal investigators: D. R. Anderson, R. M. Bean and C. I. Gibson; other investigators: D. C. Mann, K. M. McFadden, R. G. Riley, R. E. Shirmer and B. W. Wilson; specialists: D. S. Abernethy, K. Hanson and E. W. Lusty)

Environmental Standard Review Plans for the Environmental Review of Construction Permit Applications for Nuclear Power Plants (Principal investigator: D. G. Watson)

Application of Fisheries Management Techniques to Assessing Impacts (Principal investigators: D. H. McKenzie and J. R. Skalski)

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- Safety and Costs Related to Decommissioning of Nuclear Fuel Cycle and By-Product Utilization Facilities (Principal investigators: E. C. Watson, W. E. Kennedy, Jr., R. B. McPherson and B. A. Napier)

Analysis of Effects of Severe Natural Phenomena on Existing Plutonium Fabrication Facilities

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Modeling of Environmental Exposure Pathways for Very-Long-Term Exposure Scenarios (Principal investigators: B. A. Napier and D. L. Strenge

Modeling of Environmental Exposure Pathways and Consequent Radiation Doses in Reactor Accident Situations (Principal investigators: D. L. Strenge, E. C. Watson, J. K. Soldat and D. A. Baker)

Technical Assistance for Commercial Power Reactor Dose Assessment, 1979 (Principal investigator: D. A. Baker)

Environmental Statement Concerned with the Exemption of Low-Enriched Uranium and Technetium-99 as Residual Contamination in Smelted Alloys (Principal investigators: D. A. Baker, B. A. Napier and S. A. Smith)

Study of Iodine-131 Pathway Behavior Under Stored Feed Conditions (Principal investigators: D. A. Becker and R. G. Schreckhise)

Removable Surface Contamination Level Analysis for Nuclear Materials Transportation Packages (CLAT) (Principal investigator: W. E. Kennedy, Jr.)

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Entrainment and Impingment Studies of Water Intake Structures (Principal investigator: D. H. McKenzie)

Ecological Review and Analysis (Principal investigators: T. L. Page and R. L. Drake)

