BNWL-1850 PT2
UC-48

# PACIFIC NORTHWEST LABORATORY ANNUAL REPORT FOR 1973 TO THE USAEC DIVISION OF BIOMEDICAL AND ENVIRONMENTAL RESEARCH

## PART 2 ECOLOGICAL SCIENCES

9

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

JANUARY 1974

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# NOTICE



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# PACIFIC NORTHWEST LABORATORY
# ANNUAL REPORT FOR 1973
# TO THE
# USAEC DIVISION OF BIOMEDICAL AND ENVIRONMENTAL RESEARCH

## PART 2 ECOLOGICAL SCIENCES

By

Burton E. Vaughan, Manager
and
Staff Members of Ecosystems Department
Environmental and Life Sciences Division

January **1974**

**BATTELLE**
PACIFIC NORTHWEST **LABORATORIES**
**RICHLAND, WASHINGTON 99352**

# PREFACE

The Annual Report for 1973 to the U.S. Atomic Energy Commission's Division of Biomedical and Environmental Research represents a change from previous annual reports. For the past 22 years, its composition has reflected our organizational structure--each part of the report was the responsibility of the appropriate research department. In the past several years, research performed for DBER has become more interdisciplinary and more interdepartmental until now only a few projects are conducted wholly within one department. To reflect this change, this report is organized by major program categories according to our schedule-189 submissions. Each part ot the Annual Report is comprised of project reports authored by scientists from several research departments. The Annual Report consists of four parts:

| | | | |
|---|---|---|---|
| Part 1 | Biomedical Sciences | Coordinator:<br>Editor: | R. C. Thompson<br>J. L. Simmons |
| Part 2 | Ecological Sciences | Coordinator:<br>Editor: | B. E. Vaughan<br>J. L. Engstrom |
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| 1954 | HW-30306, HW-33128, HW-35905, HW-35917 |
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| 1965 | BNWL-280, BNWL-235, Vol. 1-4 |
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| 1968 | BNWL-1050, Vol. 1, Pt. 1-2, BNWL-1051, Vol. 2, Pt. 1-3 |
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| 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, Vol. 1, Pt. 1-4 |

W. J. Bair
Program Director, Life Sciences

# FOREWORD

This volume is the sixth annual report to DBER on work supported under its Land and Freshwater Sciences (RX-02-01) and Marine Sciences programs (RX-02-02). As in our preceding annual report, we have brought together in one volume all work funded under these two budget activity numbers. Within these activities, about 60 percent of the funded effort continues to 'be provided by Ecosystems Department with 30 percent provided by other cooperating departments, e.g., Radiological Sciences, Physics and Instrumentation, Biology, Water and Land Resources, and Systems. Because the cooperative patterns are now becoming fairly well established, we thought it helpful to include organizational charts for the Pacific Northwest Laboratory (PNL) and for its several departments. These charts will be found at the back of this report.

Some discussion with DBER was held last year on the feasibility of reporting on an end-of-fiscal-year basis. However, the period from January to December covers the natural cycle of data for an ecological bioyear, in the field research programs. For this reason, we plan to continue the present publishing schedule indefinitely.

In July 1973, funding for effort in support of the AEC Directorate of Licensing was terminated, with the completion of pending plans for reactor sites. At PNL, six staff members were reassigned to other (non-AEC) programs. In Marine Sciences, Dr. Charles I. Gibson was temporarily reassigned to Battelle's Clapp Laboratory, in Duxbury, Massachusetts. In the Terrestrial program, Dr. Michael Duever is on leave of absence participating in the Florida Everglades program of the National Science Foundation (NSF).

During the past year, an extensive body of data has been assembled in the Terrestrial Ecology programs. A considerable effort has been placed in making all data computer retrievable, and preliminary modelling schemes have been tested by Dr. Ronald H. Sauer, acting for the Grasslands Biome of the NSF International Biological Program. The next year (1974) will be a year of synthesis, and numerous modelling options are now available to the terrestrial staff. Cooperative effort at modelling will include the resources of both PNL and the Grasslands Biome modelling center.

Effort in the modelling of specific ecosystems--apart from statistical sampling theory--increased last year. The return of Dr. John M. Thomas to our staff in a full-time capacity has made possible the extension of this point of view to several other programs. One may note that systems modelling is reported in several sections of this document apart from the section on Analysis of Natural Systems. This reflects the desire on the part of investigators in our other programs to examine holistic aspects of the ecosystems under study.

A new plutonium program concerned with the comparative behavior of americium, plutonium, and the other main transuranium elements was commenced in July 1973. This program represents a DBER extension of exploratory work initiated under intercontractor support agreement with the Atlantic Richfield Hanford Company (ARHCO). As in past years, we have included in this report description of pertinent studies by our staff made possible through AEC funds to ARHCO. A wide range of studies on the transuranium elements is in progress at PNL covering transport, food chain, health, fuel cycle, and production or waste management aspects (covered in separate reports). We have for this reason found it advantageous to hold periodic in-house workshops with the other cognizant staff. Particularly valuable insights were made possible by Messrs. Joseph K. Soldat and Leo G. Faust arising from their work on dose commitment (Hermes Model) and fuel cycles for the Reactor Research Division of AEC. These ideas have been discussed in some detail with DBER and reflected in the schedule-189's submitted.

Because it has proved successful in developing greater interdiscipline capability, we hope to extend the workshop approach more fully in the marine sciences area during 1974. We have been somewhat limited during the period covered by this report due to the small scale of AEC-funded work at the Marine Research Laboratory, at Sequim, Washington.

In closing, mention is deserved of two other developments late in the reporting year, which will help us generally to discharge our broader responsibilities in dealing with the present energy crisis. These involved commitments by Battelle for its support of independent exploratory studies: a) to develop specific analytical techniques in marine oil toxicology, and b) to identify unrecognized risks entailed in generating electrical energy by coal combustion. Effort will entail multidiscipline cooperation with staff members from the Atmospheric, Radiological Sciences, Water and Land Resources, and other PNL Departments.

Burton E. Vaughan
Manager, Ecosystems Department

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**SAMPLING FOR CONTAMINANTS**

**MODELLING ECOLOGICAL SYSTEMS**

**STATISTICAL AND MATHEMATICAL ASPECTS OF ECOLOGY**

*Our long term efforts to understand the quantitative aspects of natural systems are contiruing, with a considerable emphasis on the ecological aspects of the development of nuclear power. Our recent emphasis on sampling for contaminants has been brought to the point where an exposition of certain basic aspects is feasible, and one such report was presented to the International Statistical Institute's 39th Session in Vienna last August. Efforts to model ecological systems have concentrated on radionuclide cycling and transfers, and much of the effort was devoted to appraisal of a dairy farm study, as requested by the Division of Biological and Environmental Research. Appraisals of various statistical and mathematical aspects of ecology continued along the lines of past years, with the addition of an effort to produce a bibliography of quantitative methods in ecology.*

## QUANTITATIVE ECOLOGICAL ASPECTS OF NUCLEAR POWER DEVELOPMENT

### Sampling for Impact Evaluation

L. L. Eberhardt and R. O. Gilbert

A key criticism of the myriad of environmental impact statements produced in consequence of the National Environmental Policy Act has been that much of the field effort constitutes little more than "busywork." Other complaints have concerned the search for "magic numbers," e.g., the hope that particular diversity indices will serve as reliable indicators of some impact on an ecological community. The validity of such criticisms depends very much on what may be termed the "sensitivity" of ecological survey methods. We have been attempting to find ways and means for appraising sensitivity. Although exact answers probably cannot be obtained, we do believe that sufficient information can be assembled to guide future impact evaluation studies.

An initial stage of the investigation has to do with the objectives of a particular survey. Much of the actual field experience now available has been concerned with population management. In such cases, investigators are primarily concerned with characteristics of a particular population, so that sample sizes may conveniently be determined on the basis of setting confidence limits for that population. Much of the need for impact evaluation is concerned with the question of whether or not a particular activity, such as construction and operation of a nuclear power reactor, actually results in changes in the abundance of various animal populations. The underlying idea then may be one of hypothesis testing--does building and operating a reactor cause significant changes in local populations as contrasted with nearby areas out of the zone of influence of the reactor? From a strictly scientific point of view, no experimental design is possible in such a situation since there is just one experimental site (and usually at most one control site).

The above argument should not be considered as saying that all hypotheses about impacts cannot be tested, or appraised by statistical methods. What it does say is that particular kinds of hypotheses may be only approximately evaluated, and that survey designs must be carefully considered to see whether the objectives of the survey can be framed in a way that permits a valid statistical test.

Our major efforts in this project are concerned with trying to obtain reasonably good estimates of sample sizes required to detect specific degrees of change with a sufficiently high probability that the comparisons can be meaningful. Since a wide range of specific methods may be used to study natural populations, we cannot very well supply detailed results here. Our initial impressions are that many of the methods in current use are not sufficiently sensitive, at least with sample sizes now used, to detect changes of the degree that most people would regard as important. An accurate appraisal will depend on completion of our on-going work. In some cases, taking larger samples may suffice, but in other situations, an increased sampling effort may cause more damage than the impact proper. We suspect that the ultimate solutions will require both more caution in deciding what should be studied, and greatly increased efforts to improve existing field methods.

## Indices to Population Abundance

L. L. Eberhardt

A substantial fraction of the methods currently used for impact evaluation do not provide estimates of population density. The methods serve instead as indices to population size. Most users of such indices seem to assume that an index is directly proportional to population numbers, that is, that the index represented by y has an average value, E(y), satisfying the relationship:

$$E(y) = \beta N$$

where N represents population size and $\beta$ is an unknown constant. Our efforts in this investigation are concerned with, 1) the reality of this assumption, 2) considering alternate models, 3) questions having to do with statistical analysis of indices, and 4) obtaining useful generalized measures of the variability to be expected when a particular hind of index method is used to study some animal population.

The nature of the simple models thus far considered as realistic for particular kinds of indices suggests that statistical analyses should proceed only after a logarithmic transformation is made. Although some investigators do in fact transform index data, our study suggests that they do so mainly to try to "normalize" the data. Our impression is that normalization is not nearly as important as linearization, that is, most of the realistic models for indices consist of products of relevant variables, so that the logarithmic transformation is required to obtain the additive (linear) model required for most statistical analyses.

Our study of variability of indices presently centers around validity of the assumption of a constant coefficient of variation (standard deviation divided by the mean) for many index methods. If, as much of the data thus far examined suggests, we can accept the hypothesis of a constant coefficient of variation, then the determination of sample size and appraisal of sensitivity of population survey methods becomes very much simpler. More importantly, quite general appraisals of sample size and sensitivity can be made, thus avoiding the necessity for an overpowering amount of detail in arriving at decisions.

Much of the data examined thus far, and ranging over both terrestrial and aquatic systems, suggests coefficients of variation typically may range from 0.5 to 1.0 (50% to 100%), and higher. These results can easily be translated into confidence interval statements. Thus if it is required to have a confidence interval that will include the true mean within a range of ±10% in 95 out of 100 surveys, samples of from 100 (coefficient of variation of 0.5) to 400 (c.v. = 1.0) are required. Since many of these index methods require a substantial amount of effort for each observation, the importance of this information is self-evident. Our study is as yet incomplete, and will be continued.

## Line Transects for Population Studies

L. L. Eberhardt

In many reactor siting studies, there is a need for population estimates of a wide range of terrestrial vertebrate species. In many instances it is not feasible to conduct separate, specialized surveys for each species. Quite a few species are not readily censused by existing methods, or require time-consuming and expensive methods. In other circumstances, there is a need for a simple and rapid method for preliminary surveys. One method with considerable potential for these purposes is the line transect method.

A variety of transect methods are in use, particularly for avian species. Many of the existing methods provide some kind of an index, but one that is not readily or accurately converted to population estimates. We have been studying the mathematical and statistical aspects of methods for using line transects to provide direct estimates of population numbers. The particular method under study depends on recording both the direct-line distance to an animal when first seen (the "flushing distance") and the right-angle distance from the observer's path. One problem in attempts to convert such measurements to population estimates is that it is not known which of two conceptual models is appropriate for the behavioral response of animals to approach by an observer. In one model it is assumed that the animals have a fixed "flushing radius" and respond as soon as the observer's path crosses the boundary of a circle with that radius. An alternative model depends on the concept that the probability of flushing increases as the observer comes closer and closer to the animal.

An evaluation of the two models indicates that they are not distinguishable on the basis of field observations [cf. "A preliminary appraisal of line transects," L. L. Eberhardt (1968) The Journal of Wildlife Management 32:82-88].

For the first model, there is a well-known method of estimation, due to D. W. Hayne. In the case of the second model, it has seemed that the possible methods of estimation necessarily depend on the mathematical form of the frequency distribution postulated for probability of flushing at a given distance from the observer. We have recently devised a mathematical argument that shows the "Hayne estimator" will, in fact, provide an unbiased estimate for a wide class of such frequency distributions. In statistical terminology, this estimator is "robust." This result thus solves a vexing problem in the use of line transects.

Dr. D. S. Robson (Cornell University) has pointed out that the two models described above have a much wider range of application, including observational problems completely unrelated to the line transect application. We are currently engaged in preparing a detailed account, in cooperation with Professor Robson. We expect that further work will include tests on field data, and very likely extension of computer simulations already conducted. We hope that it may also be possible to arrange to study the response-behavior of various species by using radiotelemetry.

### Some Quantitative Aspects of Environmental Plutonium Studies

L. L. Eberhardt and R. O. Gilbert

Present indications are that the ultimate solution to the present "energy crisis" depends on the construction of many electrical generating plants powered by "breeder" reactors. Continued operation of these plants will involve processing and shipping large quantities of plutonium. It is thus especially important to have a full understanding of the fate of any plutonium inadvertently released into ecological systems. We have been investigating some of the quantitative aspects of the behavior of plutonium in ecosystems. A substantial part of our efforts have been in conjunction with extensive studies of plutonium on the Nevada Test Site, and these results are described in another section of the 1973 Annual Report. The present report deals with some additional activities.

We are particularly interested in trying to define some of the objectives of conducting environmental studies of plutonium, simply because development of efficient sampling designs requires a detailed specification of survey objectives. Unfortunately, the best-developed statistical technology has to do with estimating specific quantities of some substance, while the compelling issue in connection with plutonium has to do with the much less precisely defined objective of protecting people from harmful exposures. Our approach to that issue is based on the assumption that the only sure protection is a thorough knowledge and understanding of the fate of any plutonium introduced into the environment. Since the routes and processes involved are many, and may be complex, we suspect that effective planning requires a comprehensive model of some kind. Consequently, we have been investigating the requirements for simulation modelling of environmental plutonium. A few trials with some simple models (a matrix compartmental model, and a difference-equation model) sufficed to point out the extensive gaps by way of transfer coefficients. However, our main effort along these lines has been in trying to establish what kinds of investigations may have to be carried out to provide the necessary structual details for a useful model.

One of our main efforts has been concerned with methods of providing useful advance estimates of sample sizes required for determining the quantity of plutonium in a given area. The initial information available has had to do with concentrations in soil. Also, it has seemed evident that either the gamma or lognormal distribution would provide a suitable model for frequency distributions of concentrations. Using such data as were available in 1972, we concluded that a coefficient of variation of about 0.70 (70%) might be typical of plutonium soil concentrations in a given locale. With this information we were able to recommend sampling plans for several situations, including the recent survey of Eniwetok Atoll. It now appears that the 0.70 value is being borne out by recent data. Rather less data is yet available for vegetation, but the initial results suggest values (for the coefficient of variation) that may exceed soil levels.

As a part of this investigation, we visited environmental plutonium study sites at the Nevada Test Site, Los Alamos National Laboratory, and the Colorado State University study site at the Rocky Flats plant. These visits provided many useful ideas for further statistical investigations, and we plan to keep in touch with these studies.

Plutonium Studies at the Nevada Test Site*

R. O. Gilbert and L. L. Eberhardt

The Nevada Applied Ecology Group (NAEG) at the Nevada Test Site is currently engaged in a Plutonium Environmental Studies Program aimed at identifying and evaluating environmental and radiological health questions associated with plutonium and other radioactive contaminants on the Nevada Test Site. Four areas of the test site are currently under study: Area 13, Area 5 (GMX), Area 11 and portions of the Tonopah Test Range (TTR).

During the past year we have provided statistical design and analysis support for the soil and vegetation sampling programs. Our present concern is primarily with the design of sampling plans for estimating the total amount of $^{239-240}Pu$ present in the surface 5 cm of soil and on the leaves and branches of the native shrubs (those parts edible by livestock).

A stratified random sampling plan is being used to estimate inventory in Areas 13 and 5. First, extensive Fidler surveys were conducted and these data used to construct isopleths or strata within which soil and vegetation samples were taken at random. (The Fidler is a hand-held field instrument for taking count per minute readings of $^{241}Am$). Figure 1.1 is a 3-dimensional plot of the Fidler survey in Area 13 and Figure 1.2 shows the 6 isopleths established from these count data. The "wet chemistry" plutonium concentrations in the random samples were used to estimate the $^{239-240}Pu$ inventory and its associated 95% confidence interval. These results for the soil data from Area 13 are discussed and summarized in Gilbert and Eberhardt (1973).

Each soil and vegetation sample is gamma-scanned in the lab for $^{241}Am$ as well as counted for $^{239-240}Pu$ using

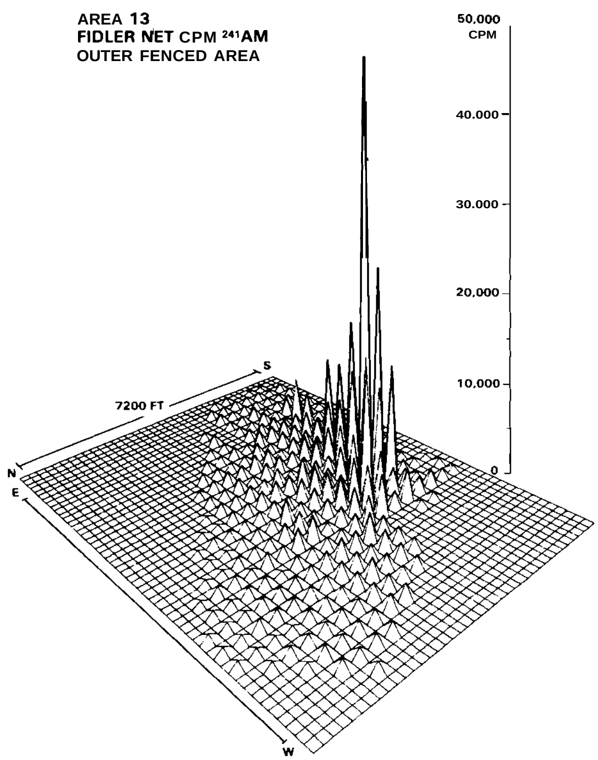


FIGURE 1.1. Fidler Survey in Area 13

*Supported by NTS.

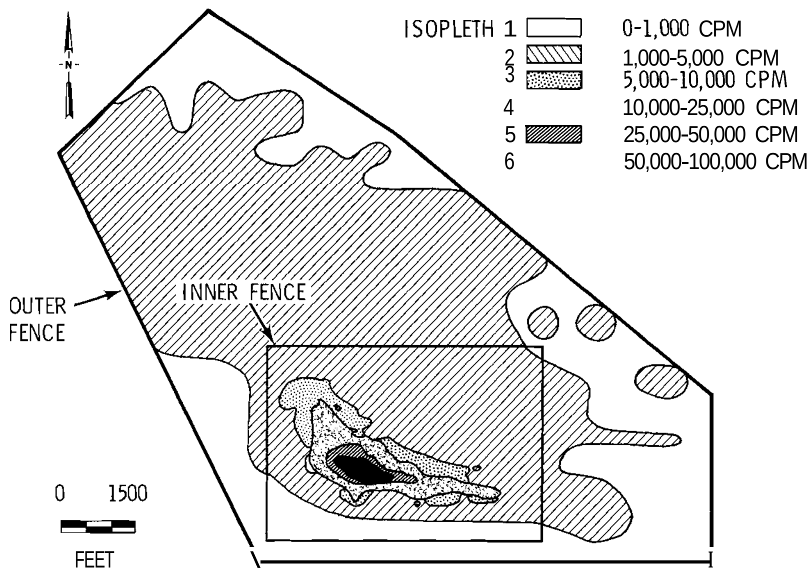


FIGURE 1.2. Area 13--Showing Strata Used in Sampling for Inventory

wet chemistry techniques. These data permit us to investigate whether the two methods give sufficiently well correlated results to warrant the use of a "double sampling" scheme, i.e., a sampling program where $^{241}$Am scans are made on all samples, but the expensive $^{239-240}$Pu counts are obtained on a relatively few samples in order to calibrate the relationship. Our goal is, of course, to determine if costs of laboratory analyses can be reduced over that required when $^{239-240}$Pu analyses are performed on all samples. Results indicate that the answer to this is probably affirmative, at least for Areas 13 and 5 from which data are available, since the $^{241}$Am scans from these areas can predict quite well the $^{239-240}$Pu "wet chemistry" results, particularly for the higher count per minute zones near ground zero (see Gilbert and Eberhardt, 1973).

Immediately before the soil sample is collected the Fidler is used to obtain a $^{241}$Am reading directly over the spot to be sampled. Since Fidler readings are relatively inexpensive to obtain, we hoped they would be sufficiently well correlated with $^{239-240}$Pu soil determinations to permit the use of a double sampling scheme in which a relatively accurate estimate of inventory could be obtained using for the most part only the Fidler readings. However, the results from Areas 13 and 5 indicate this will apparently not be possible. That is, while the Fidler is very valuable as a general survey instrument, it did not prove to be a sufficiently accurate predictor of $^{239-240}$Pu for inventory purposes.

The soils data collected in the inventory sampling program are also being examined for information relating to (a) change in Pu/Am ratio with

depth of profile sample, and
(b) within-lab variability on replicate analyses (information useful in designing interlaboratory comparisons). We are also determining whether Pu concentration on vegetation is an accurate indication of that in adjacent soil.

## SAMPLING FOR CONTAMINANTS

### Sampling for Contaminants in Ecological Systems

L. L. Eberhardt, J. M. Thomas and R. O. Gilbert

This topic constitutes a substantial part of our efforts during the last year. For a considerable number of years it has been evident that the extensive data available on cycling of radionuclides in ecological systems should provide much in the way of "design data" for studying other contaminants, such as the pesticides and heavy metals. Furthermore, it has been apparent that many of the initial studies of contaminants have been conducted with little attention to statistical aspects. We were thus very pleased to have an opportunity to address these topics before an international meeting of statisticians (39th International Statistical Institute, Vienna, August, 1973).

Our efforts in summarizing the available information on sampling for contaminants started with a survey of the objectives for such sampling. We considered the following prospects:

1) Estimation of a material balance.
2) Establishing baselines for monitoring.
3) Assessing consequences on human health.
4) Understanding environmental systems.

A considerable part of our review had to do with models. In our view, models are extremely important features of any appraisal of contaminants in ecological systems in consequence of the highly dynamic behavior of such substances. Not having a suitable model in such circumstances is very much akin to travelling without a road map--unless every turn is known in advance, little progress can be made. Five classes of models, all fitting into the general framework of "compartment" models, were considered, as a means of trying to single out those models most likely to be appropriate and useful. We have not dealt at any length with large computer models, but have instead attempted to provide an appraisal of elementary models useful both for sampling design and as building blocks for larger models.

An important feature of our study has been the investigation of technical aspects of two frequency distributions--the gamma and lognormal distributions. Both have been employed in investigations of contaminants. Since our analysis showed little prospect that the two distributions could be distinguished on the basis of field data, we concentrated on appraising the consequences of mistakenly assuming one distribution when the other was in fact appropriate. Some results useful for this purpose are available, but a good deal of computer simulation (Monte

Carlo) work had to be done to cover other areas, and to confirm approximate results. The general conclusion is that many practical purposes can be satisfied by assuming either model, without risk of serious error. For most circumstances, this finding will result in adoption of the lognormal distribution, since the logarithmic transformation leads to the convenient assumption of normality and thus applicability of standard statistical techniques.

Although the major portion of our work in this program has been concerned with matters that are essentially preliminary to designing sampling plans, we have also been able to address some initial questions in sampling design. The present need is to further develop these results with reference to actual field data.

### Sampling Aquatic Systems for Contaminants

L. L. Eberhardt

An important part of our work on modelling and sampling trace substances in ecological systems has to do with the application of results to actual field situations. In the last few years there has appeared an extensive literature reporting the results of assays for both pesticides and heavy metals in aquatic environments. One of our present efforts is to examine this data in some detail, and to attempt to show how improvements in sampling and analysis can be made.

Some of the recent reports have begun to recognize a relationship between concentration of trace substances and body size of individual fish, a result long-established for radionuclides. Most of the present analyses are made in terms of functions of age or length, and none, so far as we know, utilize the "allometric" or "power-law" relationship to body weight that we believe to be appropriate. We have thus been accumulating data and analyses to establish this point. Its importance should not be underestimated, inasmuch as there are opportunities to greatly reduce the expensive chemical analyses now required if an auxiliary variable, like weight, is used in the sampling scheme.

We are also, in accord with our work on frequency distributions of contaminants, accumulating data on the variability of some of the commoner substances (chiefly DDT) in order to provide estimates of sample sizes required for a specified precision. A parallel investigation concerns the use of the analysis of covariance (and regression techniques) with time or body weight as concomitant variables. As information accumulates, more and more attention will be required to development of more complex models, so we have been considering that aspect, but concentrating on the simpler situations first. An expository paper on our results is planned for the near future.

### Sampling for Radionuclides

L. L. Eberhardt

Although we have previously reported many of our results concerning sampling and statistical analyses for radionuclides, there are several features that require some further investigation and reporting in detail. This subproject is thus devoted to an effort to extend some of our earlier results and to apply them to field data. The passage of some 6 or 7 years since our earlier results were published has made a considerable amount of new data available for analysis.

One of the features of this study is an appraisal of the various values of the coefficient, β, in the allometric relationship:

$$y = \alpha w^{\beta}$$

where y represents concentration of some radionuclide in an organism having body weight w. While the basic coefficient has the value 0.75, in accord with well-known metabolic principles, various other values may be observed in practice, depending on the form or manner in which observations (y) are taken. We thus propose to illustrate this point with field data. A related endeavor is to use regression and analysis-of-covariance techniques on logtransforms of this equation (as described in the report on sampling aquatic systems for contaminants).

One valuable set of data that we have been investigating for some of the analyses described here is the set collected in conjunction with the "Sedan" test conducted at the Nevada Test Site as part of the Plowshare program. Our reanalysis of some of this data suggests further attention to it should be most useful. One of the major considerations that we have in mind is the prospect of various kinds of accidental releases of radionuclides, for which sampling methodology should be well-established long in advance. To our knowledge, this is not true at present.

Sampling for Curve-Fitting

L. L. Eberhardt, J. M. Thomas and R. O. Gilbert

A great many of the laboratory and field studies involving radionuclides and other trace substances are ultimately summarized by fitting some sort of kinetic model to the data. Usually such models represent a trace over time of the concentration or body-burden of some substance. One can thus envision the whole process as having to do with curve-fitting. One quite surprising feature of contemporary practice is that there does not seem to have been any consideration of the optimum pattern of times for observing concentrations. To our knowledge, two patterns are in common use. One consists of uniformly spaced intervals, and the second is a geometric pattern, apparently resulting from the common practice of plotting retention data on logarithmic scales (a geometric pattern results in a uniformly spaced pattern on a logarithmic scale).

Our interest in this notion that a better pattern of sampling in time might be found led to the discovery that the problem has indeed been studied in the context of various kinds of industrial research, initially by G. E. P. Box. We have thus been engaged in attempting to extend the available results to the context of radionuclide studies. Thus far, the most interesting feature is that "best" schemes seem to center around a pattern of observations in which the number of sampling points is equal to the number of parameters to be fitted. For the usual two-component retention curve, the theory thus says that only four points in time should be used for sampling (replicate determinations would be made at each point). Since this approach is quite definitely in opposition to both present practice and "common-sense" knowledge, it seems to us well worth careful study.

Our progress thus far on the project has involved fairly extensive computer simulations and the preparation of portions of a draft report on the subject. Since a good deal of mathematical manipulation is involved, progress comes slowly. Also, various other pressing problems have forced us to defer work on this one, but we hope to return to it soon. As always, a particular and immediate need is to begin trials of the theory in actual practice.

## MODELLING ECOLOGICAL SYSTEMS

### Dairy Farm Study

J. M. Thomas and L. L. Eberhardt

Late in 1972 we were asked to assess the possibilities for developing computer models and/or evaluating portions of the data collected during a long-term fallout study conducted at a commercial dairy farm in Saint George, Utah.

Experimental protocols, data collection and reduction were handled by the Laboratory of Nuclear Medicine at UCLA prior to the termination of the project. At that time Mr. Stan Zellmer (of UCLA) was appointed to help us in locating and summarizing the existing data. This report very briefly summarizes our efforts to date.

1) Model(s)

Our initial attempts to use either a simulation model or to fit parameters using nonlinear techniques were only partially adequate in explaining the seasonal concentration of $^{137}Cs$ in/on growing alfalfa plants. The data employed was incomplete at that time, so some additional samples were submitted for radioanalyses and incorporated into mean values on harvest dates where data was meager. In addition, we used various methods to verify the accuracy of mean values (see below). The model employed (Figure 1.3) led us to question literature values for several rates we used and to attempt to obtain more accurate values from ancillary studies conducted at UCLA. We also believe our initial model may be deficient in not allowing return of cesium stored in either roots and/or soil to harvestable alfalfa--particularly under conditions of low fallout.

2) Evaluation of Data

a) Alfalfa

We had hoped that because up to 70 individually hand-cut square yard samples were available for many harvest dates that we could relate individually determined fallout cesium

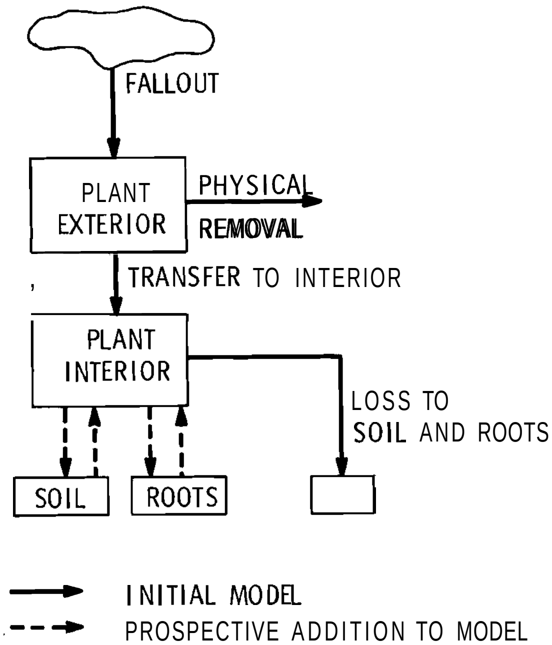


FIGURE 1.3. Schematic Representation of a Possible Alfalfa Model

and/or strontium on an area or concentration basis to a particular statistical distribution. This would be extremely valuable in assessing sample size requirements for future field studies. During the course of summarizing the data referred to under Models above, we discovered a time-related pattern in the data that is likely to influence the shape of the frequency distributions. Through the cooperative efforts of Mr. Robert Wood of UCLA we were able to identify some of the problem sample sets but we decided to discontinue analyses for possible underlying statistical distributions.

Preliminary analysis of concentration and yield data in alfalfa indicates that these factors may be statistically independent. Verification will involve-within harvest date regression analysis. The implication of this preliminary finding, if validated, is that growth and hence canopy area, may not be directly related to cesium or strontium concentration in the plant. This tentative conclusion should be viewed in light of low-level dry fallout, under arid, commercial farming conditions, and a particular kind of plant.

Additional data has been collected and evaluated on alfalfa after field baling, on plants with soil ball intact (returned and grown in the laboratory) and rootstock returned and grown in sand and nutrient media at UCLA. Results from these data sets:

1) aided in locating a discrepancy in cesium concentration means for the 1964 harvest year;
2) indicate that about 10 to 15% of field concentration values may come from root stores;
3) an additional incremental amount may be available from St. George soils.

b) Other Data

We have summarized data from fallout collectors and have begun to relate these values to air values measured in Fort Collins, Colorado to obtain maximum deposition velocities. Prospects for success appear good and subsequent use of this value is contemplated in further modelling efforts. Evaluation of irrigation water contributions and soil data from 2 years is nearly complete. The last portion of the model and associated data (i.e., transfer from feed to milk) has previously been published by the UCLA group.

3) Future Prospects

We hope to finish the summarization of data soon, and to improve the model of radionuclide movement in alfalfa plants. We will identify possible model deficiencies and areas of questionable data.

## STATISTICAL AND MATHEMATICAL ASPECTS OF ECOLOGY

### Similarity Analysis

L. L. Eberhardt and J. M. Thomas

Our interest in application of the "power-law"

$$y = \alpha w^{\beta}$$

to analysis of data on radionuclide uptake and retention continues, but the pressure of other projects (e.g., "impact" problems) has prevented much progress in the past year. Our main emphasis has been on the "proportionality" coefficient, a, with the power constant, β, assumed to be 0.75. A theoretical justification for using this value has just recently appeared (T. McMahon, "Size and Shape in Biology," Science 179:1201-1204, 1973). Using estimated values of a, we derived a "similarity ratio" that appears to have substantial promise as a tool for extrapolation (e.g., from mouse to man). Some details of our past work on the subject are to be found in the 1972 Annual Report.

Our work on "Similarity Analysis" this year has largely been devoted to further literature search (for reference material and data) and to a preliminary appraisal of the statistical aspects of the proposed relationship. Briefly, the main question to be dealt with rests on the assumption that, for two given species:

$$\alpha_{1i} = k\alpha_{2i}$$

where i pertains to the ith substance (e.g., radionuclide) being studied. We thus need to estimate k for a given pairwise comparison. How to do this will evidently depend on the assumption of a particular frequency distribution for estimates of a. Presumably the variance estimate for a given set of data will depend on the precision of the experimental work. Since there are only quite limited data available, it evidently will be necessary to make repeated use of some sets (mainly those available for human subjects, if the first order of business is taken to be "extrapolation to man").

Continued efforts in this program are expected to be devoted to the statistical questions associated with extrapolation and to assessment of further data vis-á-vis the similarity relationship.

### Bias in Capture-Recapture Studies

R. O. Gilbert

Over the past several years we have been studying the bias in Jolly-Seber estimates of animal abundance. These estimates are obtained from mark-recapture experiments in which animals are captured, marked with a unique number or sign and released for possible recapture at later times. This research was originally motivated by long-term mark-recapture studies on small mammal populations on the ALE reserve and more recently by the likelihood that such studies will become more widely used in connection with environmental impact studies in both terrestrial and aquatic environments. Approximations of the bias have been obtained for the situation when all animals are not equally catchable on a given trap night, i.e., when "heterogeneity" is present. These and other results are reported in Gilbert (1973).

During the past year additional results in bias estimation have been obtained in two areas: 1) when both heterogeneity and contagion are present, where "contagion" refers to the situation where the probability that an animal is captured is dependent on past capture experience, and 2) when mark-recapture data from adjacent trap days are pooled in an effort to minimize the effects of capturing only a few animals on each trap day. Concerning the first point above, it is becoming increasingly clear that contagion and heterogeneity are more likely to be the rule rather than the exception in mark-recapture experiments. Results have been obtained for three types of contagion: 1) a general increase in probability of capture with time (trap "proneness"), 2) a general decrease with time (trap "shyness"), and 3) a mixed reaction where some of the animals increase in catchability and others decrease. The results indicate it is difficult to make generalizations about the type and magnitude of bias to expect in mark-recapture studies unless one has considerable knowledge about probabilities of capture and how they change with time, and such information is usually not available.

Concerning the pooling of data, results have been obtained for two Jolly-Seber type estimates of population abundance. Computer simulations and Taylor series approximations indicate that these pooled estimates can in certain circumstances reduce the bias due to heterogeneity, but their variances are not necessarily reduced from the levels of the usual, unpooled estimate. It is becoming increasingly clear that for both the bias and variance to be small, the only solution is for all animals to have probabilities of capture greater than 0.30 or 0.40.

We hope in the near future to examine the consequences of our findings in terms of the power or sensitivity of mark-recapture studies to detect differences in population abundance between two or more areas. This would be valuable information relative to the planning of environmental impact studies.

## ALE-IBP Sampling and Statistical Analysis

R. O. Gilbert

Statistical design and analysis support was provided for a number of ecological studies on the ALE reserve including the IBP Grassland Biome study site during the past year. Specific activities included:

1) Altering the IBP plot sampling design to allow for studying the recovery process of native shrubs

after removal of a heavy cattle grazing pressure sustained over the past 2 years. This included the cessation of grazing on one of the plots grazed in 1971 and 1972 (the "recovery" plot in Figure 1.4), increasing the number of sampling blocks in each treatment from six to eight, eliminating sampling in one of the ungrazed plots, choosing new 15 x 30 meter vegetation sampling "blocks" to replace blocks utilized over the past 2 years and abandoning the use of strata within treatments since they were not contributing to a reduction in the variance of biomass estimates. In July 1973, a range fire swept over the IBP plot so that it was necessary to establish a new control (ungrazed) plot in a nearby unburned area.

2) Analyses of data obtained on three native plant species collected during May and June of 1973 on the Recovery and Control IBP treatment areas to investigate the effects of prior grazing on height of vegetation and seed leaves, length of seed heads, proportion of vegetation clumps with seed heads, number of seed heads per clump, clump size, and on mineral and nutrient content in the seeds.

3) Analysis and synthesis of the large number of small mammal mark-recapture records obtained over the 6-year period from 1967-1972 on ALE. This extensive set of data is being analyzed in part using the Jolly-Seber model, with which we have become quite familiar due to our study of its bias over the past several years.

4) The design of field lysimeter studies to investigate the uptake over time of $^{238}Pu$ by three species

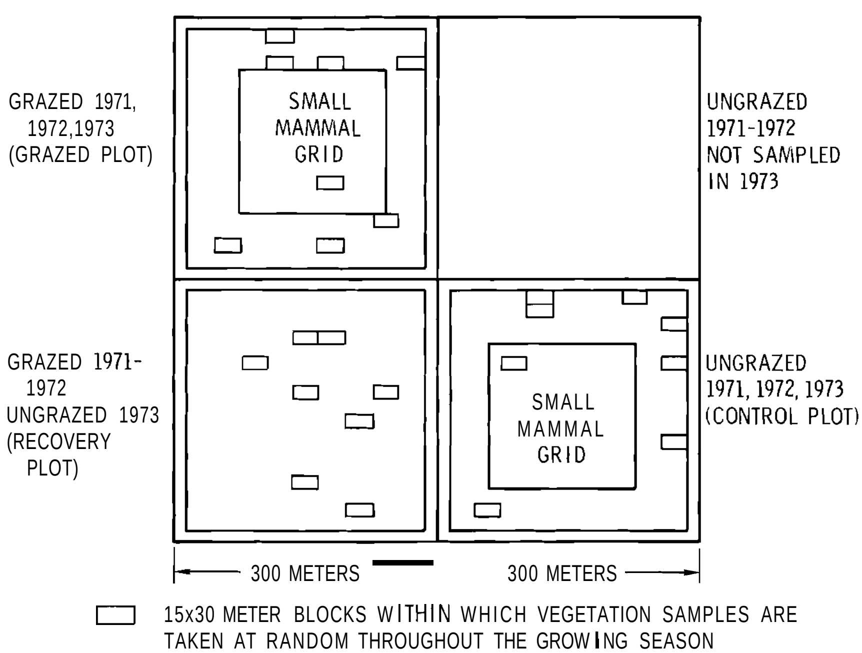


FIGURE 1.4. ALE-IEP Grassland Study Sampling Design, 1973

of plants (cheatgrass, peas and wheat) under different conditions of moisture and soil fertility.

5) The synthesis of the large body of information gathered over the years on plant production related to seasonal changes on the "Old Fields" on ALE (Lower and Upper Snively Ranches). These data are particularly pertinent to waste management problems associated with native environments.

During the past year there has been increased interest in summarizing and synthesizing data collected in long-term studies on ALE (the studies mentioned in 3) and 4) above are two examples). As statisticians we expect to play an important role in the analysis of these data. The results from these long-term studies should yield information useful in the construction of computer models of some components of the desert shrub ecosystem currently under study on ALE.

Bibliographic Citation Computer System

J. M. Thomas, L. L. Eberhardt and M. I. Cochran

We have long felt the need for a computer retreivable souce of bibliographic citations dealing with the subjects of mathematics, statistics, and computers in ecology. Accordingly, we obtained an extensive set of computer programs from the Pacific Southwest Forest and Range Experiment Station. Considerable effort has been expended in modifying and adapting this system to the Hanford CDC-CYBER-70 computer. Assembly of the bibliographic material has been a joint effort with Professor Vincent Schultz (Washington State University). Dr. Schultz has been personally involved in the task of coding, keypunching, keywording and verifying some 2400 references needed for two of the three prospective bibliographies. This task is nearly complete and preliminary interrogations and trial indices appear to be extremely useful. We have used the system to locate references dealing with sampling in the aquatic environment and as a resource for several publications. We are working toward a major publication based almost entirely on the reference system. Even before we were convinced the system would be useful and cost effective, other scientists within the department requested its use. We currently have one other user and expect additional scientists will "automate" their personal bibliographies in the near future.

The system is not intended to supersede or supplant the very large and effective information resource centers existing countrywide. Instead our system is an individually oriented bibliographic resource where scientists themselves are responsible for the quantity and quality of personal files on rather specialized aspects of much larger scientific fields. The value of the files is directly proportional to the effort an investigator wishes to initially give them. Our current capabilities for any set of bibliographic citations are:

1) To correct, add and delete to a portion of a citation.

2) To print all or part of any or all citations in any order or line width.
3) To produce indices of a priori selected portions of citations, i.e., author, keyword, etc.
4) To search any field or fields of some or all citations for words, phrases, or sentences under and-or-not logic.
5) To print complete word vocabularies of any field to obtain indexing terms.

Other papers in this report related to Modelling are:

Sauer, R. H. "Simulation Model of a Cheatgrass Ecosystem." See pages 167 to 170 in the Terrestrial Ecology section.

Thomas, J. M., C. D. Cushing and L. L. Eberhardt. "A Conceptual Model of Radionuclide Transfer in Columbia River Biota." See pages 89 to 91 in the Freshwater Ecology section.

Cushing, C. E., J. M. Thomas and L. L. Eberhardt. "Modelling of Radionuclide Cycling by Periphyton." See pages 92 to 93 in the Freshwater Ecology section.

## PUBLICATIONS AND PRESENTATIONS

PUBLICATIONS

Eberhardt, L. L., "Modeling Radionuclides and Pesticides in Food Chains." In: Third National Symposium on Radioecology. Vol. 2, pp. 894-897, (May 10-12, 1971), 1973.

Eberhardt, L. L., "Some Problems in Estimating Survival from Banding Data," In: Population Ecology of Migratory Birds, Wildlife Research Report 2, 1972 (Released in 1973).

Eberhardt, L. L., Some Quantitative Aspects of Environmental Plutonium Studies, (Draft report circulated for comment; planned as BNWL report).

Eberhardt. L. L. and R. O. Gilbert, Gamma and lognormal Distributions as Models in Studying Food-Chain Kinetics, BNWL-1747, 1973.

Eberhardt, L. L., R. O. Gilbert, H. L. Hollister and J. M. Thomas, "Sampling for Contaminants in Ecological systems," (Submitted for Publication).

Gilbert, R. O., "Approximations of the Bias in the Jolly-Seber Capture-Recapture Model," Biometrics 29(3) : 501-526, 1973.

Gilbert, R. 0. and L. L. Eberhardt, "Statistical Analysis of Pu in Soil at the Nevada Test Site - Some Results," Presented at the Nevada Applied Ecology Group Plutonium Information Meeting, Las Vegas, Nevada, BNWL-SA-4815 REV, October 2-3, 1973.

Hanson, W. C. and L. L. Eberhardt, "Cycling and Compartmentalizing of Radionuclides in Northern Alaskan Lichen Communities," In: Third National Symposium on Radioecology Vol. 2, pp. 71-75, (May 10-12, 1971), 1973.

O'Farrell, T. P., J. D. Hedlund, R. J. Olson and R. O. Gilbert, "Radiation Effects in Free-Ranging Pocket Mice, Perognathus parvus, During the Breeding Season," Science 179:289-291, 1973.

Rickard, W. H., J. F. Cline and R. O. Gilbert, "Behavior of Winter Annuals as Influenced by Microtopography and Elevation," Northwest Science 47(1):41-49, 1973.

Rickard, W. H., J. F. Cline and R. O. Gilbert, "Soil Beneath Shrub Halophytes and Its Influence Upon the Growth of Cheatgrass," Northwest Science (in press).

Rickard, W. H. and L. L. Eberhardt, "Fallout Radiocesium in Sedges and Trout of a Cascade Mountain Bog," In: Third National Symposium on Radioecology, Vol. 2, pp. 349-352, (May 10-12, 1971), 1973.

Thomas, J. M. and L. L. Eberhardt, "Similarity Ratios and Patterns in Retention of Trace Substances," In: Third National Symposium on Radioecology, Vol. 2, pp. 924-928, May 10-12, 1971), 1973.

PRESENTATIONS

Eberhardt, L. L., "General Statistical Considerations," Plutonium Information meeting, Nevada Applied Ecology Group, Las Vegas, October 2, 1973.

Eberhardt, L. L., "Quantitative Aspects of Environmental Plutonium Studies," Informal Seminar at Colorado State University, June 5, 1973.

Eberhardt, L. L., "Quantitative Aspects of Trace Substances in Natural Environments," Informal Seminar at Los Alamos National Laboratory, June 1, 1973.

Eberhardt, L. L., "Sampling for Contaminants in Ecological Systems," International Institute of Survey Statisticians and International Statistical Institute, Vienna, Austria, August 1973.

Eberhardt, L. L., "Sampling for Radionuclides and Other Trace Substances," Seminar in the Radiological Sciences Department, June 28, 1973.

Gilbert, R. O., "Statistical Analysis of Soils--Some Results," Plutonium Information meeting, Nevada Applied Ecology Group, Las Vegas, October 2, 1973.

## ENVIRONMENTAL CHEMISTRY

- THE POTENTIAL FOR PLUTONIUM COMPLEXATION IN SOIL AND UPTAKE BY PLANTS

  CHARACTERISTICS OF HANFORD SOILS AND AQUATIC SEDIMENTS

- FATE AND EFFECTS OF OIL ON MARINE COASTAL ECOSYSTEMS
- ° HANFORD INTERCONTRACTOR SUPPORT
- RADIOECOLOGY OF IODINE-129
- SUSPENDED PARTICLE INTERACTION

° INTERCONTRACTOR STUDY

## THE POTENTIAL FOR PLUTONIUM COMPLEXATION IN SOIL AND UPTAKE BY PLANTS

*Previous studies have indicated that plutonium is largely insoluble in soil over the short-term and is not accumulated by plants. However, it is possible that naturally occurring ligands in soil arising from organic matter decomposition processes may form complexes with plutonium increasing plutonium solubility in soil and uptake by plants. Furthermore, the possibility exists that the chemical form of plutonium may be directly altered by the soil microflora as has been demonstrated for other metals.*

*The present studies were undertaken to determine (1) the effects of plutonium on the soil microbial population and on soil microbial processes, (2) the potential for formation of plutonium complexes in soil and the role of the soil microflora in this process, (3) the extent of plant uptake and translocation of plutonium or its complexes, and (4) the bond types and chemical forms of plutonium or its metabolites in microbial and plant tissues and soils. The progress of these investigations is summarized below.*

### Influence of Plutonium on the Soil Microflora

R. E. Wildung, T. R. Garland,
H. Drucker* and G. S. Schneiderman*

To provide a basis for evaluation of the microbial influences on plutonium transformations in soil and as a first phase in isolation of plutonium resistant organisms, the effect of soil plutonium concentration on the soil microflora was measured as a function of changes in microbial types and numbers and soil respiration rate.

A noncalcareous Ritzville silt loam of pH 7.0 was amended with $^{239}$Pu as the soluble (valence 4) nitrate, at levels of 0.05, 0.5 and 10 μCi/g and with starch, nitrogen and water to provide optimal microbial activity. Subsamples of soil were periodically removed to determine the changes in types and numbers of soil microflora and plutonium water solubility with time. During this period, soil respiration rate was monitored by continuous collection of soil-evolved carbon dioxide.

* Biology Department

The growth curve of the fungi (Figure 2.1) was generally typical of the growth response for other classes of microorganisms. Total microbial numbers were compared at the end of logarithmic growth. The organisms generally reached this stage after 8 to 14 days of incubation. Growth rates were compared over the intervals of maximum microbial growth for each organism at each plutonium concentration. The results are summarized in Table 2.1.

It is apparent that plutonium did not generally affect the rate of growth but decreased the total numbers of all classes of microorganisms at levels as low as 0.05 µCi/g or 1 µg/g. The fungi were the exception, differing from the controls only at a plutonium concentration of 10 µCi/g or 180 µg/g. Thus, the plutonium did not affect maximum generation rate but rather affected its duration--limiting microbial numbers.

The accumulative carbon dioxide curve (shown in the following report) generally corresponded to the growth curve of the fungi. In the case of the other classes of organisms, the maximum logarithmic growth occurred before the rate of carbon dioxide evolution reached minimum levels. Soil respiration rate and cumulative carbon dioxide over the incubation period were significantly reduced only at the 10 µCi/g level of Pu amendment, although numbers of all classes or organisms except the fungi were depressed below this level (Table 2.1). This is in marked contrast to the results of previous studies conducted in this laboratory with a number of other heavy metals such as silver and thallium, in which respiration rate was a sensitive measure of metal effect at levels as low as 10 ppm in soil. It should be noted,

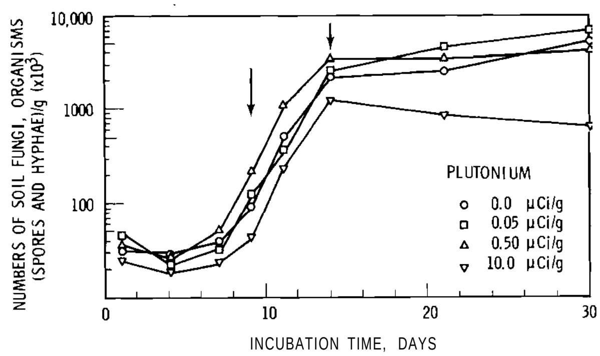


FIGURE 2.1. Influence of Plutonium Concentration on the Growth of Fungi in Soil. Arrows denote time intervals at which growth rates and total numbers were compared with other microbial types.

TABLE 2.1. Summary of the Effects of Plutonium at Several Soil Concentration Levels on the Distribution of Microorganisms in Soil Relative to Controls. A positive sign denotes a significant effect. A zero indicates that there was no significant effect.

| | EFFECT ($p<0.05$) OF PLUTONIUM ON | | | | | |
|---|---|---|---|---|---|---|
| | GROWTH RATE AT PLUTONIUM CONCENTRATIONS (µCi/g) OF | | | TOTAL NUMBERS AT PLUTONIUM CONCENTRATIONS (µCi/g) OF | | |
| MICROBIAL TYPE | 0.05 | 0.5 | 10.0 | 0.05 | 0.5 | 10.0 |
| BACTERIA | | | | | | |
| AEROBIC AND MICROAEROPHILLIC | | | | | | |
| NON-SPORE FORMERS | 0 | 0 | 0 | + | + | + |
| SPORE FORMERS | 0 | 0 | 0 | + | + | + |
| ANAEROBIC AND FACULTATIVE ANAEROBIC | | | | | | |
| NON-SPORE FORMERS | 0 | + | 0 | + | + | + |
| SPORE FORMERS | 0 | 0 | 0 | + | + | + |
| FUNGI | 0 | 0 | 0 | 0 | 0 | + |
| ACTINOMYCETES | 0 | 0 | + | + | + | + |

however, that the effect on respiration rate was dependent upon the magnitude of the soil respiration rate which, in turn, was dependent upon the initial level of microorganisms in soil. In soils exhibiting a lower carbon dioxide evolution rate, the reduction of respiration rate due to plutonium amendment was more pronounced.

## Potential Role of the Soil Microbiota in the Solubilization of Plutonium in Soil

R. E. Wildung, T. R. Garland and H. Drucker*

To provide a preliminary assessment of the potential for microbial alteration of plutonium solubility in soil under aerobic conditions, soils sterilized by gamma irradiation were treated, incubated and microbial types and numbers and soil respiration rate measured in the same general manner as described for the nonsterile soil in the foregoing report.

At intervals during incubation over a 30 day period, sterile and nonsterile soils, which contained 10 μCi plutonium/g of soil, were subsampled and the subsamples (lg) suspended in 1 liter of distilled water. After a 4 hr equilibration period, an aliquot of the soil suspension was filtered through 5, 0.5 and 0.01 μ millipore filters. The plutonium in the 0.5 and 0.01 μ filtrates was designated water soluble although it was recognized that plutonium may have been present as fine collodial suspensions.

In an ancillary experiment, incubation was continued for 65 days until the carbon dioxide evolution rate reached a constant level. The plutonium-containing sterile soil was then inoculated with the plutonium-treated nonsterile soil and the respiration rate and solubility of plutonium in the inoculated soil measured for a period of 30 days.

Changes in the soil respiration rate and plutonium solubility during the initial 30 day incubation are shown in Figure 2.2. The effect of plutonium on soil respiration rate has been discussed in the foregoing report. The concentration of plutonium in the 0.45 μ filtrate ranged from approximately 0.5 to 1.5% of the plutonium applied during the incubation period. It was initially higher in the sterile soil than in the nonsterile soil but was relatively constant with time in the sterile soil. The initial increase was anticipated in view of the known increases in soluble organic matter which result from gamma irradiation of soil.

Plutonium solubility in the nonsterile soil, while initially lower, increased by a factor of 3 with incubation time to 14 days and remained significantly higher than the sterile soil during the incubation period. This increase generally followed the accumulative carbon dioxide curve, and maximum solubility occurred at the end of logarithmic growth for all classes of organisms. The concentration of plutonium in the 0.01 μ filtrate, which represented a plutonium

* Biology Department

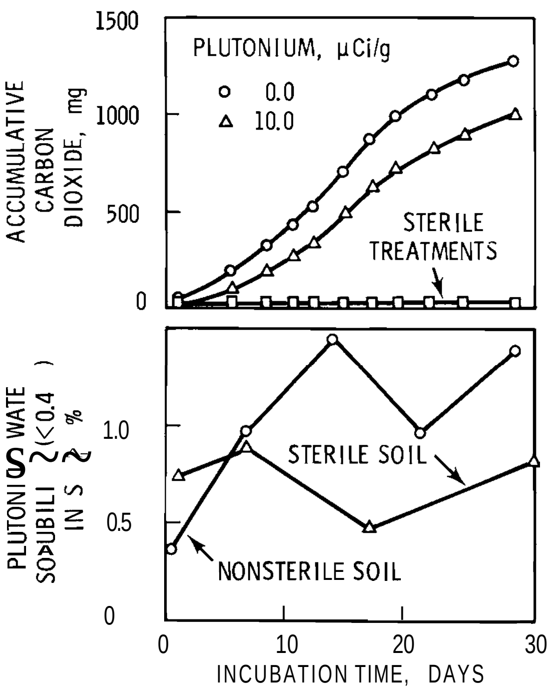


FIGURE 2.2. Changes in Soil Respiration Rate and Solubility of Applied Plutonium with Time of Soil Incubation

level less than 0.2% of that applied, did not change significantly with treatment.

When the sterile soils were inoculated with nonsterile soil, carbon dioxide evolution increased at a much more rapid rate without a lag phase, and this was accompanied by an additional factor of 2 increase in water solubility of plutonium after only 4 days of incubation. Again, there was no change in the <0.01 µ fraction which amounted to approximately 10% of the plutonium present in the <0.45 µ fraction.