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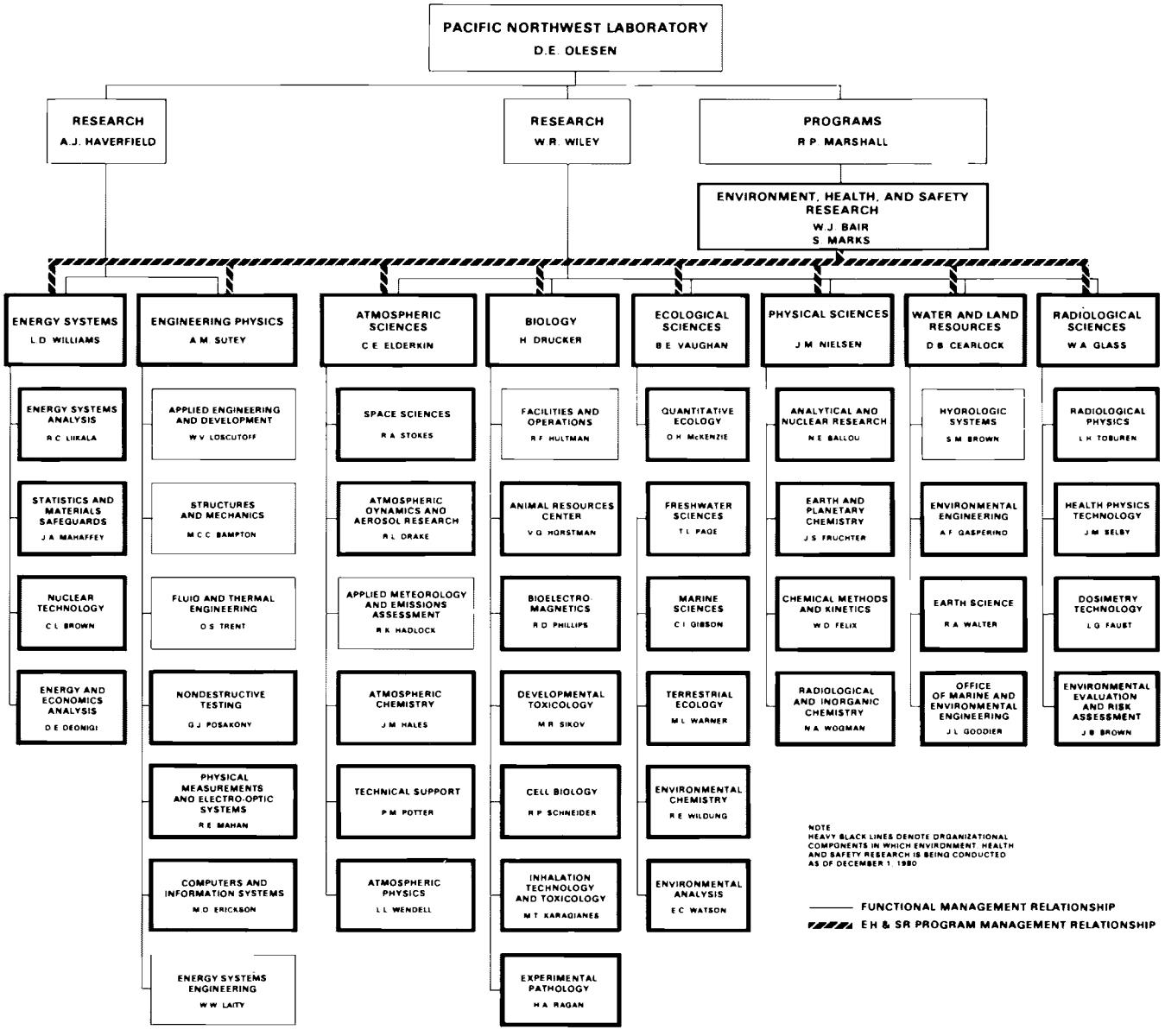
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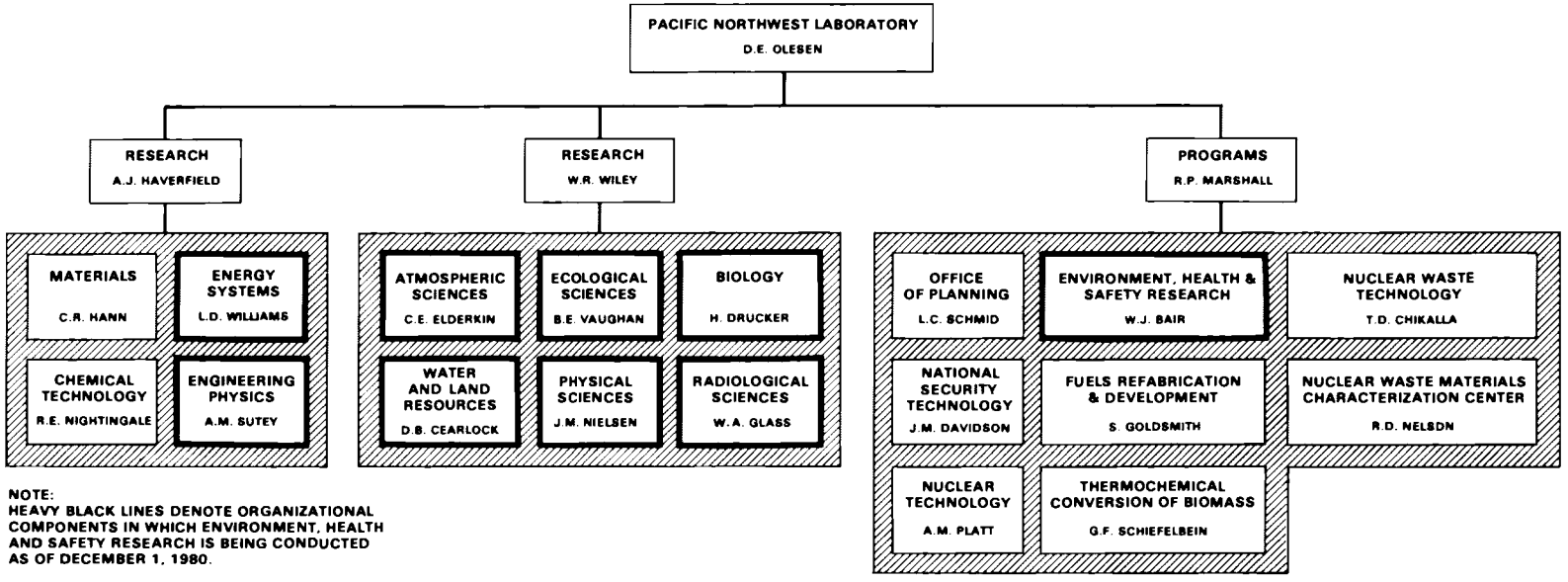