At least under the conditions of this study, the evidence strongly suggests that the solubility of plutonium in soil is influenced by the activity of the soil microflora. This effect is closely related to soil respiration rate. The mechanism of this effect cannot be clearly defined at this time, however, several possibilities exist. These include (i) the direct alteration of plutonium form such as modification of the plutonium polymer or plutonium valence state; (ii) the production of organic acids which may complex plutonium; or (iii) the alteration of the pH of the soil solution in the immediate vicinity of the colloid without measurable effects on the overall soil pH.

Investigations are presently under way to determine the mechanism of this effect. Resistant microorganisms are being isolated using enrichment techniques for further study of the chemical form of the metal in microbial cells and exocellular media. Furthermore, investigations are underway to characterize the form of plutonium in plants and of soluble plutonium in the soil.

## Influence of Soil Microbial Activity on the Uptake and Distribution of Plutonium in the Shoots and Roots of Barley

R. E. Wildung and T. R. Garland

Increased water solubility of plutonium on incubation under optimum conditions for microbial activity, as described in a foregoing report, may be expected to increase plutonium uptake by plants provided the plant is not able to exclude the increased metal. In order to determine the distribution of plutonium in the structural components of plants grown on plutonium containing soil and to determine if the increased plutonium solubility on incubation resulted in increased plutonium uptake by plants, the soils, incubated as previously described, were planted to barley and cultured using a split-root technique (Figure 2.3) which allowed measurement of the uptake, sites of deposition and chemical forms of plutonium in plant shoots and roots. The results were compared to the results of similar plant studies in which the soils had not been incubated.

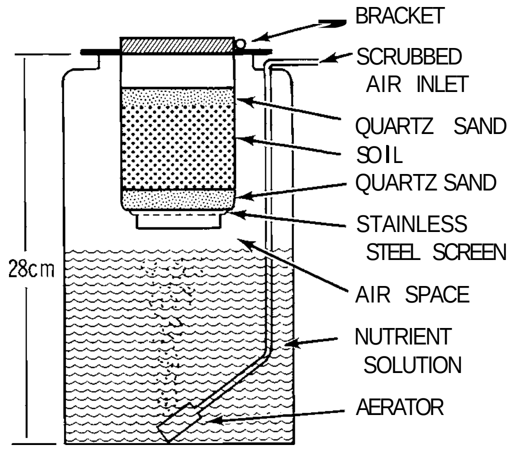


FIGURE 2.3. Split-Root System of Plant Culture

Although variability within treatments increased with decreased soil plutonium concentration, it was evident that the concentration of plutonium in barley shoots and roots decreased with decreased soil plutonium concentration regardless of the culture method employed (Table 2.2). However, the concentration factor (μCi Pu/g of tissue/μCi Pu/g of soil) increased with decreased plutonium concentration. This effect may have resulted from a concentration-dependent change in plutonium availability or from a toxic effect of plutonium on the plant which had the effect of reducing uptake. In view

TABLE 2.2. Influence of Soil Plutonium Concentration on Uptake and Distribution of Plutonium in Barley Shoots and Roots

| | Plant Uptake of Plutonium[a,b] | | | |
|---|---|---|---|---|
| | Shoots | | Roots | |
| Soil Plutonium Concentration | Concentration, μCi/g × $10^{-4}$ | Concentration Factor[c] | Concentration, μCi/g × $10^{-4}$ | Concentration Factor[c] |
| μCi/g | | | | |
| 10.00 | 5.4 | 0.54 | 36 | 3.6 |
| 0.50 | 0.95 | 1.9 | 3.0 | 6.0 |
| 0.05 | 0.07 | 1.3 | 0.55 | 11 |

a. Based on oven-dry (60°C) weight.
b. Mean standard errors were ±13, 39 and 52% (n = 3) for soil plutoniuni levels of 10, 0.50 and 0.05 μCi/g, respectively.
c. (μCi Pu/g oven-dry plant tissue/μCi Pu/g oven-dry soil) × $10^{-4}$.

of the known toxicity of plutonium to yeast cells, the latter explanation would appear the most likely. However, it should be noted that the potential exists for microbial alteration of plutonium form and availability in soil and the observed effects could be explained on the basis that microbes which participated in solubilization were susceptible to plutonium at the higher soil concentration levels as indicated in a foregoing report.

Regardless of the mechanism for increased plutonium uptake at the lower soil concentration levels, it must be emphasized that most estimates of plutonium hazard to man are based on concentration factors of approximately $5 \times 10^{-5}$, derived largely from studies at the higher soil plutonium levels. The results, therefore, suggest that new emphasis be placed on determination of plutonium uptake by plants from soils containing plutonium at environmental levels and reevaluation of previously accepted concentration factors.

The plutonium levels in barley roots differed markedly from the shoots with levels of plutonium exceeding the shoots by factors of 3 to 8, depending upon soil plutonium concentration (Table 2.2). Autoradiographs showed that in contrast to the shoots where plutonium was concentrated near the crown, plutonium was distributed over the entire length of the root. In the system employed, plutonium was not added to the nutrient solution in which the roots were grown nor was plutonium detected in the nutrient media. Thus, the plutonium in the roots originated from the soil and was translocated downward from the soil in the root system. Furthermore, the lack of detectable quantities of plutonium in the nutrient solution suggests that plutonium was bound tightly in the root tissue. The implications of these findings are also important in terms of evaluation of plutonium hazards in the environment because (i) root crops directly consumed by man may contain plutonium at levels exceeding those found in other crop plants in which the tops are consumed, (ii) plutonium, considered largely immobile in soil, may be distributed much further down the soil profile than previously expected due to its mobility in the plant root system, and (iii) the potential exists that decomposing roots may represent a significant source of plutonium of different solubility and plant availability than the plutonium directly entering the soil environment. In order to provide a better understanding of the fate and hazard of plutonium in the environment, it is essential that research be directed toward determination of (i) the uptake of plutonium by a broad range of plants from representative soil types containing plutonium at environmental levels, with emphasis on root crops, (ii) the potential for recycling of plutonium present in plant roots, and (iii) the form and behavior of plutonium in soils and plants.

# • CHARACTERISTICS OF HANFORD SOILS AND AQUATIC SEDIMENTS

*Soils investigations have been directed largely toward delineation of the role of arid soils in carbon and nutrient cycling as influenced by environmental perturbations. Until this year, primary emphasis in these studies was on the ALE Reserve. However, recently these investigations have been extended to emcompass the fate of radionuclides in a broad range of surface soils.*

*In aquatic sediment studies, investigations have been directed toward measurement of the physiochemical properties of suspended matter and sediments of the lower Columbia River watershed and mercury form and distribution in these components as these may be influenced by seasonal changes in watershed and river conditions.*

## Influence of Soil Temperature and Water Content on the Respiration Rate of Arid Grassland Soils - a Model

R. E. Wildung and T. R. Garland

In order to predict carbon and energy flow through the terrestrial ecosystem, it is necessary to understand the effect of environmental factors on soil respiration rate, i.e., the rate of carbon dioxide evolved from soil, for this is the principal mechanism for return to the atmosphere of the photosynthetic energy in plant and animal residues.

Previous reports outlined the results of field studies to determine the effects of soil temperature and water content on soil respiration rate over a 2-year period in the arid shrub-steppe. This report summarizes the results of final studies to devise a regression model suitable for description of these effects and of preliminary studies to validate the model as a predictive tool for respiration rate measured during a third year.

To determine the influence of soil temperature and water content on soil respiration rate, 12 locations were randomly selected from 4 statistical strata in an undisturbed (18 ha) field plot located on a Ritzville silt loam soil in the Arid Land Ecology Reserve. Vessels, which could be sealed to form a canopy over the soil surface, were inserted to a soil depth of 20 cm and carbon dioxide evolution was measured for 24 hr periods from April 1971 to November 1972. Concurrently, surface (0-10 cm) soil water content and temperature (10 cm) were also monitored. Soil temperature reflected seasonal cycles in climatic conditions in arid regions with minimum (0.5°C) and maximum (31.0°C) soil temperatures occurring in the winter and summer, respectively. Soil moisture ranged from 1.2 to 19.7% and was inversely related to soil temperature.

In order to determine the effects of soil water and temperature on soil respiration rate, simple correlations and empirical predictive models were constructed using the data obtained over the 2-year monitoring period. The dependent variable was considered to be soil respiration rate and the principal independent variables were taken as soil water and soil temperature. Other terms considered were the cross products, squares and logarithms of the principal independent variables. The terms included in the final regression equation were selected by the backward elimination procedure. The contributions of the independent variables to the regression were expressed as percentages of the total variation about the mean soil respiration rate as defined by the regression and were calculated by squaring the multiple correlation coefficient (R) and multiplying by 100.

The regression model was tested by comparison of predicted values with several field measurements of respiration rate during 1973.

The results of simple correlations of data obtained over the first 2 years indicate soil moisture was significantly related ($r = 0.83$, $P < 0.01$) to soil respiration rate when temperatures were above 15°C. Conversely, in the fall, winter and early spring, when soil water content was above approximately 10%, the $CO_2$ evolution rate was significantly related ($r = 0.93$, $P < 0.01$) to changes in soil temperature. Thus, soil water and temperature assumed individual importance in influencing respiration rate during the year. During the late spring and summer, the major factor limiting soil respiration was soil water; whereas in the fall, winter and early spring, soil respiration was limited primarily by soil temperature.

A multiple regression model employing soil water (w), temperature ***(t)***, and a water-temperature interaction term provided the best description of the data, accounting for 74.5% of the variation ($R = 0.86$, $P < 0.01$) in soil respiration rate rate (y). The regression equation selected is as follows:

$$y = 0.63 - 0.021\,w + 0.019\,t + 0.014\,wt$$

The multiple regression model appeared to have excellent predictive capability (Figure 2.4) and was sufficiently versatile to describe marked changes in soil respiration rate resulting from summer rains. This was due largely to the inclusion the water-temperature interaction term which served a unique purpose in quantifying the extent of change

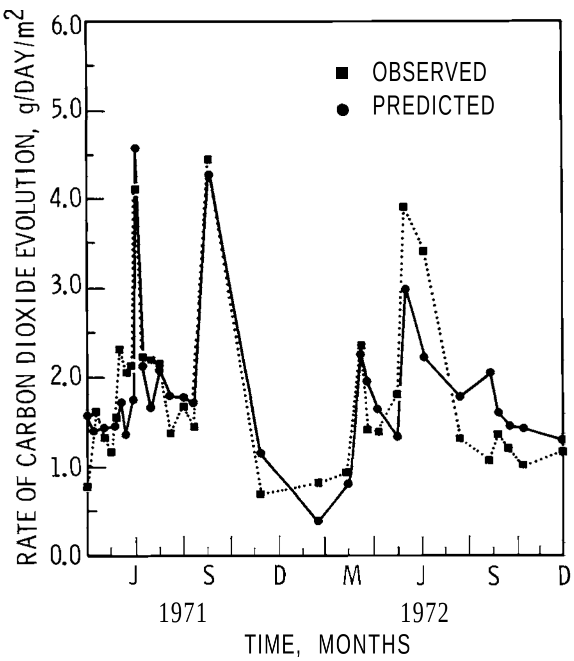


FIGURE 2.4. Seasonal Changes in Soil Respiration Rate. The observed values are the mean of 12 field replicates. The predicted values are derived from a multiple regression model (see text), which included soil temperature, soil water and a temperature-water interaction term as independent variables.

resulting from a change in the relative importance of influential parameters, allowing estimation of the effects of water and temperature on soil respiration rate over a period encompassing several seasons.

Preliminary results of the validation studies in 1973 are summarized in Table 2.3. The model satisfactorily estimated the respiration rate after June 1973. Soil respiration rates measured in the early spring when respiration rate was higher in 1973 than in 1972 were significantly different than predicted from the model. During this period, it would appear that parameters other than

TABLE 2.3. Prediction of Soil Respiration Rate, Measured in the Field in 1973, on the Basis of Water Content and Temperature Using Regression Equations Derived in 1971 and 1972

| Date of Determination | Respiration Rate: Predicted[a] | Respiration Rate: Determined |
|---|---|---|
| | -----------g/$m^2$/day------- | |
| 4-19-73 | 1.40 | 2.11 |
| 5-10-73 | 1.31 | 1.97 |
| 6-14-73 | 1.37* | 1.26 |
| 6-26-73 | 1.50* | 1.51 |
| 7-21-73 | 1.58* | 1.35 |

a. Asterisk denotes predicted values that were within the error range calculated at the 95% confidence level of the model.

temperature and moisture which were not operational in 1971 and 1972 served to increase soil respiration rate. Investigations are in progress to identify these factors and the sampling period is being extended to provide a broader information base for validation.

## Mineral Weathering Processes

R. E. Wildung, R. C. Routson* and T. R. Garland

In order to define the release of nutrients through mineral weathering of ALE Reserve soils, it is necessary to identify soil mineral assemblages and to determine the rate and sequence of weathering reactions. Rainfall provides the medium for mineral reactions and also contains soluble nutrient elements. Measurement of the quantities of nutrients entering a watershed in rainwater and the quantities of nutrients in watershed

* Water and Land Resources Department

drainage waters should allow development of a thermodynamic model of soil weathering reactions and estimation of watershed nutrient budgets.

As part of a program to develop a weathering model, the elemental compositions of the perennial springs draining three watersheds on the northeast-facing slope of Rattlesnake Mountain on the ALE Reserve (Figure 2.5) have been determined periodically since 1971. Furthermore, to estimate the seasonal range in elemental composition of the rainwater entering these watersheds, rainwater was measured at seven time intervals during 1973.

The composition of the spring water (Table 2.4) did not differ significantly with location over the 3-year monitoring period. The waters may be classified as calcium bicarbonate types. Comparing the composition of the spring waters with rainwater sampled in 1973 (Table 2.5), it is evident that percolation through soil resulted in higher water pH and increases in the concentration of all ions analyzed except potassium, iron and aluminum. These latter elements were reduced in concentration. Concentrations of iron, aluminum and

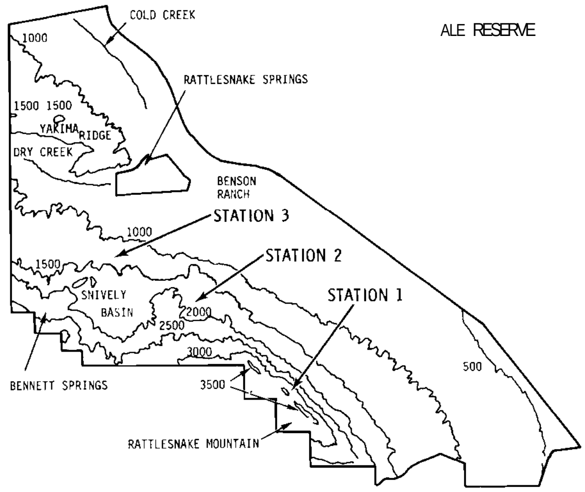


FIGURE 2.5. Locations of Perennial Springs (Stations 1,2,3) and Rainfall Collection (Station 1) Sites for Mineral Weathering Studies

TABLE 2.4. Composition and pH of Perennial Spring Waters Draining Three Watersheds on the ALE Reserve over the Period May 1971 to October 1973

| Sampling locations[(a)] | Total solids | Bicarbonate | Sodium | Potassium | Calcium | Magnesium | Sulfate | Iron | Aluminum | Silica | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration of (μg/ml) | | | | | | | | | | |
| Station 1 | | | | | | | | | | | |
| Range | 160-290 | 90-120 | 4.5-7.4 | 1.2-2.5 | 6.5-19 | 8.2-10 | 1.8-13 | 0.02-0.2 | 0.020-0.12 | 32-49 | 7.6-8.2 |
| Mean | 220 | 110 | 6.1 | 1.8 | 13. | 9.6 | 7.2 | 0.055 | 0.049 | 40 | 7.9 |
| Station 2 | | | | | | | | | | | |
| Range | 150-300 | 90-110 | 5.2-7.2 | 1.6-2.5 | 15-24 | 6.7-8.2 | 2.3-9.1 | 0.01-0.10 | 0.020-0.060 | 38-53 | 7.3-8.2 |
| Mean | 250 | 100 | 6.5 | 2.0 | 18. | 7.7 | 6.3 | 0.050 | 0.045 | 42. | 7.7 |
| Station 3 | | | | | | | | | | | |
| Range | 160-260 | 100-120 | 7.2-9.3 | 1.5-2.5 | 13-23 | 9-11 | 4.7-11 | 0.010-0.090 | 0.030-0.060 | 40-60 | 7.0-8.2 |
| Mean | 220 | 110 | 8.1 | 2.2 | 17. | 9.8 | 7.1 | 0.060 | 0.043 | 45 | 7.9 |

a. Figure ___

TABLE 2.5. Composition and pH of Rainwater on the ALE Reserve Over the Period April 1973 to October 1973[a]

| Sampling locations | Total solids | Bicarbonate | Sodium | Potassium | Calcium | Magnesium | Sulfate | Iron | Aluminum | Silica | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration of (μg/ml) | | | | | | | | | | |
| Range | 68-300 | 2-49 | 0.070-0.57 | 2.4-18 | 1.1-4.4 | 0.14-2.2 | 0.070-5.0 | 0.18-1.8 | 0.13-2.0 | 0.70-7.4 | 4.3-6.8 |
| Mean | 93 | 19. | 0.35 | 7.7 | 2.2 | 1.0 | 3.2 | 0.87 | 0.95 | 3.8 | 6.0 |

a. Station 1, Figure 1

potassium are normally lower in rainwater than determined and these elements may have been dissolved from particulate matter by acid used to minimize precipitation on the surfaces of the rainwater collection vessels, resulting in anomalous values.

Mineral weathering is a principal mechanism for enrichment of waters moving through the soil profile. Utilizing the concentrations of potassium or sodium and of silica in the spring waters, it is possible to estimate the stable mineral phase from previously established thermodynamic relationships. The results of application of these techniques at Station 1 (Figure 2.5) using sodium ion show the position of the water analyses at the kaolinite-montmorillonite stability boundary suggesting that kaolinite-montmorillonite minerals are the most stable in these soil systems (Figure 2.6). This is generally verified using a similar calculation employing the potassium ion and by mineralogical analyses on related soils which indicate a preponderance of montmorillonite. This information, in conjunction with soil mineralogical analyses and a material balance presently being developed for the watershed at Station 1 should provide

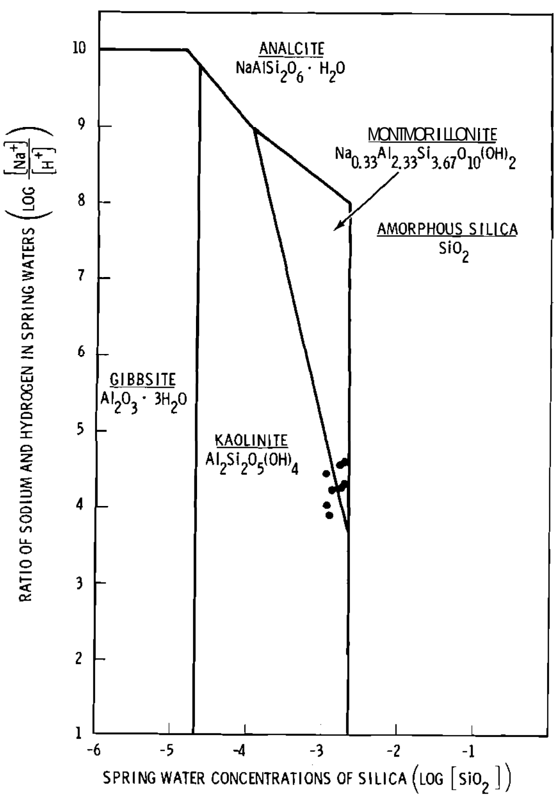


FIGURE 2.6. Stable Minerals in ALE Reserve Soils Estimated from the Elemental Composition of Perennial Streams. Phase diagram position based on water composition (Station 1, Figure 2.5) over the period May 1, 1971 to October 1973.

the first estimates of the role of mineral weathering in the mineral budget for the ALE Reserve.

Iodide and Methyl Iodide Sorption by Surface Soils

R. E. Wildung, R. C. Routson,*
R. J. Serne* and T. R. Garland

With the development of improved analytical techniques for the forms of iodine in emissions from nuclear fuel reprocessing plants and from nuclear reactors, it has become apparent that long-lived iodine isotopes, e.g., iodine-129, may enter the environment. Furthermore, a major portion of this material may, initially at least, enter the environ ment in the form of volatile methyl iodide. These materials may enter the surface soil through rainfall or direct disposal. It was, therefore, deemed essential to evaluate the retention of iodide and methyl iodide by surface soils in order to evaluate the potential for iodide recycling in surface soils and for movement through the soil profile. To assure that these measurements would have broad application, a number of soils were employed which differed widely in genesis and in physiocochemical properties.

Using a column exchange technique, the distribution coefficient (Kd), defined as the ratio, at equilibrium, of the quantity of iodide sorbed per gram of soil to iodide per ml of equilibrating solution, was determined for iodide-131 and methyl iodide-131 (trace quantities in 0.01 M $CaCl_2$) in 22 soils representing a broad range in particle size distributions, carbonate and organic carbon contents, cation exchange capacities and soil pH values (Table 2.6). Anion exchange capacity was not determined.

The Kd values for iodide and methyl iodide ranged from 0.8 to 52.6 and from 0.1 to 3.1, respectively. The difference in soil sorption between these compounds is likely due to the ionic charge of iodide relative to methyliodide which is nonionic. The results of simple correlations of soil properties with iodide and methyl iodide Kd values (Figure 2.7) indicate that silt concentration was the primary influential factor in retention of iodide.

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TABLE 2.6. Range of Properties for Surface Soils Employed in Iodide and Methyl Iodide Sorption Studies[a]

| Cation exchange capacity | pH | Contents of | | | | |
|---|---|---|---|---|---|---|
| | | Carbonate | Organic Carbon | Sand | Silt | Clay |
| me·/100g | | % | | | | |
| 5.5-90.0 | 3.6-8.9 | 0-6.46 | 0.23-28.8 | 14.1-73.1 | 17.6-58.0 | 3.8-46.6 |

a. Range of properties for 22 soil types collected in Oregon, Washington and Minnesota.

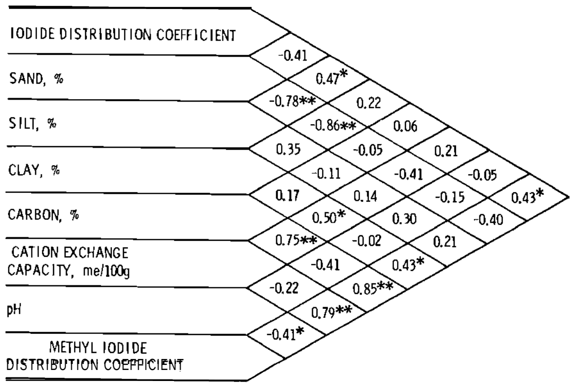


FIGURE 2.7. Simple Correlation Matrix Relating Soil Parameters to Distribution Coefficients for Iodide and Methyl Iodide. Single and double asterisks denote levels of significance of $p < 0.05$ and $p < 0.01$ respectively.

It was initially anticipated that soil clay and organic matter, which have the greatest surface area per unit weight and are generally considered to make the greatest contribution to positive charges in soil, would play a significant role in retention of iodide which is negatively charged. A possible explanation to account for the importance of the silt fraction in retention of iodide is that amorphous iron and aluminum coatings, which may exhibit considerable positive charge, differ in the particle size fractions. The amorphous coatings likely formed as a result of the incongruent dissolution of generally unstable rock-forming minerals which predominate in the silt fraction.

Methyl iodide retention by soils was positively correlated to clay, organic carbon and cation exchange capacity and negatively correlated to pH (Figure 2.7). These observations are consistant with the high surface area of clay and organic matter and the propensity of organic matter to serve in bonding by Van der Waals forces, including hydrogen bonding, of nonionic organic compounds. Because cation exchange capacity is generally related to reactive surface area, it is also reasonable that methyl iodide would be correlate1 with this parameter. In addition, it is known that the charge on both inorganic and organic soil colliods is pH-dependent. Total positive charge and surface positive charge density increase with decreased pH as a result of decreased ionization of acidic groups and increased protonation of basic groups, and these phenomena may be expected to increase the potential for hydrogen bonding and charge-induced dipole interactions, likely accounting for the inverse correlation of methyl iodide retention with soil pH.

Multiple regression techniques were employed to determine the combination of soil properties which best accounted for the retention of iodide and methyl iodide in soils. The terms included in the final regression equations were selected by the backward elimination procedure which served to order the variables according to importance in explanation of the variation in Kd values obtained for different soils. The independent variables; silt, clay and organic carbon were selected by this technique and the final regression equations incorporating these variables are given in Table 2.7. Of the variables examined, silt and organic carbon were most

TABLE 2.7. Multiple Regression Equations Relating Soil Silt ($X_1$), Clay ($X_2$) and Organic Carbon ($X_3$) Contents with Distribution Coefficients for Iodide ($Y_1$) and Methyl Iodide ($Y_2$)

| Dependent Variable | Regression Equation(a,b) | Correlation Coefficient(b) |
|---|---|---|
| Distribution Coefficient, iodide | $Y_1 = 0.33*X_1 + 0.09X_3$ | 0.71* |
| Oistribution Coefficient, methyl iodide | $Y_2 = 0.027*X_2 + 0.10*X_3$ | 0.96** |

a. Based on measurements of 22 soils.
b. Single and double asterisks denote significance at the $P < 0.05$ and $P < 0.01$ levels, respectively.

important in iodide retention but accounted for only 49% ($R^2 \times 100$) of the variation. Investigations are underway to determine if a greater proportion of the variation can be explained.

Methyl iodide retention in soil was largely a function of clay and organic carbon content which accounted for over 80% of the variation in methyl iodide retention for the soils studied. Thus, it may be concluded that in surface soils containing sufficient silt, clay and organic matter, iodide and methyl iodide have the potential for accumulation. Further studies of the chemical and biological fate of iodide in these soils would therefore appear to be warrented.

### Distribution of Mercury in Water, Suspended Particulate Matter and Sediments of the Lower Columbia River Watershed

R. E. Wildung and T. R. Garland

Previous reports have described. the distribution of mercury in water, suspended particulate matter and sediments of the lower Columbia River Watershed. Total mercury levels were determined in water and isolated suspended particulate matter (>0.45 μ) taken in October and December of 1971 and March and June of 1972 from the Columbia River at Priest Rapids, McNary and Bonneville Dams (river miles from the mouth, 396, 292 and 148, respectively); the Yakima, Snake and Walla Walla Rivers at their confluence with the Columbia River (river miles 335, 324 and 314, respectively) and the Ringold and Esquatzel wasteways (river miles 354 and 344, respectively) which return irrigation water to the river.

The studies indicated (i) the concentrations of suspended particulate matter in the Columbia River ranged from 1.2 to 100 mg/liter with highest concentrations occurring during the spring, when land runoff was at a maximum, (ii) the concentration of particulate matter throughout the sampling period increased down river with lowest concentrations occurring at Priest Rapids Dam and highest concentrations at Bonneville Dam likely due to the contributions from rivers and wasteways downstream from Priest Rapids which contained 13 to 210 mg/liter suspended matter during the spring, (iii) the concentrations of mercury in filtered waters were less than methodlogical sensitivity (0.1 μg/liter), (iv) suspended matter in the Columbia River contained 1.5 to 120 mg/kg mercury, (v) mercury concentrations in suspended matter were inversely related to the total concentration of suspended matter and were highest in the winter, a period of minimum terrestrial runoff, (vi) mercury concentrations in particulate matter decreased downstream in the Columbia River, a phenomenon which may have resulted from dilution effects, release of mercury to solution or sedimentation of suspended matter of highest mercury concentration, and (vii) the concentrations of mercury in sediments behind Columbia River dams were low relative to the concentration in suspended matter at the same locations, indicating that particulate matter of lower mercury concentration entered the river downstream or that mercury was released during or soon after sedimentation.

The samplings were continued at less frequent intervals in 1973 to verify previous findings. In addition, to provide insight into the factors which governed the observed phenomena, the studies were extended to improve the methodological sensitivity for measurement of mercury in water to 0.005 µg/liter and to determine the distribution of mercury in the water and sediment columns behind the Columbia River impoundments.

The results of the analyses of the distribution of mercury in water and suspended matter in 1973 using an improved analytical method (flameless atomic absorption) are illustrated in Table 2.8. The concentration of suspended matter in water and of mercury in suspended matter are consistant with the results described above for the 1971-1972 period. Furthermore, mercury in filtered Columbia River

TABLE 2.8. Distribution of Mercury in Water and Suspended Matter of the Columbia River and Tributaries[a]

| Sampling Location | Water Depth | Concentration of Suspended Matter -- mg/l ----- | Mercury content of Water[b] µg/l | Mercury content of Suspended Matter --mg/Kg-- |
|---|---|---|---|---|
| Columbia River | | | | |
| Priest Rapids Dam | Surface | 3.0 | <0.005 | 52 |
| | Bottom | 12 | <0.005 | 15 |
| McNary Dam | Surface | 6.7 | <0.005 | 31 |
| | Bottom | 9.6 | <0.005 | 27 |
| Bonneville Dam | Surface | 6.0 | 0.005 | 19 |
| | Bottom | 10.6 | <0.005 | 24 |
| Yakima River | Surface | 85 | 0.028 | 2.6 |
| Snake River | Surface | 23 | <0.005 | 7.8 |
| Walla Walla River | Surface | 19 | 0.008 | 15 |
| Ringold Wasteway | Surface | 69 | 0.007 | 6.6 |
| Esquatzel Wasteway | Surface | 49 | 0.007 | 12 |

a. Sampled August 10, 1973
b. Filtrate (0.45 µ)

water was 0.005 μg/liter or lower at all sample sites. However, with the exception of the Snake River, the other tributaries contained detectable quantities of mercury in the filtered waters. The Yakima River contained mercury in filtrates at a level of at least a factor of three higher than the other tributaries. The Yakima, at this sampling station, consists largely of irrigation return flow during August.

The concentrations of particulate matter in waters behind the Columbia River dams were generally higher at the bottom (1 m above the sediment surface) than at the water surface. As in the case of the surface waters, levels of mercury in filtered bottom waters were less than detection limits. Mercury concentrations in suspended matter from the bottom waters were lower than in the material isolated from surface waters at Priest Rapids Dam, but this was not the case at the other sites. At Priest Rapids Dam, mercury may have been lost on sedimentation or the bottom water sample may have included a significant fraction of resuspended material from the sediments, which contained less mercury than the suspended matter in the surface waters. On the basis of the preliminary evidence, it would appear that the lower concentrations of mercury in suspended matter at sites downriver from Priest Rapids were due either to release of mercury to solution or to dilution effects and not to differential sedimentation of materials of highest mercury levels. Further investigations are required to verify these conclusions and to delineate the mechanisms involved.

Measurements of the mercury content of sediment cores are in progress; however, preliminary results from McNary Dam indicate that the concentration of mercury is highest (range 0.13 to 0.26 mg/Kg) in the first 25 cm and decreases markedly (range 0.03 to 0.08 mg/Kg) below 25 cm. The sedimentation rate at McNary Dam has been estimated to be 10-15 cm/year. Thus, assuming that scouring did not account for a significant loss of sediments, initial studies indicate that recent sediments either contain a factor of three more mercury than sediments deposited 2-3 years earlier or a mechanism exists for loss of mercury from the older sediments, e.g., the conversion of inorganic or methyl mercury to dimethyl mercury under anaerobic conditions. Future studies will be directed toward documentation of the distribution of mercury in sediments with sediment depth as related to suspended matter and sediment physicochemical properties and to determination of the chemical form of mercury in surface sediments and sediment interstitial waters.

## ● FATE AND EFFECTS OF OIL ON MARINE COASTAL ECOSYSTEMS

*These chemical studies were conducted conjointly with the biological investigations described in the Marine Sciences Section of this report.*

### Determination of Soluble Aromatic Hydrocarbons in Suspensions of Petroleum in Seawater

R. M. Bean and J. W. Blaylock

Work currently being sponsored by Battelle, as well as previous work in other laboratories, has shown that aqueous extracts of crude petroleum elicit a variety of toxic responses in aquatic biota. It, therefore, was of interest to develop methodology for determining the water-miscible hydrocarbon composition of oil/water mixtures, and particularly the aromatic hydrocarbons, which are known to be toxic. It was further desirable to develop means for discriminating between miscible and suspended hydrocarbon in various bioassay systems, preferably using techniques which permitted sampling at locations remote from analytical instrumentation. In view of the wide variety of experimental conditions to be studied, it was also an objective to employ a method requiring minimum analysis time, and if possible, to provide data permitting correlation with simple spectrophotometric procedures.

In the procedures outlined below, an operating definition of hydrocarbon "solubility" was established through the use of a filtration technique. The light aromatic hydrocarbon composition of filtered and unfiltered water from bioassay systems was examined using gas chromatography. The aromatic composition was then compared with infrared measurements to determine the potential of the IR technique for routine analysis.

Water samples to be filtered were sampled into a Millipore pressure filtration device fitted with a 0.45 μ filter disk and prefilter. Approximately 30 pounds of nitrogen pressure was used to force the water through the apparatus. The filtered water was transferred to a separatory funnel, acidified, and extracted with 20 ml carbon tetrachloride. The organic layer was stored in a sample vial with a teflon-lined cap. Unfiltered samples were collected directly into separatory funnels and extracted as above. The carbon tetrachloride extracts were scanned with an infrared spectrophotometer and the absorbances at 3040 $cm^{-1}$ and 2930 $cm^{-1}$ recorded. Analysis for individual hydrocarbon components was performed using a temperature programmed gas chromatograph equipped with a flame ionization detector. An aliquot of the $CCl_4$ extract was removed and 5.0 μliter of a carbon tetrachloride solution of indene added as an internal standard. Three μliter of sample was separated using a 17 ft × 1/8 in. stainless steel column of 4% carbowax 20M TPA supported on chromosorb W. Identification and quantitation of individual aromatic hydrocarbons was performed by reference to analytical standard solutions. Compounds emerging after o-Xylene were not separately identified, and are designated as "$C_9$ monoaromatics." Saturated hydrocarbons boiling at temperatures of 100°C or less were found to emerge from the chromatographic column prior to the solvent. An estimate of these "light ends" was made using the response of n-heptane as a reference.

The gas chromatographic analysis described above is directly applicable to unfiltered water samples containing about 1 mg/liter dissolved aromatic hydrocarbons and not containing appreciable (>30 mg/liter) quantities of insoluble oil. The presence of insoluble oil droplets in the sample can seriously interfere with the chromatogram. This interference is effectively removed by the millipore filtration technique.

The use of filtration can result in low reported values for soluble hydrocarbons because of mechanical and evaporative losses. Recoveries of aromatics, as measured by infrared absorption from the filtration of two aqueous hydrocarbon solutions prepared by extracting Prudhoe Bay crude oil with distilled water and filtering the extract, were 83.8 and 82.7% in two separate trials, with an additional 4.8 and 6.4% recovered by extraction of the filter paper.

Comparison of the results obtained from replicate bioassay water samples, one of which was filtered prior to analysis and the other which was analyzed directly are represented on Table 2.9 for two experiments involving different crude oils. In each case, agreement in aromatics analysis between filtered and unfiltered samples is satisfactory. Losses in "light ends" resulting from filtration are evident, however.

A goal of this work was the development of a rapid procedure for estimation of aromatics in solution during flow-through bioassay experiments so that routine monitoring of experiments would be possible. Figure 2.8 shows the aromatics concentration in a number of seawater extracts of Prudhoe Bay and S. Louisiana crude oils as determined by gas chromatography plotted against the infrared absorbance at 3040 $cm^{-1}$ per liter of water extracted with carbon tetrachloride. The good correlation of the data suggests that infrared absorbance at this wavelength will provide a reliable estimate of aromatics concentration in seawater systems for these two oils.

The use of carbon tetrachloride as the extracting solvent has allowed comparison of infrared and gas chromatographic data. However, a more preferable solvent for gas chromatographic determination of aromatics is

TABLE 2.9. Gas Chromatographic Analysis of Filtered and Unfiltered Bioassay Water Samples. (Concentrations expressed in milligrams per liter of seawater).

| Component | Prudhoe Bay Crude Filtered | Prudhoe Bay Crude Unfiltered | S. Louisiana Crude Filtered | S. Louisiana Crude Unfiltered |
|---|---|---|---|---|
| ≤100°C "Light ends" | 1.04 | 3.04 | 2.23 | 3.91 |
| Benzene | 0.98 | 1.10 | 0.73 | 0.78 |
| Toluene | 1.64 | 1.97 | 1.13 | 1.25 |
| Ethyl Benzene | 0.14 | 0.17 | 0.08 | 0.10 |
| m, p-Xylene | 0.45 | 0.58 | 0.45 | 0.52 |
| o-Xylene | 0.18 | 0.21 | 0.18 | 0.17 |
| $C_9$ Monoaromatics | 0.19 | 0.44 | 0.30 | 0.70 |
| Total Aromatics | 3.58 | 4.47 | 2.87 | 3.52 |
| Total Hydrocarbon (GC) | 4.62 | 7.51 | 5.10 | 7.43 |
| Total Hydrocarbon (IR) [a] | 1.94 | 12.92 | 2.44 | 29.36 |

a. Analytical wavelength: 2930 $cm^{-1}$

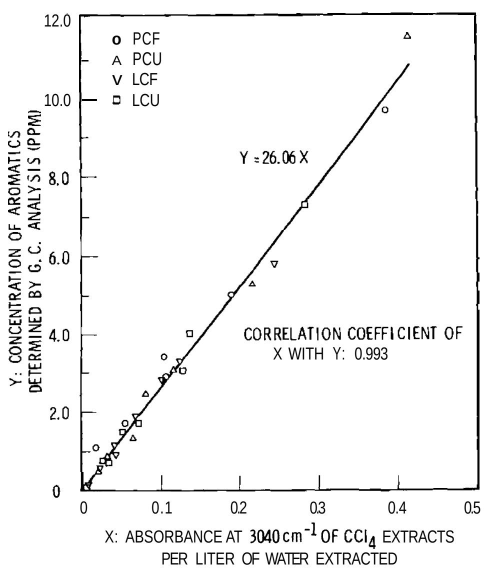


FIGURE 2.8. Correlation of Aromatics Concentration with Infrared Absorbance at 3040 $cm^{-1}$. □, unfiltered aqueous extract of Prudhoe Bay crude; ◇, filtered aqueous extract of PBC; △, unfiltered aqueous extract of S. Louisiana crude; ○, filtered aqueous extract of SLaC.

carbon disulfide, since better separation between benzene and $CS_2$ is experienced on the carbowax column, and the flame ionization detector is relatively insensitive to this solvent. Further work is required to determine the efficiency of extraction of aromatic hydrocarbons with carbon disulfide.

## ° HANFORD INTERCONTRACTOR SUPPORT

*Radioactive wastes in the Hanford environment are stored as buried liquids and solids, or as sediments in ditches and ponds. Knowledge of the behavior and fate of long-lived waste radionu-elides in local biota is essential to safe handling practices and sound environmental control. Work to date has emphasized the behavior of transuranium elements in soil-plant systems and possible interactions with other waste chemicals such as com-plexing and chelating agents.*

### Environmental Maintenance of Radioactive Waste Storage Sites*

K. R. Price

Each of the eight inactive production reactors at Hanford has several radioactive dry waste storage sites associated with it. Most sites were retired several years ago and covered with earth. Recently, a few radioactive weeds have appeared growing over the sites and a program was initiated to temporarily curtail plant growth until a permanent storage mode is developed. Previous use of herbicides sprayed on some areas were not completely effective. Other areas are inaccessable to mechanized equipment.

Six types of dry pellet-form herbicides were applied by hand to about 15 acres of demonstration plots designed to evaluate weed control effectiveness. An additional 63 acres were sprayed with an herbicide used routinely along project roadsides and railroad rights-of-way. Vegetation measurements of canopy coverage and frequency combined with the estimates of species change will be used to compare effectiveness of treatment.

Future laboratory and greenhouse studies will investigate the effect of herbicides on plant uptake of radioactive wastes. The use of hydrophobic agents (e.g. cationic asphalt emulsions) to retard moisture penetration also will be tested in conjunction with herbicides treatments. The complete elimination of vegetation, however, is not considered a practical solution to this long-term problem. As an alternative, the establishment and culture of a highly competitive and innocuous cover crop will be studied.

### The Behavior of Waste Radionuclides in Soil-Plant Systems*

K. R. Price

This program continues to investigate soil-plant interactions with nuclear wastes under field and laboratory conditions for plants and soils

* United Nuclear Industries (UNI) intercontractor support.

* Atlantic Richfield Hanford Company (ARHCO) intercontractor support.

characteristic of Hanford waste storage sites. Special attention is given to the behavior and fate of long-lived radionuclides, especially the transuranium elements. Basic information relevant to environmental waste management has been provided from the following studies:

- The effect of transuranic chemical form on plant uptake.

  Results of shoot uptake of transuranium elements applied to soil as organic acid complexes have been reported (Price, K.R., BNWL-1755, 1973). Studies on chemical form were extended to include EDTA and DTPA chelates of $^{237}Np$, $^{239}Pu$, $^{241}Am$ and $^{244}Cm$. Tumbleweed (Salsola kali) and cheatgrass (Bromus tectorum) plants were grown on soils treated with transuranic-chelate solutions, harvested after 2 months, and analyzed for transuranic uptake.

  EDTA increased Pu percent uptake compared to uptake from dilute nitrate solutions (Table 2.10). Americium and Cm uptake was affected slightly by EDTA, whereas, Np uptake was reduced. However, the influence of chelation by DTPA on plant uptake was dramatic. Plutonium percent uptake was increased by more than 800-fold relative to the nitrate form. Americium and Cm uptake was increased by about 100-fold. Neptunium uptake again was apparently reduced relative to nitrate. The concentration factors for the Pu-DTPA treatments are 0.143 for tumbleweed and 0.031 for cheatgrass. DTPA chelation results in a change in the order of plant uptake from Np>Am≃Cm>Pu to Am≃Cm>Pu>Np. The change in order of uptake is in line with observations on the behavior of these transuranics in soil where the percent Np recovered in the soil solution was less than other transuranics. Neptunium chelation with EDTA or DTPA is known to incur a reduction in oxidation number.

  Root/shoot ratios for the Am- and Cm-nitrate treatment were determined to be between 0.5 and 1.0. The Np-nitrate value was 4.0 for both species. However, Pu

TABLE 2.10. Plant Uptake of Transuranium Elements Added to Soil as Nitrates or Chelates

Uptake Relative to Nitrate[(a)]

| | Tumbleweed Shoot Tissue | | | Cheatgrass Shoot Tissue | | |
|---|---|---|---|---|---|---|
| | Nitrate | EDTA | DTPA | Nitrate | EDTA | DTPA |
| $^{237}Np$ | 1.0 | 0.1 | 0.2 | 1.0 | 1.1 | 0.7 |
| $^{239}Pu$ | 1.0 | 9.9 | 904 | 1.0 | 9.5 | 811 |
| $^{241}Am$ | 1.0 | 1.5 | 98 | 1.0 | 0.6 | 74 |
| $^{244}Cm$ | 1.0 | 1.4 | 64 | 1.0 | 1.1 | 121 |

a. Based on percent plant uptake from soil.

root uptake from Pu-nitrate was about 600-fold higher than shoot uptake. Root-shoot ratios relative to nitrate are shown in Table 2.11 and indicate that chelation drastically reduces Pu root uptake compared to shoot uptake, whereas, Am and Cm ratios are increased. In the case of Pu, chelation apparently not only increases plant uptake from soil but also may facilitate transport from root to shoot. Chelation of Am and Cm increases plant uptake but may not have an influence on root to shoot transport. Chelation apparently results in reduced uptake of Np into roots or shoots.

- The influence of depth of waste burial on plant uptake and redistribution within the soil.

Neptunium-237, $^{239}Pu$, $^{241}Am$, and $^{244}Cm$ nitrate and oxalate solutions were added at mid-depth to large pots. Tumbleweed and cheatgrass shoot and root tissues were harvested after a 2-month growth period. Roots were harvested separately from soil above and below the placement zone. In a similar experiment, $^{239}Pu$ or $^{241}Am$ layers were placed near the soil surface of large pots. Uptake into shoot tissue (i.e., concentration factors) was within a factor of two of uptake determined previously from small pots. A depth effect was noted for root uptake. In all cases, except $^{237}Np$, uptake into root tissue was detected only below the radioactive layer and not above it. It is unlikely that the transuranics leached through the soil from the placement zone and contaminated the root samples.

- The relationship between plant age and uptake of transuranium elements from soil.

Tumbleweed and cheatgrass plants were harvested periodically for 16 weeks to define the affect of plant age on uptake of $^{239}Pu$ and $^{241}Am$ from dilute nitrate solutions added to soil. Initial plant uptake was very high but decreased with time through about 6 to 10 weeks and then leveled off.

TABLE 2.11. Root/Shoot Ratios of Transuranium Elements Taken up from Soil

Root/Shoot Relative to Nitrate[a]

| | Tumbleweed | | | Cheatgrass | | |
|---|---|---|---|---|---|---|
| | Nitrate | EDTA | DTPA | Nitrate | EDTA | DTPA |
| $^{237}Np$ | 1.0 | ∿0.3 | ---- | 1.0 | <0.1 | ---- |
| $^{239}Pu$ | 1.0 | <0.1 | <0.1 | 1.0 | 0.3 | 0.4 |
| $^{241}Am$ | 1.0 | 5.0 | 41.0 | 1.0 | 68.0 | 22.0 |
| $^{244}Cm$ | 1.0 | 21.3 | 20.0 | 1.0 | 58.0 | 22.0 |

a. Based on pCi/g ash-free weights

Uptake patterns are similar between the radionuclides with Am uptake much greater than Pu uptake as noted in other experiments. It was noted during these experiments that fertilizers such as ammonium sulfate can result in increased $^{239}Pu$ uptake by more than a factor of two.

- Other brief studies investigated the affect of plant growth on soil pH, the distribution of U, Np, Pu, Am, Cm, Bk, Cf and Es within the plant body, the uptake of $^{252}$Californium III by tumbleweed and cheatgrass, and the rooting pattern of tumbleweed under field conditions. Plant growth tends to ameliorate soil pH when added organic chemicals induce initial changes; however, the overall growth effect was soil acidification. Without complexation or chelation, transuranium elements (except Np) were distributed unevenly throughout soybean plants with highest concentrations occurring in older tissues. No buildup in immature fruits was noted. Plant uptake of $^{252}Cf$ from dilute nitrate solutions added to soil was less than uptake of $^{241}Am$ of $^{244}Cm$ as indicated by their concentration factors:

| | Tumbleweed | Cheatgrass |
|---|---|---|
| $^{241}Am$ III | 0.0014 | 0.00060 |
| $^{244}Cm$ III | 0.0022 | 0.00048 |
| $^{252}Cf$ III | 0.0005 | 0.00009 |

Californium-252 is a neutron emitter (SF ≃ 3%) and poor growth of $^{252}Cf$ treatment plants was noted. Roots of field-grown tumbleweeds were observed from an excavation across an old burial trench to grow 2.75 m deep. More roots occurred in the backfilled material than in adjacent undisturbed soil.

It is apparent that the chemical form of waste radionuclides stored in the environment can influence the behavior of these elements in soil-plant systems. Moreover, transuranium elements are unevenly distributed within the plant body in space or time, and downward translocation in root systems may be favored over upward movement. Environmental waste management implications of these results are several: (1) environmental monitoring samples should consist of seedlings or older tissues collected near the base of the plant, (2) young and succulent plants attractive to foraging animals likely will contain the greatest concentrations per gram of tissue and would foster maximum plant-to-animal transfers, (3) plant root systems provide a mechanism whereby radioactivity can be spread from a layer buried beneath the soil surface and may extend several meters deep under field conditions. Complexing or chelating agents present in environmental waste storage sites would be expected to enhance plant uptake of plutonium.

# • RADIOECOLOGY OF IODINE-129

*Iodine-129 has an extremely long half-life ($1.6 \times 10^7$ yr) and a low energy. It has a fission yield in the range of 1-1.4% depending on fuel composition and history. Predictions of potential releases to the environment have been of the order of $10^4$Ci if 1% of the $^{129}I$ produced by the year 2060 is released. Little attention was devoted to releases of $^{129}I$ in effluents of nuclear fuels reprocessing plants until recently when levels of $^{129}I$ were reported to be building up in the vicinity of the Nuclear Fuels Service Plant in West Valley, New York. We have undertaken a study including theoretical dose calculations, field studies of the $^{129}I$ presently in the environment, and laboratory studies of iodine movement in soils and plants in order to determine the long-term consequences of releases of $^{129}I$ to the environment.*

## Radiation Doses from Iodine-129

J. K. Soldat* and Betty Klepper

The environmental behavior of iodine has been studied for a number of years with particular concern for $^{131}I$. Consequently, many of the ecological parameters needed to calculate dose rates have been experimentally determined along with many of the physiological factors needed to relate environmental levels to living organisms, including man. A report dealing with $^{129}I$ levels presently found in soils and vegetation and resulting radiation doses to man and biota has been prepared (BNWL-1783). The following summary is largely derived from that report.

Because of its long half-life, one must assume that eventually $^{129}I$ will become a part of the total iodine pool of any ecosystem. Assuming that the $^{129}I$ and $^{127}I$ eventually occur in the same chemical forms, the ratio of $^{129}I$ to $^{127}I$ available to living organisms will determine radiation doses received by them. External doses to both terrestrial and aquatic organisms from $^{129}I$ are insignificant compared to internal doses because of the low energy of the beta and gamma radiations emitted.

At first, the major factor in plant contamination is via aerial

* Physics and Instrumentation Department

deposition on leaves with only a minor contribution from plant accumulation from soils. However, if the radioiodine were not removed from the plow layer or changed to an unavailable form, then the soil-root pathway would become increasingly important with time and would contribute to crop contamination at a rate equal to foliar deposition after about 70 years.

For many organisms, including man, the organ of interest is the thyroid. The important dose pathway is ingestion rather than inhalation, and the principal dietary components of concern were determined to be milk, vegetables, meat, drinking water and aquatic foods.

Table 2.12 shows some calculated dose rates to the thyroid for humans of various ages. (For assumptions and calculations, see BNWL-1783.) First, if $^{129}I$ were the only iodine isotope in the environment, then the dose rate would be maximum for the adult thyroid at approximately 34 times the Federal Radiation Council maximum permissible dose rate (1500 mrem/yr) and the one-year-old child would receive 9 times the dose in the present guide. The reason for the higher adult dose rate is that the concentration of iodine in the thyroid for adults is 360 ppm compared to 90 ppm for the infant. Therefore, the limiting atom ratio, $^{129}I$: $^{127}I$, should be based on the

TABLE 2.12. Human Dose Rates to the Thyroid from $^{129}I$ (mrem/yr)[a]

| Assumptions | 1 year | 4 years | 14 years | Adult |
|---|---|---|---|---|
| If all iodine in the thyroid were $^{129}I$: | 14,100 | 28,000 | 44,000 | 54,700 |
| If air concentration were 1 $\rho Ci/m^3$: | | | | |
| via inhalation | 16.5 | 8.3 | 13.3 | 29.6 |
| via milk | 4640 | 1860 | 1550 | 2330 |
| via leafy vegetables | 0 | 388 | 547 | 1110 |
| via beef consumption | 0 | 250 | 375 | 1000 |
| Total | 4700 | 2500 | 2500 | 4500 |
| If water concentration were 1 $\rho Ci/\ell$ | | | | |
| via drinking water | --- | --- | --- | 3.85 |
| via fish | --- | --- | --- | 1.43 |
| via invertebrates | --- | --- | --- | 0.48 |
| Total | | | | 5.8 |

a. For assumptions and calculations, see BNWL-1783 adult thyroid and should be 1:34 or 0.03, if the guide of 1500 mrem/yr is not to be exceeded. This ratio corresponds to $4.8 \times 10^6$ ρCi $^{129}I$ per gram of total iodine (4.8 μCi/g). However, for all ages, the thyroid concentration of $^{129}I$ which would yield 1500 mrem/yr is $1.7 \times 10^5$ ρCi per gram of total thyroid.

The table also shows the dose rates to be expected via various pathways if unit air and water concentrations were to exist. Milk is certainly the most important dietary component and causes the total dose to the one-year-old child to exceed the dose rate to the adult because milk makes up such a large proportion of the infant diet. For comparison, actual concentrations of $^{129}I$ which have been reported are only $10^{-5}$ ρCi per $m^3$ of air, $2 \times 10^{-2}$ ρCi per liter of rain, $10^{-3}$ ρCi per liter of snow, and $2 \times 10^{-4}$ ρCi per liter of river water (BNWL-SA-4694).

<u>Iodine-129 in Soil and Vegetation in the Environs of Nuclear Fuels Reprocessing Plants</u>

W. H. Rickard, D. G. Watson, Betty Klepper, J. F. Cline, F. P. Brauer* and J. E. Fager*

Environmental samples have been taken in the environs of three nuclear fuels reprocessing plants: on the Hanford Reservation; near West Valley, New York, at the Nuclear Fuels Service Plant; and near Morris, Illinois, at the Midwest Fuel Recovery Plant. The first location has had an operating plant for about 30 years, the second for only a few years, and the third had not yet begun processing when samples were taken. For detailed sampling information, see BNWL-1783. Activation analysis, as described by Brauer and Rieck in BNWL-SA-4478, was used to determine $^{129}I$ and $^{127}I$ in samples.

Table 2.13 shows the $^{129}I$ and $^{127}I$ in the herb-litter layer and in the soil at various depths for a pasture-grass sward at each location. As illustrated in Table 2.13, the greatest concentrations of $^{129}I$ were measured in the herb-litter layer and in the surface 2.5 cm of soil. Penetration of $^{129}I$ into the soil profile appeared to be limited. The concentration measured at the 60 cm depth was approximately 1% of that measured in the surface soil in samples taken on the Hanford Reservation. This gradient of $^{129}I$ concentration with soil depth can be contrastzd with the gradient for $^{127}I$, which presumably has been in the soil profile for a very long time. The $^{127}I$ concentration increases or remains constant with depth at all locations.

Values for the atom ratio ($^{129}I$:$^{127}I$) in Table 2.13 show the distribution relationships to be expected from the results for the two isotopes. There was a decrease of $^{129}I$ content with increasing soil depth and no decrease of $^{127}I$ with depth so that the atom ratio fell with depth.