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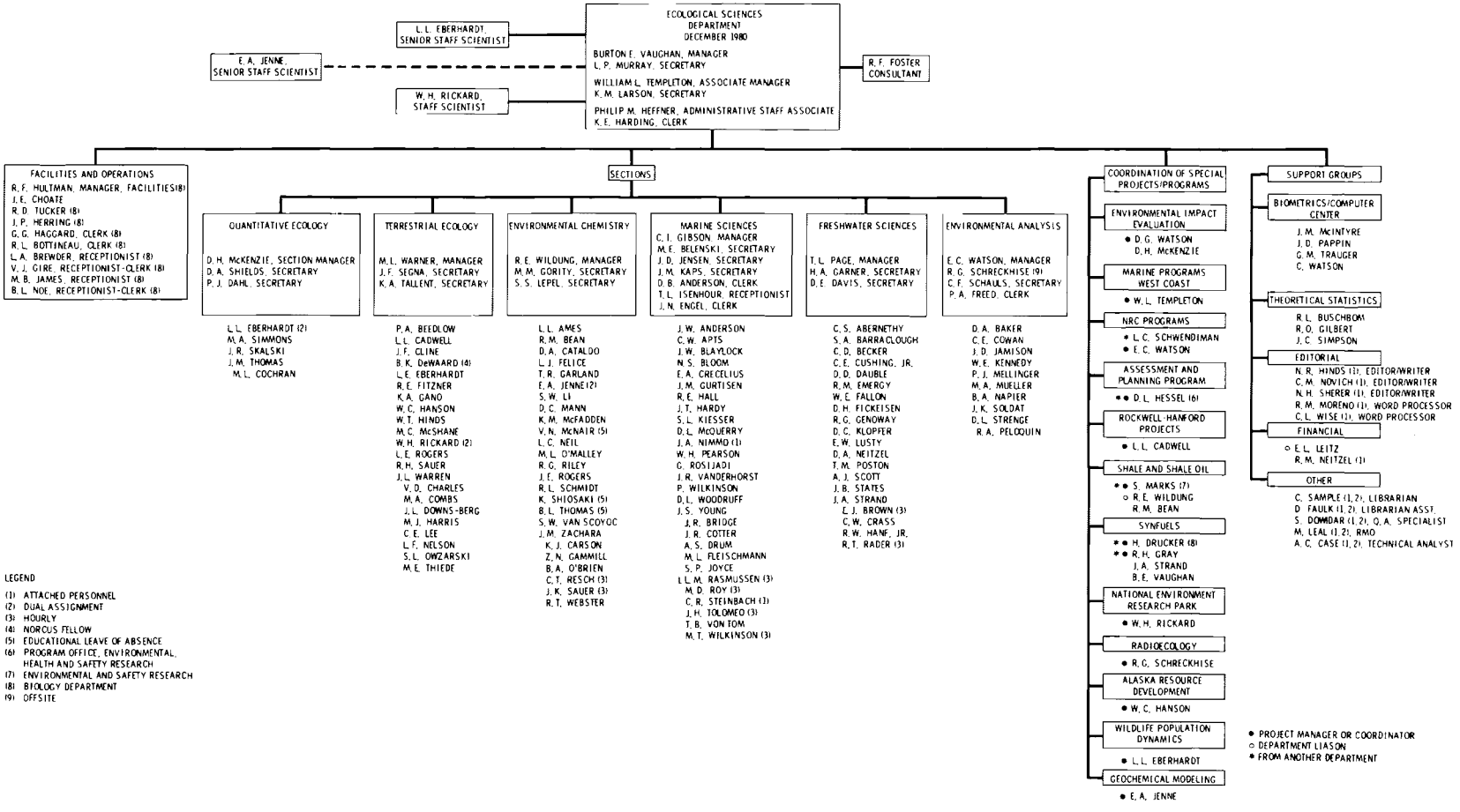
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