There appears to have been no rapid downward movement in the soil profile of $^{129}I$ with soil water as

* Radiological Sciences Department

TABLE 2.13. Iodine Contents in the Herb Layer and in the Soil Profile for Pasture Areas Near Three Nuclear Fuels Reprocessing Plants

| Sample | Atom Ratio $^{129}I:^{127}I$ | pCi $^{129}I$ Per g(a) | pCi $^{129}I$ Per m2 | ng $^{127}I$ Per g(a) | ng $^{127}I$ Per m2 |
|---|---|---|---|---|---|
| Hanford Reservation-Lower Snively | | | | | |
| Litter-herb | $4.5 \times 10^{-5} \pm 4.0 \times 10^{-6}$ | $2.9 \times 10^{-3} \pm 1.0 \times 10^{-4}$ | 2.0 | 360 ± 20 | $2.5 \times 10^{5}$ |
| Surface 2.5 cm of soil | $3.6 \times 10^{-5} \pm 2.1 \times 10^{-6}$ | $3.3 \times 10^{-3} \pm 2.6 \times 10^{-4}$ | 67.2 | 520 ± 45 | $1.1 \times 10^{7}$ |
| A 2.5 cm layer at 15 cm | $7.4 \times 10^{-7} \pm 1.3 \times 10^{-7}$ | $5.8 \times 10^{-5} \pm 4.9 \times 10^{-6}$ | 1.9 | 410 ± 15 | $6.7 \times 10^{7}$ |
| A 2.5 cm layer at 60 cm | $8.1 \times 10^{-8} \pm 1.1 \times 10^{-8}$ | $1.9 \times 10^{-5} \pm 2.3 \times 10^{-6}$ | 0.6 | 1300 ± 42 | $7.6 \times 10^{8}$ |
| West Valley New York | | | | | |
| Litter-herb layer | $5.4 \times 10^{-5}$(2)(b) | $7.0 \times 10^{-3}$(2)(b) | $1.6 \times 10$(2)(b) | $6.7 \times 10^{2}$(2)(b) | $3.4 \times 10^{5}$(2)(b) |
| Surface 2.5 cm layer of soil | $1.3 \times 10^{-5}$(2) | $5.6 \times 10^{-3}$(2) | $1.9 \times 10^{2}$(2) | $4.4 \times 10^{3}$(2) | $8.0 \times 10^{7}$(2) |
| 2.5 cm layer of soil at 15 cm | $5.7 \times 10^{-7}$(1) | $4.1 \times 10^{-4}$(1) | ---- | $4.9 \times 10^{3}$(1) | $1.3 \times 10^{8}$(1) |
| Morris, Illinois | | | | | |
| Litter-herb layer | $2.5 \times 10^{-8}$(2) | $3.2 \times 10^{-6}$(2) | $2.3 \times 10^{-3}$(2) | $7.2 \times 10^{2}$(2) | $4.8 \times 10^{5}$(2) |
| Surface 2.5 cm layer of soil | $3.6 \times 10^{-9}$(2) | $4.6 \times 10^{-6}$(2) | $5.9 \times 10^{-2}$(2) | $7.2 \times 10^{3}$(2) | $9.1 \times 10^{7}$(2) |
| 2.5 cm layer of soil at 15 cm | $<4.0 \times 10^{-10}$(2) | $<6.2 \times 10^{-7}$(2) | $<2.6 \times 10^{-2}$(2) | $4.4 \times 10^{3}$(2) | $1.5 \times 10^{8}$(2) |

a. Basis is grams freeze-dried weight.
b. Numbers in brackets refer to the number of replicates.

might be expected. Soils are generally considered to be cation exchangers. The negatively-charged exchange sites would reject the iodide anion, theoretically allowing the iodine to move with the soil water. It must be assumed at this time with the evidence presented that, if $^{129}I$ is moving as an anion, its movement through the soil profile is slowed by some soil component, possibly organic matter or positively-charged sites. It can be postulated that over a very long period of time, if no more $^{129}I$ is added to the system, the $^{129}I$ now in the soil will distribute itself throughout the upper zones of the soil profile in a similar way to that shown for $^{127}I$ in the table.

These grassy sites had less $^{129}I$ associated with the vegetation and soil than did forested sites. A grassy sward is exposed to a smaller volume of air than forest stands because of differences in stature. It is also likely that more leafy material is contributed to the soil surface by forests than by grass swards. Thus, it is reasonable that forest stands are more efficient at sorbing airborne materials than adjacent grassy swards.

Aquatic samples (Table 2.14) were taken to act as a guide for more extensive sampling to be done at the

TABLE 2.14. Summary of $^{129}I$ and $^{127}I$ in Aquatic Samples of the Hanford Reservation, 1973

| Sample | Atom Ratio $^{129}I:^{127}I$ | pCi $^{129}I$ Per g[a] | ng $^{127}I$ Per g[a] |
|---|---|---|---|
| | Rattlesnake Springs | | |
| Sediment | $7.1 \times 10^{-7}$ (1)[b] | $9.9 \times 10^{-4}$ (1)[b] | $7.9 \times 10^{3}$ (1)[b] |
| Watercress | $2.8 \times 10^{-7}$ (1) | $2.8 \times 10^{-4}$ (1) | $5.7 \times 10^{3}$ (1) |
| Cattails | $4.2 \times 10^{-7}$ (1) | $3.6 \times 10^{-5}$ (1) | $4.8 \times 10^{2}$ (1) |
| | Gable Mountain Pond | | |
| Sediment | $5.3 \times 10^{-4}$ (1) | $1.2 \times 10^{-2}$ (1) | $1.3 \times 10^{2}$ (1) |
| Cattails | $2.1 \times 10^{-3}$ (1) | $3.0 \times 10^{-2}$ (1) | $8.2 \times 10$ (1) |
| Myriophyllum | $3.4 \times 10^{-3}$ (1) | 1.7 (1) | $2.8 \times 10^{3}$ (1) |
| Gold fish "thyroids" | $1.2 \times 10^{-2}$ (1) | 8.3 (1) | $4.0 \times 10^{3}$ (1) |

a. Basis is grams freeze-dried weight.
b. Numbers in brackets refer to the number of replicates.

end of the growing season (September 1973). As was expected, Gable Mountain Pond sediment and biota showed higher levels of $^{129}I$ than did Rattlesnake Springs materials. Cattails, which had been chosen as a plant likely to be available at all collection sites so that comparative information could be obtained, unfortunately does not appear to be a good accumulator species for iodine. In the Gable Mountain Pond samples, there may be an accumulation of $^{127}I$ from the sediment to Myriophyllum and from the Myriophyllum to the goldfish "thyroids." Curiously enough, the accumulation of $^{129}I$ appears to be even greater and consequently the atom ratio, $^{129}I:^{127}I$, increases up the food chain. Of course, these samples are unreplicated and were taken to do no more than indicate the sampling design which should be used for the next study. Obviously more data are needed before any conclusions can be drawn.

## Iodide Uptake Patterns and Water Use by Several Crop Plants

J. F. Cline and Betty Klepper
Technical Assistance: R. T. Webster

Plants accumulate ions, including iodide, from soils, and certain plant families are well-known to be efficient accumulators for reasons of physiological differences which are not especially well understood. Since many ions are known to be assisted in their transport laterally across root tissues and longitudinally to the shoot by the movement of water in the transpiration stream, it is possible that there is sufficient correlation between water use and plant iodine accumulation in shoot tissues to permit water use to be used as an index for predicting iodine accumulation ability of the various species which make up the vegetational mosaic of a region. Since there is already a large literature on water use rates for crop plants and since transpiration is relatively simple to measure, such an indicator could prove to be useful for screening purposes. The experiments reported here were run to measure water use and foliar iodine accumulation for a number of crop plants.

Ritzville surface material (23.3% sand, 64.1% silt and 12.6% clay) was air-dried to 8% moisture and sieved through a 0.3 cm screen. Sufficient soil to fill a I-quart ice cream carton (800 g, oven dry basis) was mixed in a V-blender after being spiked with aqueous carrier-free ha$^{125}$I. Corn, beans and barley had 80 μCi per pot (0.1 μCi per g dry weight); the other species studies had 100 μCi per pot (0.125 μCi per g dry weight). The soil was placed in plastic-lined cartons, watered with 40 ml of Hoagland's solution and with sufficient water to bring the soil to 20% moisture content, and planted with the species being tested. Plants used were corn (Zea mays L. var "Cross Bantam"), bush bean (Phaseolus vulgaris L. var "Tendergreen"), barley (Hordeum vulgare L. var "Vangard"), leaf lettuce (Lactuca sativa L. var "Black Seeded Simpson"), spinach (Spinacia oleracea L. var "Giant Noble Leaf"), beet (Beta vulgaris L.), cress (Lepidium sativum L. var "Curled Garden"), and radish (Radaphus sativus L. var "Cherry Belle"). Four replicates of each species were grown. In corn and beans each had eight additional pots, four with 20 g and four with 40 g of organic matter per pot added in the form of dried and ground cheatgrass litter.

Plants were grown for 30 days in a growth chamber maintained on a 16 hr photoperiod (3000 ft-candles) at a temperature of 28°C and 40-45% relative humidity. Each day pots were watered to return them to the 20% moisture level and records of the water used by each pot were kept. At the end of 30 days, plant tops were harvested, divided into stems and leaves and counted with a 3 × 3 NaI (TR) well crystal. Samples were then oven-dried at 60°C for 48 hr and weighed.

Results are presented in Figure 2.9. Clearly there is no simple, direct relationship between water use and iodine uptake. Accumulation ratios for $^{125}$I ranged from 0.05 for barley to nearly one for radish (μCi per g dry weight of plant tissue/μCi per g dry weight of soil). Leaves accumulated more than stems whenever these parts were sampled separately. Accumulation was generally a function of leaf age with older leaves having the highest $^{125}$I contents. The representatives of the Gramineae (corn and barley) accumulated less than the Leguminosae (bean), Compositae (lettuce), and Chenopodiaceae (spinach and beets), but the Cruciferae showed extremes with cress being among the lowest and radish being the highest accumulator species tested. Bean and corn grown with high levels of organic matter amendment grew poorly but showed patterns of uptake essentially similar to those shown in Figure 2.9 for those species.

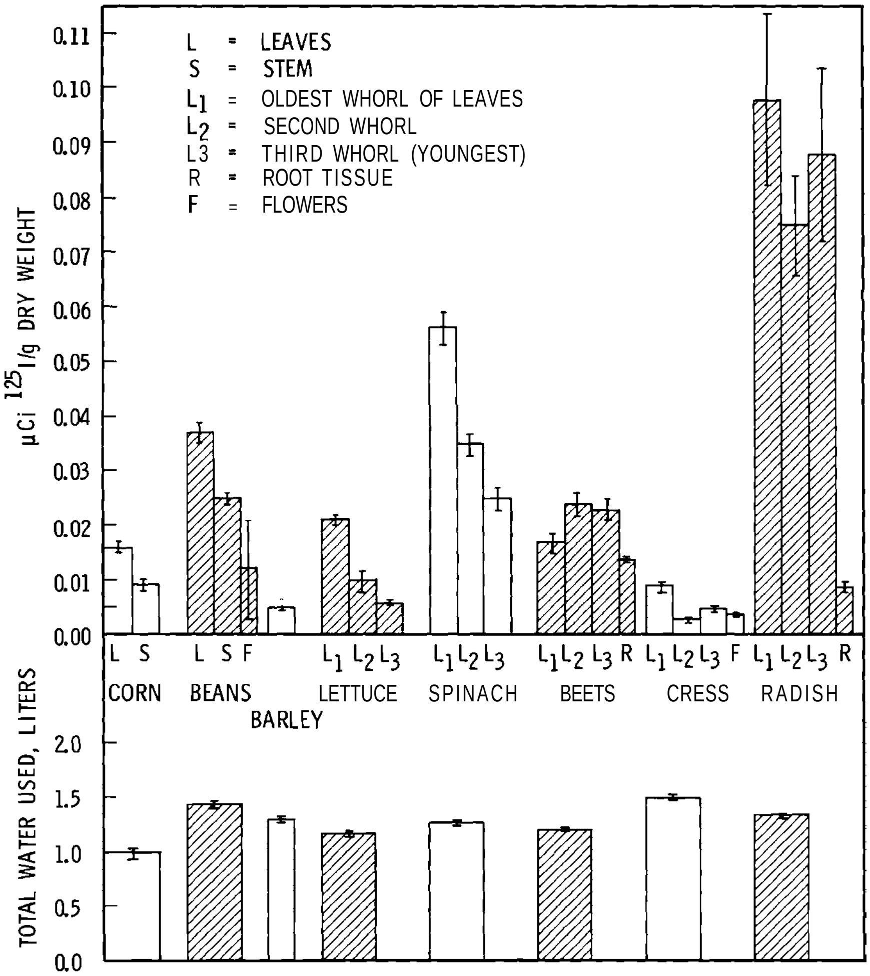


FIGURE 2.9. Uptake of $^{125}I$ and Water by Several Plant Species

Effects of Soil Iodine Levels on Plant Growth and Uptake of Radioiodine

Betty Klepper and J. F. Cline

Technical Assistance: R. T. Webster

Experiments described in the previous section were done with carrier-free $Na^{125}I$ since radioiodine ($^{129}I$) released from nuclear fuels reprocessing plants is essentially carrier-free. (Actually, the $^{129}I$:$^{127}I$ ratio in effluents is about 4:1.) However, stack effluents can become incorporated into landscapes with soils of differing iodine contents. This experiment was done with $^{125}I$ incorporated into soils with 0, 5, 10, and 15 ppm iodine added as NaI to Ritzville silt loam topsoil. This soil has a $^{127}I$ content of about 0.6 ppm Thus treatment levels were 0.6, 5.6, 10.6, and 15.6 ppm.

Spinach, leaf lettuce and radish were grown and harvested as described in the previous section. In this experiment, the root-soil system was also sampled. The soil was removed intact from each pot and cut horizontally into three approximately equal parts. Two cork-borer samples were taken from each section for radioassay. All counts were decay corrected to the harvest date when the $^{125}I$ content was 41 µCi per pot. This represents 0.05 µCi per g dry weight of soil if plants had not removed any $^{125}I$. Table 2.15 shows the $^{125}I$ accounted for in shoots and soils; soil values were corrected for self-absorption. Radioiodine was recovered in expected amounts (41 µCi per pot) with an experimental error of about 15% except that recovery for all treatments from pots containing radish plants was less than 41 µCi; and, for radish, recovery decreased at high iodine levels. It is possible that radish plants synthesize a volatile iodine compound, but radioactivity was not detected either in routine air monitoring samples or on growth chamber walls at the end of the experiment.

Vertical distribution of radioiodine in pots (Table 2.15) showed

TABLE 2.15. Plant Growth and Iodine Uptake at Different Levels of Soil Iodine

| Species | Part | PPM CARRIER IODIDE 0 | 5 | 10 | 15 |
|---|---|---|---|---|---|
| | | Dry Wt (g) | | | |
| Spinach | shoot | 1.65±0.15 | 1.35±0.30 | 1.32k0.03 | 1.21±0.24 |
| Lettuce | shoot | 2.38±0.05 | 1.49r0.08 | 0.08r0.03 | ----- |
| Radish | shoot | 1.54±0.10 | 1.51±0.13 | 1.40k0.06 | 1.31±0.04 |
| | | $^{125}I$ Recovered (µCi) | | | |
| Spinach | shoot | 0.043 | 12.7 | 10.7 | 17.2 |
| | soil | 47.3 | 36.1 | 26.9 | 20.3 |
| Lettuce | shoot | 0.041 | 5.0 | 0.99 | 2.4 |
| | soil | 52.7 | 40.0 | 37.1 | 40.4 |
| Radish | shoot | 0.046 | 1.3 | 4.4 | 8.2 |
| | soil | 36.7 | 33.1 | 23.0 | 21.7 |
| | | Soil Distribution of $^{125}I$ (µCi/gDW) | | | |
| Spinach | upper | 0.035 | 0.023 | 0.015 | 0.012 |
| | middle | 0.057 | 0.031 | 0.019 | 0.016 |
| | lower | 0.030 | 0.041 | 0.035 | 0.025 |
| Lettuce | upper | 0.046 | 0.022 | 0.023 | 0.015 |
| | middle | 0.039 | 0.032 | 0.030 | 0.034 |
| | lower | 0.054 | 0.048 | 0.045 | 0.060 |
| Radish | upper | 0.037 | 0.017 | 0.015 | 0.012 |
| | middle | 0.028 | 0.025 | 0.019 | 0.017 |
| | lower | 0.032 | 0.043 | 0.025 | 0.027 |

that, in the presence of carrier, there was less $^{125}I$ in the upper part of the soil. This could have been caused by downward leaching of radioiodine in the "profile" in the presence of carrier iodine.

High treatment levels of soil iodine suppressed growth of all species and was toxic for lettuce (Table 2.15). Data on radioiodine in leaves (not shown) confirmed that older leaves accumulated more $^{125}I$ than did younger leaves. Table 2.16 shows the concentration factors (μCi per g DW of plant/μCi per g DW of soil) for leaves of various physiological age based on a soil value at harvest of 0.05 μCi per g DW. Actually, concentration factors would be greater than those shown because soil levels were reduced by plant uptake. Concentration factors are strongly dependent on both soil iodine content and leaf age and can change by two orders of magnitude with respect to either of these factors. Thus, as a function of these two variables alone, iodine concentration factors may differ by as much as four orders of magnitude for the same plant species. These concentration factors are greater than the value ($\sim 10^{-2}$) previously assumed for the soil-plant accumulation factor in the dose calculations reported in BNWL-1783.

TABLE 2.16. Concentration Factor in Edible Part (μCi per g DW Plant Part/μCi per g DW Soil)

| | | PPM CARRIER IODINE | | | |
|---|---|---|---|---|---|
| | | 0 | 5 | 10 | 15 |
| Spinach | oldest leaves | 1.25 | 338 | 499 | 609 |
| | middle leaves | 0.23 | 58.5 | 95.3 | 225 |
| | youngest leaves | 0.097 | 9.5 | 33.0 | 46.8 |
| Lettuce | oldest leaves | 0.53 | 206 | 273 | --- |
| | middle leaves | 0.33 | 52 | 273 | --- |
| | youngest leaves | 0.051 | 7.2 | 273 | --- |
| Radish | root | 0.16 | 3.1 | 11.0 | 20.0 |

## • SUSPENDED PARTICLE INTERACTION

*Parameters still experimentally undetermined for airborne effluents are deposition, reentrainment and leaching characteristics with respect to plant foliage and also the internal translocation patterns of foliarly-deposited plutonium compounds. This work is being undertaken to develop a better understanding of the environmental mobility of plutonium with respect to plant canopies and should produce transfer coefficients of use to health physicists interested in calculating doses to man from airborne plutonium effluents.*

### Deposition Characteristics of Aerosol Particles onto Foliage and Other Surfaces

Betty Klepper and D. K. Craig*
Technical Assistance: E. F. Blanton, J. P. Herring and R. T. Webster

An aerosol exposure wind tunnel has been constructed and calibrated for use in studies concerned with interactions between foliage and airborne plutonium particles. The wind tunnel (Figure 2.10) is 9 ft long and is enclosed in a plexiglas glovebox comprising three sections: a transfer hatch, an experimental section where material is put into and removed from the wind tunnel, and an aerosol generation section. The glovebox is continually exhausted at a rate of about 40 cfm through an absolute filter. The wind tunnel is located in a small room adjoining a controlled environment growth chamber which contains a holding box for growing contaminated plants; the holding box is also exhausted continually through an absolute filter at about 40 cfm.

The wind tunnel is constructed of stainless steel and is closed by one absolute filter at the inlet and by two such filters at the outlet. These filters are rated for a maximum flow rate of 50 cfm (1415 $\ell \cdot min^{-1}$) and they restrict the maximun windspeed available at the experimental section to about 0.6 mph (25 $cm \cdot sec^{-1}$).

The experimental section, which is about 1 sq ft in cross-section

* Biology Department

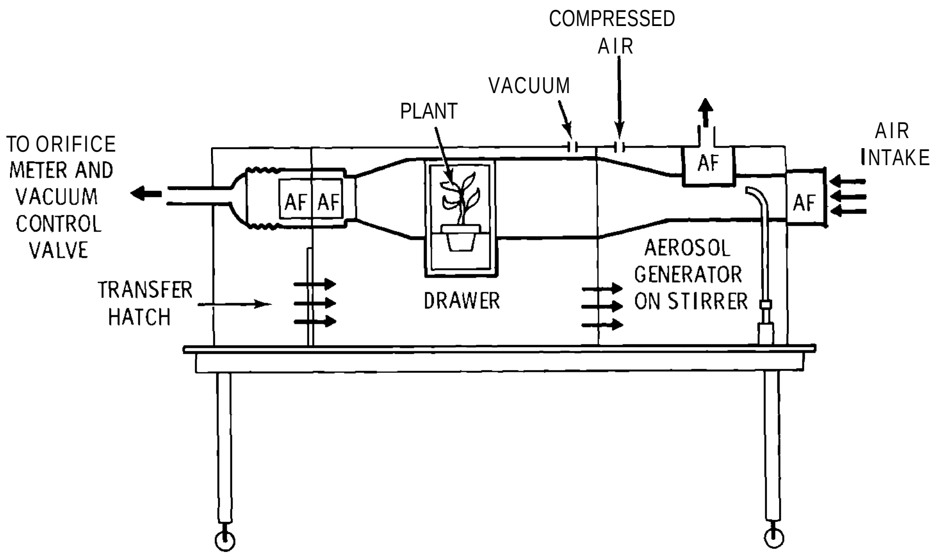


FIGURE 2.10. Transverse Section of Glove Box and Aerosol Exposure Wind Tunnel

(929 $cm^2$), contains a filing-cabinet-style drawer which seals the tunnel in either the fully-open or fully-closed position so that aerosol generation need not be discontinued during loading and unloading. On either side of the drawer are sampling ports where membrane filter samples are taken for aerosol concentration determination, cascade impactor samples for aerodynamic size characterization and thermal precipitator samples for aerosol visualization by electron microscopy. The drawer has a false bottom 6 in. deep with a top containing two 4-in. holes to accommodate two potted plants.

Plants are grown in pint ice cream cartons in Ritzville silt loam topsoil. Ten-day old bean seedlings with unifoliate leaves fully expanded and with the terminal bud unexpanded were used in experiments where a $^{198}$Au-labelled colloidal gold aerosol was generated and deposited at several wind speeds. The short half-life (64.8 h) and easily measured gamma decay energy (400 keV) make $^{198}$Au a convenient isotope to use. The $^{198}$Au was incorporated into a gold colloid at approximately 100 μg Au/ml and the colloid was nebulized in either a Lovelace nebulizer (at about 60 $\mu l \cdot min^{-1}$) or a RETEC nebulizer (about 420 $\mu l \cdot min^{-1}$). The aerosol was passed through a heated tube to dry the droplets out. Plants were oriented in various directions in the experiments. Also, 1-in. wide strips of masking tape were exposed at different orientations to the wind. Horizontal strips were located at 2 in., 6 in., and 10 in. above the duct floor and strips perpendicular to the direction of airflow were placed with their center at 4 in. and 8 in. above the floor of the duct.

The deposition velocity of these aerosols onto the upper side of a smooth horizontal surface (masking tape) was approximately constant over an air velocity range of 0.15 to 20 cm/sec and at various heights in the test region but increased from 4.12 ± 1.56 × $10^{-4}$ cm/sec to 3.70 ± 1.70 × $10^{-3}$ cm/sec as the aerosol generation rate was increased by a factor of about 7 (from the Lovelace to the KETEC nebulizer). For vertical and bottom surfaces, deposition velocities were approximately one order of magnitude less than for top surfaces. (For example, see Table 2.17.)

In 12 runs at an air velocity of 0.42 cm/sec, about 0.1% of the total activity passing through the test section was deposited on the above-groundsurfaces (mean area = 101 14 cm$^2$) of two bean seedlings (Table 2.18). The aerosols had an AMAD of about 0.8 μM and a GSD of 1.65. The deposition velocity for plant surfaces is 4.10 × $10^{-3}$ cm/sec and is greater than the value (Table 2.17) for an inert horizontal surface 2 in. from the bottom of the wind tunnel (2.49 × $10^{-3}$ cm/sec for top surfaces and 2.36 × $10^{-4}$ cm/sec for bottom surfaces). The deposition onto foliage is being investigated further using aerosols of various plutonium-containing compounds; plutonium translocation subsequent to deposition is also being studied.

The wind tunnel has been used to measure the relative deposition of plutonium aerosols onto the skin and into the respiratory tract of rats in connection with on-going studies in the Biology Department. Furthermore,

TABLE 2.17. Deposition of Aerosols on Horizontal Surfaces. Particle Size: AMAD = 0.8 to 1.0 μm, GSD = 1.55 to 1.77.

| Wind Tunnel Conditions | | Height Above Bottom of Duct | Deposition Velocity (cm per sec) | |
|---|---|---|---|---|
| Flow Rate cm per sec. | Concentration nCi/cm$^3$ X $10^3$ | | Top Surface | Bottom Surface |
| 0.16 | 301 | 2 in. | 1.98 X $10^{-3}$ | 1.14 X $10^{-4}$ |
| | | 6 in. | 1.92 X $10^{-3}$ | 8.40 X $10^{-5}$ |
| | | 10 in. | 2.33 X $10^{-3}$ | 1.98 X $10^{-4}$ |
| 0.42 | 203 | 2 in. | 2.49 X $10^{-3}$ | 2.36 X $10^{-4}$ |
| | | 6 in. | 1.47 X $10^{-3}$ | 1.25 X $10^{-4}$ |
| | | 10 in. | 4.45 X $10^{-3}$ | 1.19 X $10^{-4}$ |
| 0.83 | 142 | 2 in. | 3.03 X $10^{-3}$ | 3.11 X $10^{-4}$ |
| | | 6 in. | 2.09 X $10^{-3}$ | 1.47 X $10^{-4}$ |
| | | 10 in. | 5.31 X $10^{-3}$ | 2.02 X $10^{-4}$ |
| 8.76 | 88.7 | 2 in. | 7.08 X $10^{-3}$ | 6.59 X $10^{-4}$ |
| | | 6 in. | 4.20 X $10^{-3}$ | 3.31 X $10^{-4}$ |
| | | 10 in. | 3.35 X $10^{-3}$ | 3.07 X $10^{-4}$ |
| 20.4 | 34.9 | 2 in. | 5.25 X $10^{-3}$ | 1.11 X $10^{-4}$ |
| | | 6 in. | 5.71 X $10^{-3}$ | 1.09 X $10^{-3}$ |
| | | 10 in. | 4.90 X $10^{-3}$ | 1.43 X $10^{-3}$ |

Aerosol Generation Rate = 470 nCi/sec. (713.4 ng/sec.)

TABLE 2.18. Deposition of Aerosols[a] onto Bean Plants Under Constant Conditions in a Wind Tunnel

| Run # | Specific Activity Colloid µCi/ml | Specific Activity Samples µg/µCi | Mean Aerosol Conc. pg/cm³ | Deposition Rate Onto Leaves pg/cm²/sec | Mean Deposition Velocity cm/sec | Activity On Foliage % of Total |
|---|---|---|---|---|---|---|
| Au3-01 | 95.52 | 1.047 | 74.25 | 0.2001 | $2.69 \times 10^{-3}$ | 0.076 |
| -02 | 95.52 | 1.047 | 61.91 | 0.3749 | $6.06 \times 10^{-3}$ | 0.181 |
| -03 | 95.52 | 1.047 | 88.89 | 0.4235 | $4.76 \times 10^{-3}$ | 0.129 |
| -04 | 95.52 | 1.047 | 71.47 | 0.2536 | $3.55 \times 10^{-3}$ | 0.115 |
| Au4-02 | 14.43 | 6.930 | 62.58 | 0.3833 | $6.12 \times 10^{-3}$ | 0.162 |
| -03 | 14.43 | 6.930 | 95.70 | 0.3558 | $3.72 \times 10^{-3}$ | 0.106 |
| -04 | 14.43 | 6.930 | 79.07 | 0.2625 | $3.32 \times 10^{-3}$ | 0.082 |
| -05 | 14.43 | 6.930 | 138.32 | 0.6133 | $4.43 \times 10^{-3}$ | 0.117 |
| Au5-01 | 100.9 | 0.991 | 96.14 | 0.4190 | $4.36 \times 10^{-3}$ | 0.107 |
| -02 | 100.9 | 0.991 | 70.53 | 0.2956 | $4.19 \times 10^{-3}$ | 0.092 |
| -03 | 100.9 | 0.991 | 107.67 | 0.3561 | $3.31 \times 10^{-3}$ | 0.067 |
| -04 | 100.9 | 0.991 | 80.20 | 0.2108 | $2.65 \times 10^{-3}$ | 0.054 |
| Mean ± Standard Deviation | | | | | $4.10 \times 10^{-3} \pm 1.14 \times 10^{-3}$ | $0.107 \pm 0.037$ |

a. Aerodynamic Equivalent Particle Size:
AMAD = 0.778 ± 0.036
GSD = 1.652 ± 0.035

it is being used in studies of the interaction of plutonium aerosols with soil particles in a source-term study for Space Nuclear Systems Division of AEC. Feasibility studies are underway for the construction of a larger wind tunnel which will permit extension of environmental plutonium studies to wind conditions sufficiently high to cause resuspension.

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## FRESHWATER ECOLOGY

- EFFECTS OF THERMAL DISCHARGE ON AQUATIC BIOTA
- EFFECTS OF THERMAL DISCHARGES ON FISH BEHAVIOR AND SENSORY PHYSIOLOGY
- COMBINED EFFECTS OF TEMPERATURE, POLLUTANTS AND DISEASE
- EFFECTS OF TRITIUM ON AQUATIC ENVIRONMENTS
- FACTORS AFFECTING BIOGEOCHEMICAL CYCLING

# EFFECTS OF THERMAL DISCHARGE ON AQUATIC BIOTA

*Temperature in aquatic environments not only acts directly upon a cold-blooded organism by influencing survival at thermal extremes, but also indirectly in often subtle and insidious ways. Both the direct and indirect effects of thermal alterations from man-made sources remain unknown for most aquatic biota because, as a diverse group, they are characterized by extreme ranges in form, habits, distribution, life cycles, and environmental requirements. Studies at our laboratory have been designed to quantify the ecological impact of temperatures upon the more important vertebrate and invertebrate inhabitants of aquatic systems. The program is intended to be creative. It requires the recognition of unusual direct and indirect effects, the development of innovative approaches to examine them, and the cooperation of interdepartmental disciplines to solve them. Studies of the interaction of temperature with other environmental stresses and the relationship of temperature to physiological requirements are integral parts of this program.*

## Effects of Thermal Discharge on Aquatic Invertebrates

C. D. Becker and R. G. Genoway

The crayfish Pacifastacus leniusculus (= P. trowbridgi) is one of the most important freshwater invertebrates in the Columbia Kiver and the Pacific Northwest. The reasons are threefold: 1) it occupies and is abundant in a wide range of aquatic habitats, 2) it is a major producer and consumer in the trophic scheme, and 3) it serves as food for several species of valued sport fishes and occasionally man.

We have utilized the crayfish extensively as an experimental organism in a series of thermal bioassays to determine its resistance to elevated temperatures following abrupt exposure (thermal shock). Crayfish were obtained from two sources because of the possibility that physiological differences that influence thermal resistance may develop between geographically separated populations of the same species. One source was the central Columbia River, a large stream with maximum summer temperature near 20°C and relatively low fluctuations in daily temperatures (<±0.5°C). The other was Rock Creek, a small tributary of the Columbia River with maximum summer temperatures near 30°C and relatively high daily fluctuations (>±4°C) during the summer and fall. Crayfish were obtained at seasons when actual stream temperatures were near the desired acclimation level to avoid possible bias from abnormal artificial acclimation in the laboratory. Acclimation temperatures upon which the tests were based ranged from 5 to 30°C at 5°C intervals.

The thermal tolerance experiments are now complete, the data have been analyzed, a preliminary report has been presented and final report is being prepared for eventual publication. Although some statistical differences were found in the thermal resistance of crayfish from the Columbia River and Rock Creek, these differences may be the result of normal biological variation and were insignificant for practical purposes. The essential information from all experiments is summarized in Figure 3.1.

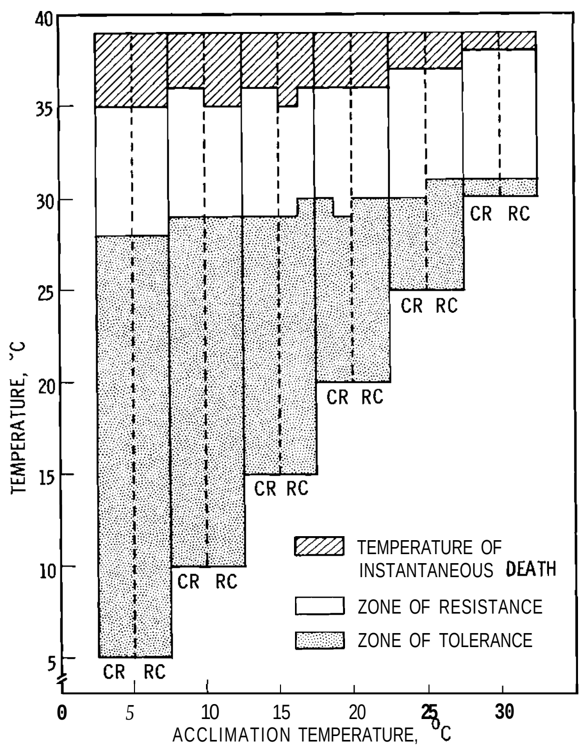


FIGURE 3.1. Thermal Resistance of *Pacifastacus* Based on Different Acclimation Levels.
Columbia Crayfish (CR)
Rock Creek Crayfish (RC)

As the acclimation temperature rises from 5 to 30°C, the upper incipient lethal temperature of crayfish increases only slightly, from 28 to 31°C. The range of the zone of thermal tolerance, encompassing all temperatures where the crayfish can exist for at least 48 hr (theoretically, indefinitely), decreases rapidly as the acclimation temperature rises. For example, at an acclimation of 5°C, crayfish can survive abrupt exposure to elevated temperatures up to about ΔT 23°C but, at an acclimation of 30°C, they can resist only ΔT 1-2°C. The zone of thermal resistance, where crayfish can survive only a finite period of time that decreases from less than 48 hr to a few minutes as the temperature rises, has a uniform range of about 7°C.

Calculation of the upper temperature triangle for crayfish provides a value of 424, expressed as square degrees centigrade. This value may be compared with those obtained similarly for species of fish common to the Columbia River and available from the literature: young coho salmon (*O. kisutch*), 285; young chinook salmon (O. tshawytscha), 310; yellow perch (Perca flavescens), 335; and brown bullhead (Ictalurus nebulosus), 537. Thus, crayfish are considerably more tolerant of temperature elevations than young salmon, and probably more so than most native "cold-water" fishes, but less tolerant than the brown bullhead, an introduced "warm-water fish."

### The Effect of Fatigue on the Thermal Tolerance of Fish

M. J. Schneider, R. G. Genoway and S. A. Barraclough

The assessment of impact resulting from thermal discharges is currently based upon thermal tolerance data which dates back to the 1940's. The experiments which generated this data were usually conducted with water temperature being the only variable, i.e., all other parameters were held at optimal conditions. Data of this nature has obvious inadequacies when one is attempting to evaluate the environmental impact in a field situation where aquatic organisms are under a variety of simultaneous stresses. Recognizing the need for sophisticated laboratory studies of combined stressor effects, this project is investigating the response of physically fatigued fish to elevated water temperatures.

At the outset of this study it was necessary to select a means of monitoring the physical state of the test species, rainbow trout, Salmo gairdneri. The blood concentrations of lactic acid and glucose were chosen due to their role in energy metabolism.

A relatively small volume of blood is required for measurement and the procedures are rapid and accurate. The lactic acid concentrations were analyzed by an adaptation of the Marbach and Weil (1967) enzymatic method while the glucose concentrations were measured with a Beckman Glucose Analyzer.

Abrupt and large changes in the concentrations of both lactate and glucose can be elicited in a fish circulatory system by a variety of stimuli (Caillouet, 1964). As a result the first objective in this study was to devise a method for isolating and immobilizing individual fish without introducing error into the measurement due to specimen handling. It was assumed that the method which consistently revealed the lowest measurement for glucose and lactic acid in a resting fish was the method which revealed the most accurate information about "routine" metabolic levels of each blood constituent (Job, 1955). Several methods of immobilization were tested including MS222, methyl pentanol, benzocaine, electrical shock, and cold shock. The results of this test are presented in Figure 3.2 and reveal that cold shock produced the smallest elevation in lactate and glucose. For the remainder of the studies cold shock induced in an ice bath has been used to immobilize a specimen before drawing a blood sample. Due to the responsiveness of fish energy metabolism (as measured by the appearance of lactic acid and glucose) and the inherent complexities of working with combined effects,

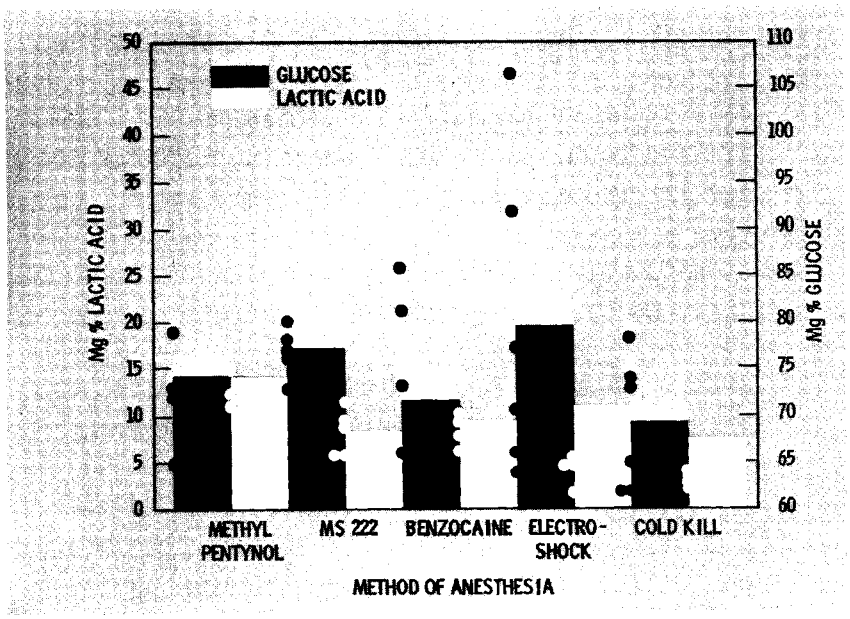


FIGURE 3.2. Method of Anesthesia Versus Lactic Acid and Glucose Values

a series of experiments were conducted to delineate the effects of the individual stresses, temperature and exercise, before working with them in combination. The effect of a sudden temperature shock on the blood constituents was conducted first. The results of these experiments have been compiled and reported at the Savannah River Thermal Ecology Symposium in May of 1973. In these experiments fish were maintained at the acclimation temperature of 12°C for at least 4 weeks prior to the initiation of the study. For each study fish were removed from the acclimation tank and placed in an exposure tank at 27°C for 3 min. At the end of this time they were returned to the acclimation temperature. Fish were removed from the acclimation temperature at 5 min intervals and blood samples taken for analysis. At each of the 32 time intervals 4 to 13 fish were taken for blood measurements of glucose and lactic acid. The time course of appearance of both lactic acid and glucose shows large fluctuations in concentrations in Figure 3.3. A review of the literature on the effects of stimuli, predominantly exercise, on the appearance of these components does not reveal similar fluctuations in time. This may, in part, be due to the frequency of sampling by earlier investigators or be a factor introduced by the thermal shock since the fish in this experiment were not being forced to swim. In fact, they were being held in a darkened chamber and swimming movements during the exposure time was minimal.

Previous studies have shown that the major source of the blood lactic acid is the metabolism of muscle glycogen (Black, 1962). Black et al.

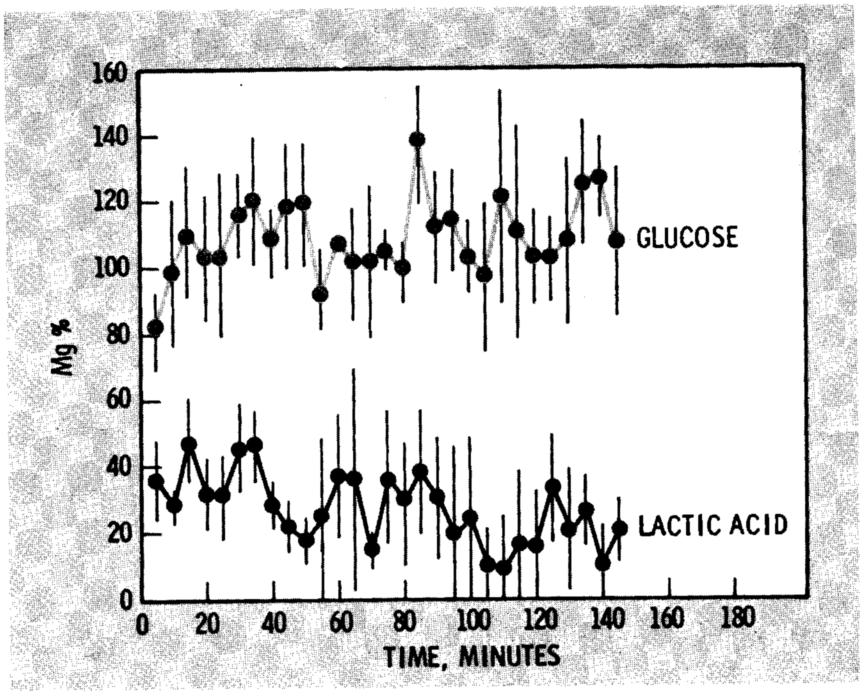


FIGURE 3.3. Time Course of Appearance of both Lactic Acid and Glucose Shows Large Fluctuations in Concentrations

(1960) could find no evidence to indicate that blood glucose was being utilized by muscle tissue directly in energy production. Further, there is evidence that the rate of transfer of lactic acid from muscle to the blood, although temperature dependent, is remarkably rapid. Despite this rapid transfer, the level of muscle lactic acid remains higher than the blood throughout the recovery period (Black, 1962). The evidence from Black's studies indicate, therefore, that the source of blood lactic acid is the muscle, and from this we can conclude that the source of the fluctuations reported here following thermal stress may reflect similar fluctuation in the pattern of release from the muscle. The fluctuations of glucose seen in the present investigation may be closely coupled to those of lactic acid through gluconeogenesis in the liver. Because the fish used in this experiment had not been fed prior to the tests, the only source of blood glucose was the liver. It is hypothesized that the lactic acid released into the blood from the muscles would be transported to the liver where it would be converted back to glucose. It is possible that this glucose could then be released back into the blood for transport to the muscle. This explanation seems to be supported by the close relationship of fluctuations for both lactic acid and glucose following the thermal shock.

The next phase of the studies have investigated the effect of forced exercise at acclimation temperature. In these studies fish were introduced into a rotating ring filled with water. The rotation creates a current to which the fish respond by swimming. The effect of swimming for different time periods on the blood glucose and lactic acid has been recorded. The data gathered in this experiment has not been completely analyzed statistically and cannot be reported at this time. Another series of experiments have also been conducted for which data analysis is incomplete. In these studies, the effect of different degrees of work at a series of temperatures for fish acclimated to different temperatures has been recorded. The preliminary results of all these studies have allowed the generation of criteria for defining the amount of swimming necessary for total fatigue. Fish in this state are being compared with rested fish to determine the thermal tolerance for a wide range of body sizes. When the data has been totally analyzed for this experiment and the other mentioned above it will be reported. These publications are expected to be ready early in 1974.

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## Combined Effects of Thermal and Chemical Discharges

T. O. Thatcher

During the normal operation of thermal electrical power generating plants large volumes of water are passed through the cooling condenser systems. A potential for creating multiple physiological stresses to aquatic organisms exists when the heated effluents, which may contain some chemical contaminants, are returned to the surface waters which often already carry a load of chemical pollutants from other sources. A literature survey has been recently completed which identifies and describes the toxic effects of a large number of chemicals associated with power plant effluents (see Toxicity of Power Plant Chemicals to Aquatic Life, Becker and Thatcher, 1973). Also, numerous studies have been reported in the literature which provide voluminous data on the separate injurious effects of chemical pollutants or thermal alterations. Also, it is known that an acute increase in water temperature will generally increase the metabolic rate of poikilothermal animals such as fish and, due to increased ventilation rate, the animal will be exposed to greater quantities of any toxicants present. However, the change in temperature may optimize the operation of protective enzyme systems within the animal or may increase the environmental metabolism of the pollutant such that a lessening of the toxicity may occur. Whatever the results, very few studies have appeared in the literature reporting on the combined effects of thermal and chemical stresses. To fill this void several series of experiments have been initiated in our laboratory to examine this interaction of contaminants.

The standardized procedure being used for this study involves obtaining a large population of similar age and size experimental animals and dividing them into four groups. Each group is then acclimated at one of four temperatures (approximately 5, 10, 15, and 20°C) for 2 to 4 weeks and then subgroups are exposed to a chemical pollutant at each of these temperatures in a standard 96-hour continuous flow through bioassay.

One series of these experiments in which rainbow trout were exposed to mercury has been completed (see Figure 3.4). In this case there was an obvious beneficial effect to the fish transferred from 10°C to 15°C rather than remaining at 10°C or undergoing a change to 20°C. The trout exposed to mercury at 15°C required at least three times as much of the toxicant to kill 50% of them as at 20°C. These data were presented in a paper at the Thermal

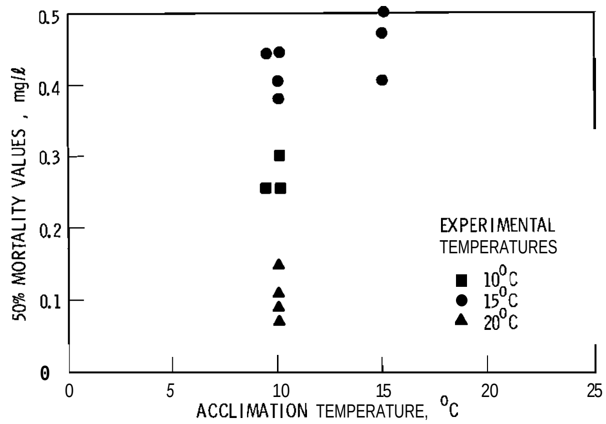



FIGURE 3.4. Fourteen 96 hr Rainbow Trout Bioassays

Ecology Symposium sponsored by the Savannah River Ecology Laboratory and will be published soon in the proceedings of that conference.

A second series of these experiments is nearly complete. In this study brook trout from four acclimation temperatures are being subjected to chlorine at three exposure temperatures. Differences in resistance have been observed at the various temperatures but the range of tolerances is not nearly as widespread as in the mercury study. Accurate comparisons will depend on results of the computer analyses at the completion of the series.

The chlorine investigation is going into greater depth than the initial mercury experiments. The enlarged scope of these studies will include other species and sub-lethal effects. At present, crayfish are being exposed in 96-hour bioassays at three temperatures similar to the brook trout observations. Also, effects on growth and reproductive potential are being studied in further brook trout experiments.

## • EFFECTS OF THERMAL DISCHARGES ON FISH BEHAVIOR AND SENSORY PHYSIOLOGY

*Knowledge of the behavioral response of free-roaming fishes to thermal discharges is important to understanding the influence such discharges could have on their ecology. Studies begun in fiscal year 1974 are investigating the response of salmonid fingerlings to warm water discharges into model raceways. It is intended that the studies will eventually be validated in the field. A second phase of this program addresses the effect of exposure to elevated temperatures on the sensory physiology of fish. Utilizing conditioning procedures, the sensory functions of fishes will be tested before and after thermal shock.*

### Effects of Thermal Discharges on Fish Behavior and Sensory Physiology

E. Hunt and M. J. Schneider

Two lines of investigation have been undertaken to characterize, respectively, (1) the prompt reactions of juvenile anadromous fish when abruptly exposed to a thermal discharge and (2) the consequences of their exposure to such discharges, such as thermal injury, on their sensory capacities.

#### Response of Juvenile Fish Swept into a Thermal Discharge

Modelling studies using buoyant bubbles to serve as fish have been made to hydraulically characterize the movement of juveniles when swept by the mainstream current into a cooling water discharge jet into the stream (Nece and Kent, 1971). The present investigations have been undertaken to determine whether juvenile fish, without the previous experience of being subjected to such a discharge, act passively to the hydraulic forces produced by the thermal jet or react in a manner that is likely to result in their entrance into the jet, or its wake, and consequently be exposed to elevated temperatures. To obtain preliminary information, a laboratory experiment has been undertaken which will provide visual (and photographic) observation of the reactions of fry and fingerlings swimming in a raceway when they are driven backward by the current into the region of a discharge jet.

The raceway used in this study consists of a 20-ft long trough, 12 × 8 in. in cross-section, which is supplied from a headtank of water pumped directly from the Columbia River. Water level is maintained at a depth of 6-7 inches over a wide range of average flow rates by use of wiers of various heights located at the raceway outflow. Presently, the upper limit of average current is approximately 2 ft/sec. Juveniles of up to 50 mm length, while swimming against the current, are swept backward by such current.

In a rectangular raceway, the cross-sectional flow is not uniform (Jaske, Chem. Engin. Prog., 64:1-9, 1968) and a quarter-round sections of 5 in. radius plastic pipe were installed to obtain a rounded bottom surface the length of the raceway to provide a more uniform cross-sectional flow rate. Prior to installation of the round sections, fry tended to seek the bottom corners of the streamway, and after installation they frequently varied their position and exhibited no strong position preference. The plastic pipe sections are white and provide an excellent visual background for tracking up to three or four fish at a time.

In the typical experiment, one or more naive juvenile fish will first be held in a 5 ft section of the upper end of the streamway to accommodate them during a period of several minutes to swimming in a stationary position in a stream flowing at a moderate rate. The holding screen at the lower end of the section will then be raised and the stream flow rate increased slowly to allow the fish while still swimming to drift backward into the lower reaches of the streamway. The swimming fish will be forced in this manner into the region of a discharge current provided by a jet located in the bottom of the raceway approximately 6 ft downstream from the holding section.

The size and velocity of the discharge jet will be selected to obtain a discharge current into the streamway that is within the range of those tested in the hydraulic model by Nece and Kent (1971). The discharge current will be measured using dynamic flow-rate measurements with a small-sized probe (Thermal Systems, Model 1054B) of the cross-sectional flow in the mainstream, in the region of the discharge and downstream, in the wake of the discharge jet. Additional characterization of the discharge jet and its wake will be obtained using dye marker techniques, and when the discharge jet is with heated water, temperature measurements with a small-diameter probe will be used.

Observations of the behavior of the fish, tested singly or in small groups, will be made in the region of the discharge jet and downstream. These observations will be made through small openings in the canopy, located 2.5 ft above the raceway, that completely covers the raceway and provides both a uniform "sky" and protects the fish from seeing the observers. To quantify these observations, photographic or video recordings will be used and time and motion measurements made from the recordings.

It is expected that the final preparations of the raceway and discharge jet and the procedures for handling the fish and observing their behavior will be completed in time to start the experimental runs early in the spring. Accordingly, it will be possible to most accurately model climatic and water conditions for downstream migrants in these experiments.

## Sensory Capacities of Fish Following Thermal Injury

Evidence has been developed indicating that following exposure at sublethal levels to heated water the juvenile fish has a reduced capacity to withstand predation (Coutant, 1970). The present investigation has been undertaken to determine whether thermal or other injury produces changes in various sensory capacities (auditory, visual, olfactory, etc.) that might be related to the ability of the fish to escape predation or, in later life, to harvest food and reproduce successfully.

The general method for measuring sensory thresholds utilizes the Pavlovian conditioning process in which a heart rate response, elicited by a mild electric shock initially, is evoked by the conditional stimulus (e.g., a tone) after the conditional stimulus has been repeatedly paired with the shock. After training, when the conditional stimulus will evoke the heart rate response in the absence of shock, the threshold measurement is made by determining the minimum intensity of the conditional stimulus that will evoke the response. The conditioning procedure to be used is similar to that developed by Otis _et al_ (1957) for training goldfish rapidly in a single conditioning session.

Figure 3.5 shows a juvenile fish swimming while confined to the conditioning apparatus that has been developed for this investigation. In this apparatus, the fish is confined to a 28.5 cm long lucite tube, 5.5 cm inner diameter, suspended in the trough. The flow rate through the tube is set by the number of outlet holes in the end weir of the trough and adjustment of the inflow to equal the outflow. During conditioning and testing a flow rate will be used that is just sufficient to produce a slow rate of swimming and a stable heart rate in the absence of stimulation. For each size of fish used, the flow rate through the confinement tube will be measured with a small-diameter probe (Thermal-Systems, Model 1054B) placed centrally at the outflow grill of the tube with the fish in place. The unconditioned stimulus, electric shock, will be delivered through two long, narrow steel electrodes located laterally on the inside walls of the confinement tube. Conditional stimuli will be delivered appropriately, for example, by a sound transducer at the inflow port to the confinement tube for auditory stimulation and by controlled mixing of a chemical olfactant at the inflow to the trough for olfactory stimulation.

The heart rate of the freely swimming fish in this apparatus has

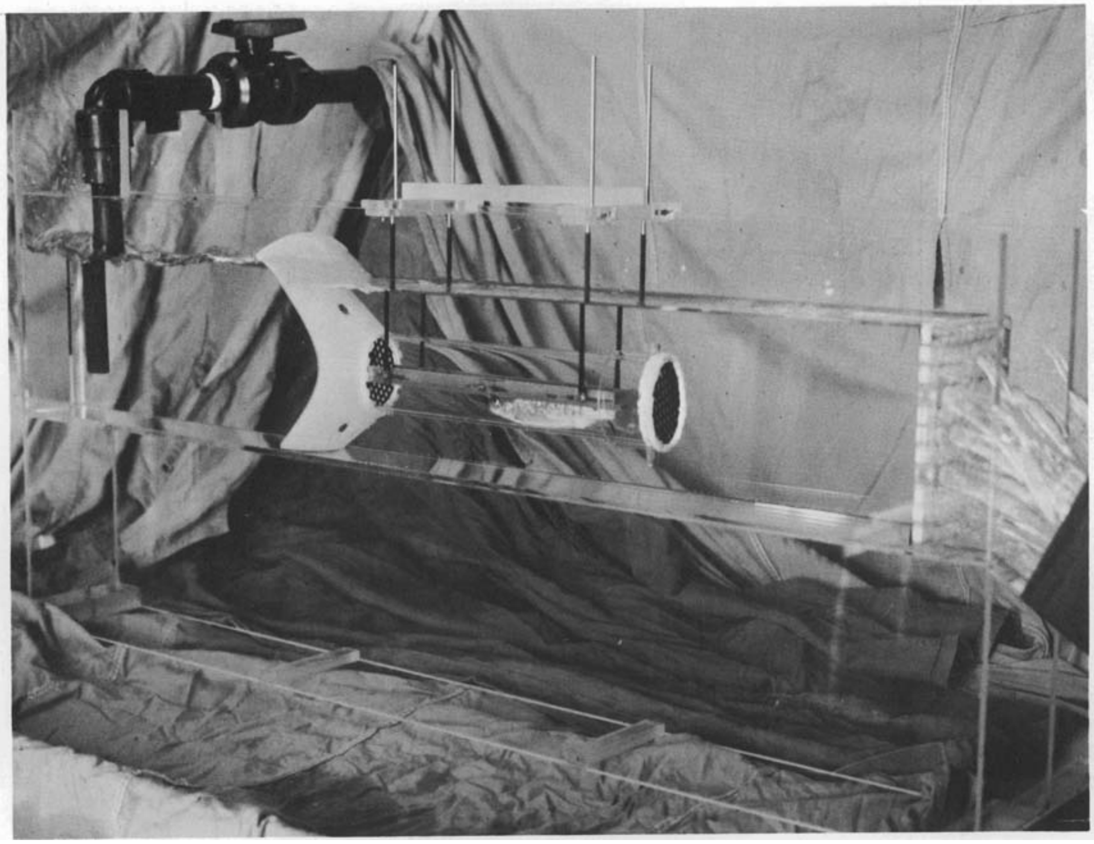


FIGURE 3.5. Juvenile Fish Swimming While Confined to the Conditioning Apparatus

been measured from a continuous electrocardiographic recording obtained through a single lead to the fish. Figure 3.6 shows a typical ECG recorded with this electrode system. The electrode consists of a barbed steel pin, approximately 6 mm in length, which is inserted in a rostral direction through the skin of the ventral medial surface between the opercula. To this electrode is attached a fine wire lead that is suspended with minimum tension through a narrow slot along the top surface of the confinement tube. This physical arrangement allows the fish to move freely, and even turn around, within the tube without being obviously impeded. A differential amplifier (Grass, Model 7P1), grounded through one shock electrode at the confinement tube, is used to record the potential between the cardiac electrode and the second electrode that is simply submerged in the flowing water. The heart rate is derived from the ECG signal by means of an interval timing circuit (Grass, Model 7P4) and is recorded separately. Figure 3.7 shows the general decrease in heart rate and an increase in variability with a decrease in water flow rate that was sufficient to promote faster swimming.

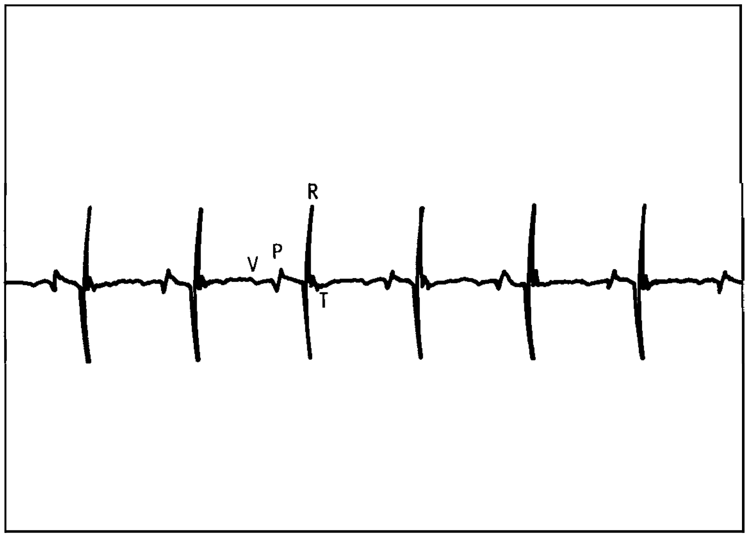



FIGURE 3.6. Heartbeat of Fish. V is Activity in Sinus Venosus, P is Conduction in the Auricles, R is Conduction of Ventricles, T is Repolarization of Ventricular Surface.

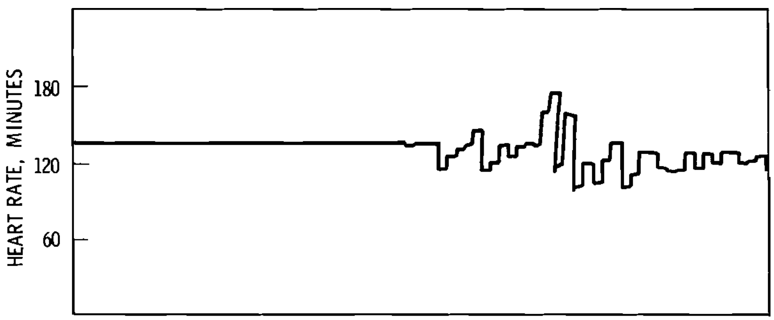



FIGURE 3.7. Heartbeat of Fish When Exposed to Stimuli

Presently, determinations are being made of flow rates that will produce stable heart rates in juvenile fish with minimum adaptation to the conditioning apparatus. The use of stable baseline cardiac rates will provide the most sensitive condition for detection of heart rate changes with stimulation by the unconditioned stimulus (shock) and, following training, the conditional stimulus. The initial threshold tests will be made using an auditory stimulus. The appropriate equipment for providing controlled presentations of the conditional stimulus and shock and for recording are being assembled.

## • COMBINED EFFECTS OF TEMPERATURE, POLLUTANTS AND DISEASE

*Aquatic biota in the natural state are often exposed to several stressors simultaneously. The ecologist today is often required to assess the impact of warm water chemically polluted effluents on fishes and other life forms. The literature presently contains little information on the combined effects of such factors, be they synergistic, antagonistic or simply additive. This program is designed to provide this information. Currently the studies consider the combined effects of warm water and chemical additives used in treating power plant cooling makeup water, e.g., biocides and corrosion inhibitors.*

### Dissolved Gas Studies

D. H. Fickeisen

Dissolved gas supersaturation studies during the calendar year have been primarily focused on determining tolerances of locally resident fishes to supersaturation in laboratory controlled bioassay tests. The thermal saturation system previously described was tested and found satisfactory for creating atmospheric gas supersaturation in the laboratory with good control. However, during the year it became apparent that temperature effects on tolerance to gas supersaturation were highly important and that the slope of the temperature versus dissolved gas tolerance curve might change directions as a function of the species tested. The thermal system is limited to operation at relatively warm temperatures (generally greater than 20°C), but the Environmental Protection Agency and National Marine Fisheries Service have successfully designed and installed pressurized systems of supersaturating water which function at a wide range of temperatures. A system that could create supersaturated water at cool as well as warm temperatures would be required to investigate the effects of temperature on dissolved gas tolerance, an aspect particularly important in view of recent fish kills at power plants due to gas bubble disease. In the pressure system, compressed air is injected into a water line under about 40 psi pressure and enters a pressure chamber where the atmospheric gasses enter solution. The high gas content water resulting is then delivered to a series of test troughs after mixing with normally saturated water to obtain the desired series of test saturations. Temperature control is provided before the water enters the pressure tank by a solenoid controlled mixing valve. This new system was completed in mid-September and has been determined superior to the thermal system in several aspects The most important of these is that supersaturated water can now be supplied at a wide range of temperatures. In addition, temperature control is within a much narrower range (0.2°C versus 0.5°C with the thermal system), and the system is not dependent on chilling river water to near freezing temperatures, which puts a strain on cooling equipment and resulted in several mechanical failures of chillers during the year.

About ten species of locally resident fishes were collected from local environs by electroshocking and beach seining and exposed to supersaturated water at different levels to determine relative tolerance to gas supersaturation. Many differences in time to death were noted with the species tested, as indicated by the relative positions of the species names in Figure 3.8. This study was considered a scanning review of relative tolerances and while absolute tolerances were not expressed in terms of median exposure values for a given length of time, it served well to define gross species differences. Since all of these tests were conducted at 20°C, it is particularly interesting to note that the cold water species (those with a relatively cold thermal preference) were less tolerant than the warm water

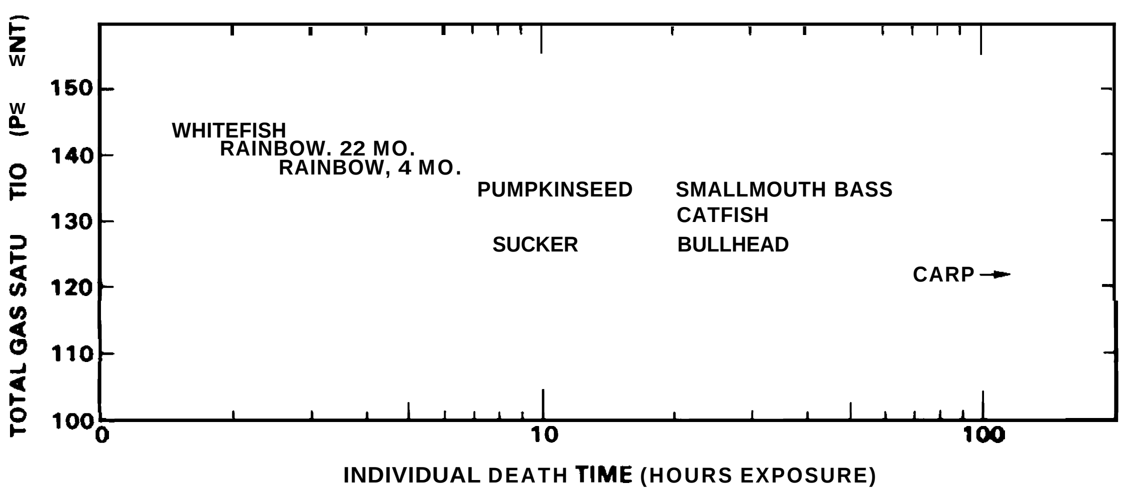



FIGURE 3.8. Summary of Preliminary Bioassays. Relative survival time for different species exposed to dissolved gas supersaturation. Each name indicates the approximate median position of several to many points representing individual fishes.

species. Thus, whitefish, rainbow trout, and suckers appear near the origin of the figure, indicating a short time to death at low levels of gas supersaturation. In addition to determining time to death, signs of gas bubble disease were recorded and photographed during random necropsies of the test fish. In the majority of the cases examined (about 85%), the cause of death was clearly hemostatis caused by blockage of the heart with emboli. An additional 10% died of gill congestion, again caused by embolism. The remainder had suffered severe hemorrhaging due to ruptured emphysematous blebs of gasses. Preliminary experiments determined that when removed from highly supersaturated water many individuals showing external signs of severe gas bubble disease were able to recover. In addition, smallmouth bass ceased feeding approximately 2 hr before loss of equilibrium when exposed to supersaturated water while controls did not.

A schedule and plans for testing the tolerances of dissolved gas supersaturation of four species of fishes to four different temperatures (8, 12, 16 and 20°C) has been devised, relying on the preliminary scanning experimental data. These experiments began in October. The $LE_{50}$ values for 96-hr will be determined and compared at the different temperatures during the next year. Recovery experiments will also be expanded to determine the stages of gas bubble disease from which fishes can recover.

Field studies were continued, with a program of monthly winter sampling on the Snake and Columbia Rivers to determine dissolved gas levels during non-spill seasons when runoff was low enough so that dams were not required to operate spillways. These studies revealed typical saturation levels of 95-105% of saturation, which should cause no harm to fishes. In addition, the runoff during the spring freshet in the Pacific Northwest reached a record low flow during the past season, and very little spillway operation was necessary, resulting in dissolved gas levels in the Snake River generally lower than 110% and around 115% in the Columbia River. Since the National Marine Fisheries Service is expected to continue periodic dissolved gas sampling on the Columbia River System, a tentative decision has been reached to terminate routine field sampling unless it relates to a specific biological experiment. This decision is subject to review early in the next calendar year when a major review of field sampling data is planned, and when the plans of other agencies will be available.

Sampling of the Yakima River near its mouth also continued, with saturation levels generally between 97 and 105%, however, in mid-May, oxygen levels on 2 consecutive days were between 163 and 180% saturation. These numbers were obtained by gas chromatography and were confirmed with a DO meter which also indicated little surface-to-bottom stratification in either oxygen or temperature. During this period, nitrogen levels remained less than 105% except at one sample which was 134% and may represent a sampling error. One explanation for the large difference in dissolved oxygen and nitrogen is that an algae bloom was taking place, and indeed large amounts of floating periphyton were observed.

A program was initiated to compare saturation levels in the Palouse River and the Walla Walla River, two streams with very similar flow and geographical characteristics, except that the Palouse has a fall about 200 ft high. It was postulated that air entrainment could occur at Palouse Falls, resulting in gas supersaturation. Below the falls the river enters a series of pools and riffles, and field sampling on three occasions indicated supersaturation of the Palouse by as much as 112% at the basin below the falls. The gas levels rapidly decayed to equilibrium with distance downstream. At this time, levels above the falls were at or near equilibrium (100%) saturation. The Walla Walla River was usually undersaturated in terms of oxygen and near saturation in terms of nitrogen, however, on one occasion samples indicated 124 and 128% saturation at the river's mouth. This program will be continued during the next year. There is some indication from laboratory studies that fishes may acclimate to supersaturated waters, although the results are very preliminary. If so, it would be interesting to compare fishes from the Palouse and Walla Walla Rivers, should the dissolved gas levels indeed prove significantly different throughout the year.

A comparative evaluation of the Weiss dissolved gas saturometer with the gas chromatographic method of dissolved gas determination was completed and it was concluded that the saturometer is accurate in laboratory situations and may have value as a field instrument provided it is operated properly by a trained operator. No statistically significant difference was noted between paired samples analyzed by gas chromatography and by the saturometer.

Publications prepared during the calendar year included a paper describing the results of preliminary scanning bioassays and a manuscript describing the comparative studies of the saturometer is presently being reviewed for clearance. Initial preparation of a draft paper describing the gas chromatographic analytical system is being prepared.

In May, two staff members attended a workshop on the pathology of gas bubble disease sponsored by the Environmental Protection Agency and as a result, a necropsy protocol has been developed for fishes suspected of gas bubble disease. The Western Division of the American Fisheries Society held its annual meeting in Salt Lake City during July and included a session on gas bubble disease which a staff member attended. The National American Fisheries Society Meeting in September in Orlando, Florida also included a session on gas bubble disease in which staff members participated, delivering a paper describing the results of preliminary bioassays.

## Combined Effects of Fish Disease and Water Temperature

M. P. Fujihara

C. columnaris disease: The lowest river flow on record and warmer than normal river temperatures during spring and summer were probably the main factors responsible for the 1 to 2 months earlier occurrence of C. columnaris disease in coarsefishes at White Bluffs and Wenatchee areas of the Columbia River. A much higher rate of infectivity also continued at these sites through the summer months which resulted in an epizootic disease condition among the coarsefishes. Coarsefish infection at the Snake River site, however, remained much lower in spite of the higher temperatures. Studies during 1973 (April through August) at the White Bluffs, Wenatchee and Snake River sites showed a direct correlation between the unusually high incidence of C. columnaris disease among coarsefishes and a higher rate of transfer of the disease to up-stream migrant salmonids than normally occurs. The average seasonal exposure and infection of coarsefishes was 29.7% and 27.5%, respectively, at White Bluffs, 26.2% and 19.9% at Wenatchee and 12.3% and 10.4% at the Snake River site. The results of these studies are summarized on a monthly basis in Table 3.1. Figure 3.9 shows the disease infectivity data from Table 3.1. All sites demonstrated a progressive increase in exposure and infection generally higher than observed in recent years. The magnitude of antibody development at the White Bluffs site was approximately twice that observed at Wenatchee and Snake River sites suggesting the degree of infection of the White Bluffs fish was considerably higher.

TABLE 3.1. Monthly Chondrococcus columnaris Exposure, Infection and Antibody Development in Coarsefishes During 1973

| Location | Sampling Month | Temp. °C | No. Fish | Disease Incidence* Exposure(%) | Infection(%) | Titers (%) | Av. Pos.Titers | Range of Pos.Titers |
|---|---|---|---|---|---|---|---|---|
| White Bluffs | April | 7.8 | 50 | 12.0 | 0 | 78 | 1:76 | 1:20-320 |
| | May | 14.5 | 50 | 22 | 14 | 88 | 1:129 | 1:20-640 |
| | June | 16.7 | 49 | 30.6 | 34.7 | 77 | 1:393 | 1:20-640 |
| | July | 19.4 | 37 | 29.7 | 37.8 | 84 | 1:505 | 1:40-640 |
| | August | 21.6 | 50 | 24 | 38 | 93.9 | 1:458 | 1:80-640 |
| Wenatchee | April | 3.3 | 50 | 20 | 0 | 64 | 1:86 | 1:20-320 |
| | May | 10.0 | 66 | 28 | 12 | 68 | 1:107 | 1:20-320 |
| | May | 13.4 | 50 | 32.5 | 16.3 | 75.5 | 1:131 | 1:20-640 |
| | June | 16.2 | 39 | 41 | 20.5 | 75.7 | 1:146 | 1:20-640 |
| | June | 16.7 | 45 | 24.4 | 26.6 | 89.0 | 1:208 | 1:20-640 |
| | July | 17.8 | 63 | 23.2 | 38.1 | 92.0 | 1:252 | 1:20-640 |
| | August | 16.7 | 34 | 32.3 | 32.3 | 81.5 | 1:182 | 1:20-640 |
| Snake River | April | 12.2 | 50 | 4 | 14 | 58 | 1:100 | 1:20-320 |
| | May | 17.2 | 50 | 24 | 14 | 81.4 | 1:107 | 1:20-640 |
| | June | 18.3 | 36 | 22 | 19.4 | 78 | 1:139 | 1:20-640 |
| | July | 21.1 | 27 | 33.3 | 11.1 | 84 | 1:265 | 1:40-640 |

* 1 to 10 surface isolates/fish - exposed but not infected.

>10 surface isolates/fish or 1 or more internal isolates/fish - infected.

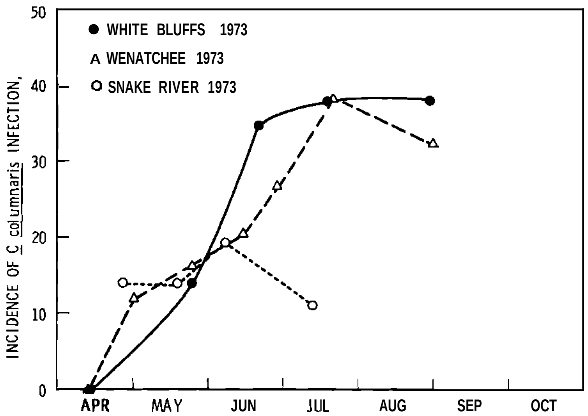



FIGURE 3.9. C. columnaris Infection of Coarsefishes at White Bluffs, Wenatchee and Snake River Sampling Sites

Water samples from Priest Rapids and Rocky Reach fish ladder outlets showed maximum releases of $1.3 \times 10^9$ C. columnaris per second into the river which is approximately 3 fold higher than normally observed. In normal disease years, water samples taken from the river approximately 1 mile upstream or 1 mile downstream from fish ladder outlets were consistently negative for C. columnaris. The extremely high release values may be partly responsible for the isolation of 0.02 to 0.05 C. columnaris organisms per ml from the mainstem of the river during months of peak infectivity. Under these extreme exposure conditions infection of salmonids can occur in the mainstem of the river as well as in fish ladders.

Moribund coarsefishes have seldom been observed in previous years, but during June and July of 1973 frequent observations were made at White Bluffs, Wenatchee and the forebay at Rocky Reach Dam. These observations and sampling of moribund coarsefishes provided additional evidence that C. columnaris disease has reached epizootic proportions among some species of coarsefishes and is causing a serious disease environment for both downstream and upstream migrant salmonids. All moribund fishes were heavily infected with C. columnaris, but antibody development was low (1:20-160) as compared to average antibody titers of 1:200 to 1:500 for coarsefishes gill-netted during the same months. The data suggest that although larger numbers of coarsefishes are being naturally immunized, many of the infected coarsefishes may succomb to the pathogen before developing sufficient protective antibodies against the disease.

A significant increase in C. columnaris exposure, infection and antibody development in coarsefishes and upstream migrant salmonids was observed at the Rocky Reach fish ladder (Table 3.2). Usually the disease is not a problem for spring chinook salmon since cooler river temperatures and lack of C. columnaris challenge encountered by these fish during upstream migration results in little or no infection. When C. columnaris becomes established in the river and fish ladders earlier in time, the disease will be a problem for this earliest run of salmonids in the Columbia River. C. columnaris is well established in Columbia River fish ladders even in average disease years during migration of sockeye and fall chinook salmon and infection may occur. Infection of salmonid species was higher than usual in 1973 because of greater disease incidence among coarsefishes in the river and fish ladders.

TABLE 3.2. Chondrococcus columnaris Disease in Coarsefishes and Salmonids at the Rocky Reach Fish Ladder (1973)

| | Sampling Date | No. Fish | Temp. °C | Disease Incidence* Exp. (%) | Inf. (%) | Titers (%) | Av. Pos. Titers | Range of Pos. Titers |
|---|---|---|---|---|---|---|---|---|
| Coarsefish | 6/2 | 50 | 12.8 | 28 | 18 | 71.4 | 1:109 | 1:20-320 |
| | 6/29 | 50 | 16.7 | 42 | 32 | 93.6 | 1:211 | 1:20-640 |
| | 8/31 | 41 | 17.8 | 36.6 | 39 | 92.1 | 1:198 | 1:20-640 |
| Salmonids | | | | | | | | |
| Jack Spring Chinook | 6/2 | 15 | 12.8 | 37.5 | 31.25 | 75 | 1:58 | 1:20-80 |
| Sockeye | 6/29 | 30 | 16.7 | 63.3 | 30 | 92.6 | 1:110 | 1:20-320 |
| | 7/21 | 30 | 17.3 | 40 | 53.3 | 100 | 1:122 | 1:20-320 |
| Jack Fall Chinook | 8/31 | 21 | 17.8 | 33.3 | 42.8 | 100 | 1:149 | 1:20-320 |

* 1 to 10 surface isolates/fish - exposed but not infected

>10 surface isolates/fish as 1 or more internal isolates/fish - infected.

Furunculosis disease: The results of monthly furunculosis disease in coarsefishes and antibody development are summarized in Table 3.3. Although a gradual increase in monthly infection was observed, there does not appear to be any significant difference in infection rate at the three sites. The White Bluffs coarsefishes had the highest antibody titers against furunculosis disease and antibody development in coarsefishes at Wenatchee and Snake River sites were similar.

Under normal river conditions average seasonal infection of upstream migrant salmonids to furunculosis disease has been approximately 3% to 5%. During this reporting period a single sampling of 30 sockeye salmon showed an infection rate of 28.6%. Since furunculosis infection in coarsefishes is usually much more prevalent than C. columnaris disease, it is reasonable to assume that under conditions of low river flow and warm temperatures the disease can also be a serious problem for both juvenile and adult salmonids. The magnitude of antibody development at all three sites suggest the degree of coarsefish infection was considerably higher than in previous years.

TABLE 3.3. Furunculosis Disease and Antibody Development in Coarsefish During 1973

| Location | Sampling Date | Temp. (°C) | No. Fish | Disease Incidence Exp. and/or Inf. (%) | Titers % | Av. Pos. Titers | Range of Pos. Titers |
|---|---|---|---|---|---|---|---|
| White Bluffs | 4/11 | 7.8 | 50 | 30 | 42 | 1:83 | 1:20-160 |
| | 5/23 | 14.5 | 50 | 40 | 75 | 1:137 | 1:20-640 |
| | 6/20 | 16.7 | 49 | 19.1 | 69 | 1:92 | 1:20-640 |
| | 7/17 | 19.4 | 37 | 56.8 | 100 | 1:308 | 1:160-320 |
| | 8/29 | 21.6 | 46 | 50 | 100 | 1:275 | 1:80-320 |
| Wenatchee | 4/12 | 7.8 | 42 | 26 | 31 | 1:103 | 1:20-320 |
| | 5/1 | 10 | 50 | 24 | | | - |
| | 5/24 | 13.4 | 50 | 26 | 45 | 1:74 | 1:20-320 |
| | 6/14 | 16.2 | 39 | 48.7 | 51.5 | 1:59 | 1:20-320 |
| | 6/28 | 16.7 | 45 | 35.5 | 58.8 | 1:51 | 1:20-160 |
| | 7/19-20 | 17.8 | 63 | 44.4 | 100 | 1:126 | 1:20-320 |
| | 8/30 | 16.7 | 34 | 55.8 | 80 | 1:130 | 1:20-160 |
| Snake River | 4/26 | 12.2 | 50 | 24 | | | |
| | 5/18 | 17.2 | 50 | 38 | 60.7 | 1:81 | 1:20-640 |
| | 6/7 | 18.3 | 36 | 36.3 | 54.5 | 1:33 | 1:20-80 |
| | 7/10 | 21.1 | 27 | 48.1 | 95.8 | 1:153 | 1:80-320 |

## Toxicity of Power Plant Chemicals to Aquatic Life

C. D. Becker and T. O. Thatcher

Construction, operation and maintenance of steam electric stations fueled by nuclear energy requires the use of a variety of chemical compounds. These compounds as well as some of the diverse products resulting from their decomposition or reaction may potentially or actually appear in the cooling water discharge and enter the aquatic environment.

One of the problems in planning power installations today is to restrict those chemicals appearing in the cooling water discharge to levels safe for aquatic life. Knowledgeable decisions must be made in order that no harm or degradation of the aquatic environment occurs and that desirable water quality characteristics are maintained during all phases of plant operation.

A survey was made in 1972-73 to identify the various chemical compounds used in association with existing nuclear power plants and cooling tower structures. All chemicals were tabulated. Information on the application of the chemicals, their likely reactions with other compounds and water, and some of the resulting products that might occur in plant discharges were briefly discussed. Finally, data on the toxicity of the chemicals to aquatic life were condensed from the available literature and presented in tabulated form.

The result was a technical manual entitled Toxicity of Power Plant Chemicals to Aquatic Life. This manual was published by the Atomic Energy Commission with the identification code WASH-1249. Copies of this report may be purchased from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

Although the information presented in the report is useful, in itself, additional value is to be derived from the cited publications. These references are valuable sources of detailed information on complex physical, chemical, and biological phenomena that can result from the release of potential toxicants from nuclear power plants into freshwater, estuarine and marine environments.

## Synergistic Effects of Temperature and Acute Radiation

M. J. Duever and C. S. Abernethy

Information on the exposure of a wide variety of organisms to radiation or thermal stresses has accumulated for many years. However, data on the combined effects of these two stresses are available for relatively few species.

As part of a long range study of the effects of multiple stresses on the different life stages of rainbow trout, 2 to 3 in. fingerlings were exposed to four radiation and two temperature levels during the past year. Each experiment included the exposure of two groups of 50 fish to four radiation dose levels. A constant temperature level of 19°C or 22°C was used in each experiment. An equal number of control fish were placed in the same tanks with the experimental~and received the same treatment as the experimentals except that they were not exposed to radiation. The controls and experimentals could be distinguished by cold brand marks. Fish were first branded, then brought to the test temperature at the rate of about 1°C per day and acclimated for 1 to 2 weeks. The experimentals were than irradiated, and mortalities recorded daily for the next 2 months. Fish were weighed prior to irradiation (in groups of five) and at the end of 2 months to detect effects of the stresses on growth. Temperatures were usually maintained within ±1°C by control of the proportion of hot and cold water entering the tank, supplemented by a water heater for fine control. Acute radiation doses of 250, 500, 1000, and 2000 R were provided by a cobalt-60 source over periods of 2.2 to 12.5 min. To assure that the desired dose level had been achieved, thermoluminescent dosimeters were attached to the inside walls of the aquarium during each exposure.

Preliminary analyses of the data showed higher mortalities in all experimental groups than in the corresponding controls even at the lowest dose levels. However, below dose levels of 1000 R differences between controls and experimentals involved five or fewer individuals, while at 1000 R they involved 3 to 17 individuals and at 2000 R, 28 to 41 individuals. Thus, only fish exposed to dose levels of 2000 R showed consistently higher mortalities. Total mortalities of both controls and experimental fish were slightly higher at 22°C than at 19°C for all radiation dose levels.

During the 22°C experiment, there was an initial mortality that was probably due to handling. It occurred primarily in the experimental group, but was also observed to a lesser extent in the controls.

A fairly regular phenomenon in the experimental group was a period of increased mortality from approximately the fifth to tenth day after exposure. Among those fish exposed to 1000 R or less, the mortality rate increased after this period and remained low to the end of the experiment. However, in the groups exposed to 2000 R, mortalities continued at a high rate until about the twentieth day after which the mortality rate decreased. After the twentieth day in the 22°C experiment, 80 to 90% of the fish had been eliminated. In the 19°C experiment about 50 to 60% remained after the twentieth day and these continued to show mortalities at a decreasing rate until the end of the experiment when 30 to 40% of the population remained.

At the beginning of each experiment, the weights of the fish were approximately equal. At the end there was a general pattern of greater weight gains with lesser radiation exposure in the experimentals and an inverse pattern among the corresponding controls (Table 3.4). The distinctly lower weights among the highest radiation exposure fish were probably due to radiation stress. The higher weights among the corresponding controls were probably due to decreased intra-specific stresses associated with lower population levels.

TABLE 3.4. Weight Gains During the Experiments

| Radiation Dose R | Weight Gain (grams) Temperature 19°C Experimental | Control | Temperature 22°C Experimental | Control |
|---|---|---|---|---|
| 250 | 22.4 | 24.0 | 12.5 | 13.5 |
| | 21.9 | 23.8 | 12.0 | 10.8 |
| 500 | 21.9 | 24.4 | 10.9 | 12.6 |
| | 22.4 | 25.0 | 11.7 | 11.5 |
| 1000 | 18.7 | 25.5 | 9.5 | 14.2 |
| | 25.4 | 23.1 | 9.0 | 13.0 |
| 2000 | 12.9 | 33.5 | 4.8 | 14.2 |
| | 18.0 | 32.3 | 6.8 | 18.3 |

None of the differences in final weights between experimental and controls were significant ($p = 0.05$) at radiation doses of 250 R and 500 R, three of the four were significantly different at 1000 R and all were significantly different at 2000 R. Both the reduced weight of the high exposure experimentals and the increased weight of the corresponding controls combined to accentuate the differences between the two groups.

Weight gains were considerably greater at 19°C than at 22°C among both experimentals and controls. The lower weight gains at 22°C were undoubtedly due to the stress of this near-lethal temperature.

## • EFFECTS OF TRITIUM ON AQUATIC ENVIRONMENTS

*The release of tritiated water (HTO) by nuclear reactors has stimulated interest in studies of accumulation and effects in aquatic organisms, particularly the more radiosensitive embryonic and larval life stages. In continuing studies of the chronic effects of tritium as HTO, antibody synthesis in response to C. columnaris and A. salmonicida was used to investigate the effects of tritium irradiation on maturation of the immune process in juvenile and adult rainbow trout. Electrophoresis was performed to determine the potential for qualitative and quantitative shifts in serum proteins which conceivably account for the reduced immune competence in irradiated test fish.*

### Suppression of Immune Capacity in Rainbow Trout Sublethally Irradiated During Embryogenesis

J. A. Strand and M. P. Fujihara

Results of serum agglutination tests to measure the potential for reduced immune capacity in rainbow trout sublethally exposed to 100 rads of tritium irradiation during embryogenesis are reported in Table 3.5.

During the present reporting period, Chondrococcus columnaris pathogens were isolated from Columbia River coarsefishes in April, 1 to 2 months earlier than in recent years. Also, a much higher rate of infectivity continued during the spring and summer months. Beginning in April, the 3-year control and tritium irradiated rainbow trout thus received their fourth seasonal antigenic stimulus from naturally occurring C. columnaris organisms from the river. A greater incidence of exposure and infection occurred in late June and early July resulting in high titers to C. columnaris. The earlier occurrence of C. columnaris enhanced synthesis of antibodies against the disease, and as

TABLE 3.5. Capacity for C. *columnaris* Agglutination in 3-Year Rainbow Trout Sublethally Exposed to Tritiated Water During Embryogenesis

| Sampling Date | No. Fish | Titer, % | Avg. of Pos. Titers | Range of Pos. Titers | Incidence in Water[(a)] Sampling Date | Incidence in Water[(a)] Organisms per ml |
|---|---|---|---|---|---|---|
| 3-year controls | | | | | | |
| 3/26/73 | 50 | 34 | 1:20 | 1:20 | -- | -- |
| 4/19 | 30 | 36.2 | 1:26 | 1:20-30 | 4/10/73 | 0.12 |
| | | | | | 4/20 | 0.03 |
| 5/15 | 40 | 77.5 | 1:40 | 1:20-80 | 5/15 | 0.24 |
| 6/12 | 30 | 73.3 | 1:54 | 1:20-320 | 6/12 | 0.20 |
| | | | | | 6/26 | 0.36 |
| 7/6 | 40 | 100.0 | 1:252 | 1:40-320 | 7/6 | 0.27 |
| 7/26 | 40 | 100.0 | 1:975 | 1:80-1280 | 7/26 | 0.64 |
| (August - Sera not obtained because of Furunculosis epizootic) | | | | | 8/15 | 0.0 |
| | | | | | 8/21 | 0.0 |
| 9/21 | 30 | 96.6 | 1:288 | 1:40-640 | 9/21 | 0.08 |
| 3-year - 1 µCi/ml $^{3}H$ | | | | | | |
| 3/26/73 | 50 | 34 | 1:20 | 1:20 | -- | -- |
| 4/19 | 30 | 73.3 | 1:35 | 1:20-320 | 4/10/73 | 0.08 |
| | | | | | 4/20 | 0.20 |
| 5/15 | 40 | 71 | 1:28 | 1:20-80 | 5/15 | 0.48 |
| 6/12 | 30 | 65.5 | 1:28 | 1:20-40 | 6/12 | 0.56 |
| | | | | | 6/26 | 1.12 |
| 7/6 | 40 | 100.0 | 1:72 | 1:20-160 | 7/6 | 0.6 |
| 7/26 | 40 | 100.0 | 1:125 | 1:20-640 | 7/27 | 1.44 |
| (August - Sera not obtained because of Furunculosis epizootic) | | | | | 8/15 | 0.0 |
| | | | | | 8/21 | 0.04 |
| 9/21 | 30 | 100.0 | 1:153 | 1:40-320 | 9.21 | 0.0 |

a. Twenty-five separate water samples were drawn from the outlet of each pond or from the tanks and four 0.25 ml aliquots were surface plated on solid growth medium.

in previous years, the percentages of fish with agglutinins and the magnitude of titers in both control and irradiated group increased during summer months. The controls, however, demonstrated higher titers, which again, suggested a suppression of immune capacity in the irradiated fish.

A chi-square test of independence was applied to the agglutinin data to verify that tritium irradiation during embryogenesis reduced the immune capacity in three-year rainbow trout. During the last three sampling intervals, the results indicated significant suppression of the immune response (Table 3.6). These data also indicate the permanency of the altered immune capacity following irradiation during embryogenesis.

During early July, heavy mortalities were incurred in the irradiated group, followed in three weeks by equally heavy mortalities in the controls. An epizootic of furunculosis disease, Aeromonas salmonicida, was identified as the probable cause of mortality; but since C. columnaris were also present in large numbers, both pathogens must have contributed to the observed mortality. Prophylatic treatment for furunculosis disease during August was unfortunately effective in drastically reducing the incidence of C. columnaris in the water. The lack of C. columnaris challenge consequently reduced titer values during the last sampling interval. The results of agglutination tests with two strains of A. salmonicida are reported in Table 3.7.

TABLE 3.6. Chi-Square Test of Independence on Titer Values from Control and Tritium Irradiated 3-Year Rainbow Trout

| Sample Date | D.F. | $\chi^2$ | Level |
|---|---|---|---|
| 3/26/73 | 1 | .00 | NS[a] |
| 4/19/73 | 3 | 2.20 | NS[a] |
| 5/15/73 | 4 | 3.73 | NS[a] |
| 6/12/73 | 5 | 4.96 | NS[a] |
| 7/6/73 | 4 | 43.92 | **[c] |
| 7/26/73 | 6 | 57.39 | **[c] |
| 9/25/73 | 5 | 11.89 | *[b] |

a. Nonsignificant chi-square at 0.05 level indicating distribution of titer values was independent of treatment.
b. Significant chi-square at 0.05 level indicating distribution of titer values was dependent of treatment.
c. Significant chi-square at 0.01 level.

The low titers produced in both control and irradiated rainbow trout against either antigen of A. salmonicida is perplexing; particularly since high titers were observed employing C. columnaris antigen, and because of the pronounced delay of infection and mortality in the control as compared to the irradiated group. However, it is possible that the control group was partially protected, at least initially, by the extremely high levels of circulating antibodies produced in response to C. columnaris. It is also likely that antibody produced in response to C. columnaris is not nearly as effective in binding and inactivating A. salmonicida antigen. Our results also suggest the potential importance of immune processes other than the primary immune response, that is, of secretory antibody, C-reactive protein and such cellular processes as phagocytosis. Further interpretation must necessarily await additional experiments scheduled for the spring months.

To determine the potential for qualitative and quantitative changes in serum components against the antigenic agent in response to irradiation, both cellulose acetate and

TABLE 3.7. Capacity for A. salmonicida Agglutination in 3-Year Rainbow Trout Sublethally Exposed to Tritiated Water During Embryogenesis

| Sampling Date | No. Fish | Antigen[a] | Titers (%) | Avg. of Pos. Titers | Range of Pos. Titers |
|---|---|---|---|---|---|
| 3-Year Controls | | | | | |
| 5/15/73 | 31 | Stock | 100 | 1:29 | 1:20-40 |
| 7/26 | 37 | Stock | 100 | 1:30 | 1:20-40 |
| 9/25 | 30 | Stock | 100 | 1:47 | 1:20-88 |
| 9/25 | 30 | Trout | 93.3 | 1:69 | 1:20-160 |
| 3-Year - 1 μCi/ml $^3H$ | | | | | |
| 5/15/73 | 25 | Stock | 100 | 1:26 | 1:20-40 |
| 7/26 | 31 | Stock | 100 | 1:27 | 1:20-40 |
| 9/25 | 27 | Stock | 100 | 1:35 | 1:20-80 |
| 9/25 | 30 | Trout | 100 | 1:53 | 1:20-160 |

a. Stock A. salmonicida isolated from Columbia River squawfish. Trout A. salmonicida isolated from diseased 3-Year control rainbow trout.

polyacrylamide gel electrophoresis are being applied, with preliminary emphasis on the former.

In Figure 3.10 for control rainbow trout, four major fractions were separated, I, II, III, and IV, in order of increasing mobility. Comparison of the position of human albumin and the most mobile trout fraction, IV, indicated that the two are electrophoretically indistinguishable. Trout fraction III corresponded closely to the alpha globulins of human serum; trout fraction II with human beta globulin and trout fraction I with human gamma globulin. The above interpretation is at best tentative and must necessarily await further experimentation before validation.

The electrophoretic separations of irradiated fish were indistinguishable qualitatively from those of control fish. Total serum protein levels in serum from the test groups are nearly the same (Table 3.8). However, both test groups of 1970 spawn are lower than a 1971 spawn of genetically similar stock; this latter group displaying no history of

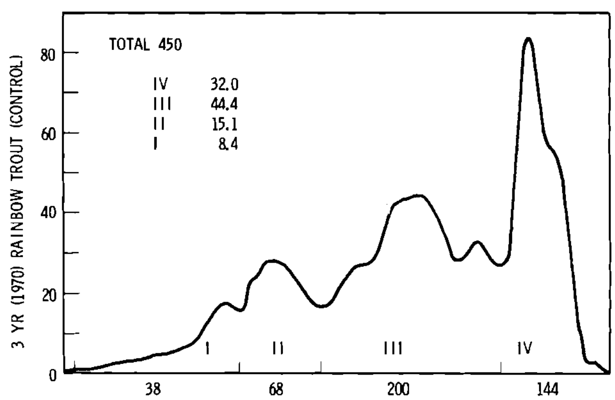



FIGURE 3.10. Densitometric Tracing of Electrophorectic Patterns of Rainbow Trout Serum Proteins

TABLE 3.8. Total Serum Protein g%

| Date | Origin/Yr | Experimental Condition | No. | g/100 ml Mean | Range |
|---|---|---|---|---|---|
| 7/26/73 | Trout Springs 70' | Control | 8 | 4.02 | 3.33 - 4.57 |
| | Trout Springs 70' | $^3$H-irradiated | 8 | 4.07 | 3.58 - 4.79 |
| 9/21/73 | Trout Springs 70' | Control | 20 | 3.83 | 3.37 - 4.50 |
| | Trout Springs 70' | $^3$H-irradiated | 20 | 3.98 | 3.57 - 4.90 |
| | Trout Springs 71' | - | 12 | 4.57 | 3.51 - 5.35 |

disease over the sampling period. The lowered level of 1970 test groups, then, is undoubtedly attributed to the high degree of infection of C. columnaris and A. salmonicida pathogens.

In Table 3.9 are reported percent protein of each of the fractions separated by cellulose electrophoresis. Too few determinations have been made thus far to adequately interpret present findings; although there is indication of quantitative differences in the relative amounts of alpha-, beta-, and gamma globulins in irradiated as compared to control test groups. However, it is not known whether such change in the serum proteins suggested in Table 3.8 reflects irradiation damage or merely a generalized disease response.

Future experiments will be conducted in essentially "pathogen free" conditions through use of a dechlorinated sanitary water system presently being installed. Intraperitoneal injection of heat-inactivated antigen will replace challenge by naturally occurring C. columnaris antigens in Columbia River water. As well, during winter months, rearing trough and pond supply will be tempered to 60°F by the addition of a source of heated sanitary water. The desire to maintain a minimum of 60°F is based on the need to provide an environment conducive to antibody stimulation in test fish over 12 months vice 5 or 6 months under most natural conditions.

TABLE 3.9. Percent Protein in Each Fraction Separated by Cellulose Acetate Electrophoresis

| Fraction | I | II | III | IV |
|---|---|---|---|---|
| Control (12) | | | | |
| Range | 7.7-13.8 | 13.1-21.5 | 42.9-51.7 | 24.8-34.4 |
| Mean | 10.3 | 15.3 | 46.4 | 27.5 |
| $^3$H-Irradiated (8) | | | | |
| Range | 7.2-9.1 | 12.0-14.7 | 49.7-51.5 | 26.3-28.3 |
| Mean | 8.5 | 13.0 | 50.6 | 27.7 |

## • FACTORS AFFECTING BIOGEOCHEMICAL CYCLING

*The main objectives of these studies are to define the present and time-dependent inventory of various radionuclides in the Columbia River-McNary Reservoir ecosystem and other aquatic ecosystems receiving radioactive wastes. Of primary interest is the determination of their rates of exchange, and the chemical, physical, and biological mechanisms that are important in the cycling of these materials in the aquatic food-webs. The ultimate goal of the studies is to develop mathematical models to predict the cycling processes and to describe the rates and mechanisms involved in the various chemical, physical, and biological parameters which govern the cycling of radionuclides in these ecosystems.*

### Decline of Radioactivity in the Columbia River - McNary Reservoir Ecosystem Following Shutdown of Hanford Reactors

C. E. Cushing, D. G. Watson, D. E. Robertson and W. B. Silker

Since January 1971, a special study of the rates and mechanisms of the radionuclide interactions in the Columbia River has been in progress with the purpose of characterizing the long-range behavior of the radionuclide inventory which was discharged into this ecosystem during the reactor operating period.

#### Physical and Chemical Studies

The Hanford produced radionuclides presently contained in the Columbia River system are from two sources: (1) those discharged from previous reactor operation which became attached to particles and deposited with the sediments in the major sedimentation basins in the river (primarily behind McNary Dam), and (2) those currently released from the dual purpose power-plutonium production N-Reactor. In April 1971, most of the radioactivity transported by the Columbia River was associated with resuspended sediments. At that time the discharges from N-Reactor, a closed-loop secondary cooled reactor, were comparably small and indistinguishable from the relatively large amounts of radionuclides entering the river water from the sediments. However, with continued scouring, sedimentation, and radioactive decay, resuspension of radionuclides has decreased and the releases from N-Reactor are most significant. Figure 3.11 illustrates the change in concentrations with time of three important radionuclides ($^{54}Mn$, $^{60}Co$ and $^{65}Zn$) in the suspended matter of the Columbia River sampled at McNary Dam and at Richland. During the first year following the shutdown of the original Hanford production reactors, the concentrations of these radionuclides at McNary decreased approximately tenfold. Scouring of the bottom sediments during the spring freshets of 1972 increased the radionuclide concentrations in the water. Following runoff, their concentrations again decreased to low levels in February 1973. In March 1973, the $^{54}Mn$, $^{60}Co$, and $^{65}Zn$ concentrations began to increase, and by July 1973 they were nearly tenfold greater than those observed in February. These increases appear to be due to radionuclide releases from N-Reactor. The radionuclide additions from N-Reactor are characterized by increases in the soluble fractions of each isotope. N-Reactor radionuclide releases are very sporadic and continuous sampling is necessary to detect changes in effluent discharge. Therefore, an integrating water sampler was installed at Richland in April 1973 to remove both ionic and particulate species of radionuclides. In April, May, and June of 1973, the concentrations of these radionuclides at Richland were substantially higher than the levels observed at McNary Dam, indicating that N-Reactor radionuclides were deposited to a large degree in the sediments behind McNary Dam and were not significantly transported downriver past the dam. This is verified by recent increases in the $^{54}Mn$ and $^{60}Co$ concentrations in the McNary Reservoir surface sediments. The highest concentrations of $^{54}Mn$, $^{60}Co$, and $^{65}Zn$ in the river at Richland occurred at a time when N-Reactor was shutdown.

As shown in Figure 3.11, the river flow rate in 1973 below McNary Dam remained essentially constant (except for weekly McNary Dam fluctuations),

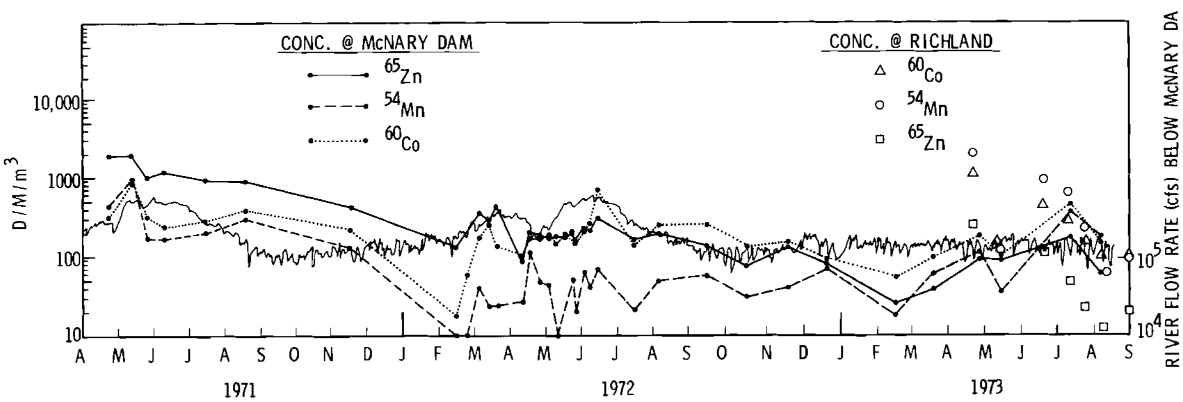
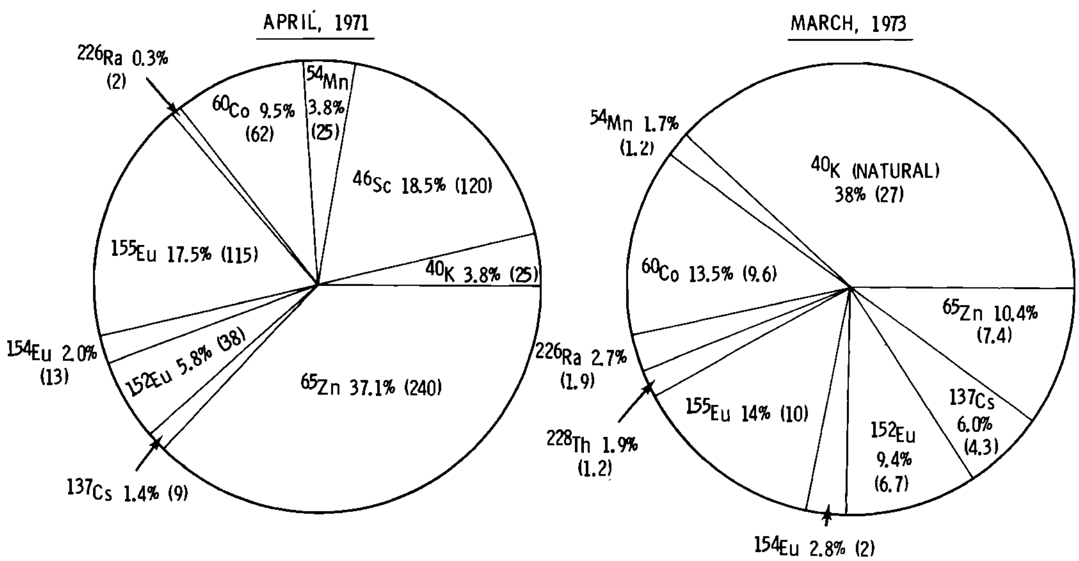



FIGURE 3.11. Radionuclide Concentrations in Suspended Matter in Columbia River at McNary Dam and Richland

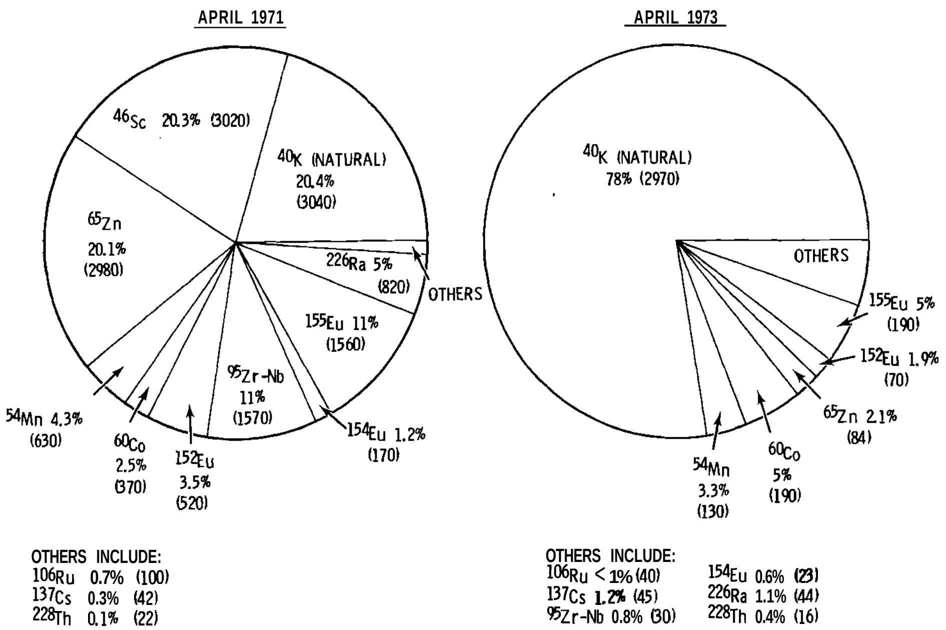
without the normal increase in flow during the freshet. Through October 1973, the Columbia River flows were the lowest in history. As a result, both sediment scouring (which occurs during the spring freshet) and sediment deposition (most of which occurs later in the summer) were minimal. This observation was based on the depth distribution of Hanford original radionuclides in sediment cores taken in early March 1973 and in late August 1973. During a year of normal river flow, sediment deposits amount to 10 to 15 cm behind McNary Dam, while in 1973, relatively little sedimentation occurred. The suspended load of the Columbia River was thus unusually small during the spring and summer.

Despite the radionuclide additions from N-Reactor, the total radioactivity in Columbia River water, sediments, and biota has decreased substantially since April 1971. Figures 3.12 and 3.13 show that the gamma-emitting radionuclides of Hanford origin are now minor components of Columbia River water and sediments, compared to the natural radionuclide $^{40}K$. In April 1971, the total concentration of the major Hanford origin gamma-emitting radionuclides in McNary Reservoir surface sediments ($^{65}Zn$, $^{46}Sc$, $^{152}$, $^{154}$, $^{155}Eu$, $^{60}Co$, and $^{54}Mn$) were approximately 25 times the natural $^{40}K$; whereas in March 1973, the $^{40}K$ contributed 30% to the gamma-emitting radionuclides in the surface sediments. This reduction in the concentrations of the Hanford origin radionuclides in the McNary Reservoir surface sediments is due to sediment scouring, radioactive decay,




PERCENTAGES INDICATE THE FRACTION OF THE TOTAL GAMMA-EMITTING RADIOACTIVITY IN THE SEDIMENTS. THE NUMBERS IN PARENTHESES ARE THE RADIONUCLIDE CONCENTRATIONS IN DISINTEGRATIONS PER MINUTE PER GRAM OF DRY SEDIMENT.

FIGURE 3.12. Change in Composition of Gamma-Emitting Radionuclides in Columbia River Sediments Behind McNary Dam Between April 1971 and March 1973




PERCENTAGES INDICATE THE FRACTION OF THE TOTAL GAMMA-EMITTING RADIOACTIVITY PRESENT IN THE WATER. THE NUMBER IN PARENTHESES ARE THE RADIONUCLIDE CONCENTRATIONS IN DISINTEGRATIONS PER MINUTE PER CUBIC METER OF WATER.

FIGURE 3.13. Change in Composition of Gamma-Emitting Radionuclides in Columbia River Water at McNary Dam Between April 1971 and April 1973

and to the burial of the radioactive sediments with fresh and relatively uncontaminated material. In water sampled at McNary Dam in April 1973, $^{40}$K accounted for 78% of the total gamma-emitting radionuclides present; in April 1971 it accounted for only 20%, with the Hanford originated $^{46}$Sc, $^{65}$Zn, and $^{155}$Eu comprising the bulk of the radioactivity.

The $^{239}$Pu concentrations in sediments presently being deposited in McNary Reservoir are at background, fallout levels and are comparable to those deposited behind Priest Rapids Dam upstream from the Hanford Project, i.e., approximately 0.03 d/m/gm dry sediment. These low concentrations extend to a depth of about 5 in. in the areas of high sedimentation rate in McNary Reservoir and then increase with depth in the sediments to a maximum of about 0.30 d/m/gm dry sediment at a depth of 19 in.

## Biological Studies

Emphasis on sampling the Columbia River - McNary Reservoir ecosystem was concentrated in McNary Reservoir in 1972-73 due to the presence there of the largest repository of radionuclides in the sediment. More species were sampled and new sampling stations were established to obtain a more thorough knowledge of this ecosystem.

Since June 1972, when the last data were reported, concentrations of the gamma radionuclides generally continued to decrease, but at a much slower rate. By June 1973, $^{46}Sc$, $^{137}Cs$ and $^{54}Mn$ were below detectable limits in most organisms. Cobalt-60 and $^{65}Zn$ continued in greatest abundance in most organisms and even these two isotopes were occasionally undetectable. $^{137}Cs$ was present in only the larger fish; the slow decline in these organisms is indicative of a slow biological turnover.

Figure 3.14 shows the concentration of $^{65}Zn$ in plankton, periphyton, chironomid larvae, and suckers since the beginning of the study; unexplainable high values appear periodically. The decrease of $^{65}Zn$ from about 100 pCi/g dry wt in chironomid larvae is in good agreement with the nine-fold decrease of this isotope in the sediments. Chironomids ingest sediments when feeding.

Analyses of water samples shows that 15 to 35% of the $^{65}Zn$ was ionic when the reactors were operating, but that less than 2% was present in ionic form in 1971 and 1972. With these data in mind, it is of interest to compare the ratios of $^{65}Zn$ in various organisms and that in their principal food for that period. Suckers graze on periphyton communities; when the reactors were operating, there was approximately 10 times as much $^{65}Zn$ in the periphyton as in the suckers. In 1971 and 1972, there was only about two times as much in the periphyton. The same ratios presently obtained for the squawfish which prey on smaller forage fish. The change in ratios approximates that of the changes in ionic $^{65}Zn$; however, recent analyses show a higher percent of

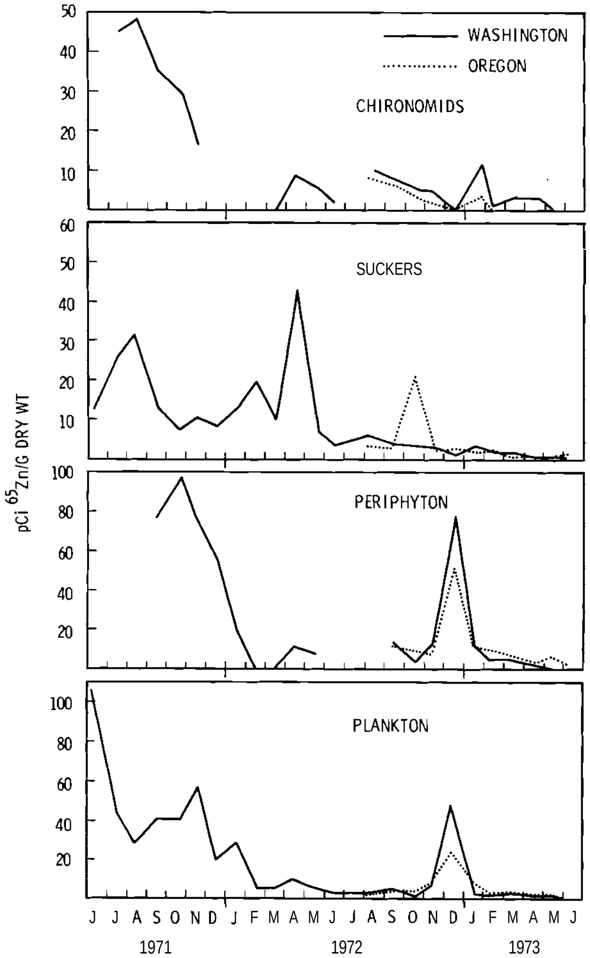



FIGURE 3.14. $^{65}Zn$ in Plankton, Periphyton, Chironomid Larvae and Suckers

ionic $^{65}Zn$ in the water at Hanford, although this probably decreases by the time the water reaches McNary Dam. Manganese-54 has been undetectable in the plankton for several months, yet it has the highest concentration of any radionuclide in the flesh of the freshwater mussels. Mussels utilize plankton for food and are known concentrators of $^{54}Mn$; the present levels of $^{54}Mn$ ($\sim$10 pCi/g dry wt) are probably related to the long biological half-life of $^{54}Mn$ in Anodanta, about 1300 days (Harrison, F. L., 1969). Zinc-65 is also present in higher concentration in the mussels than other organisms. Catfish and similar concentrations of $^{65}Zn$ as their food items, crayfish and forage fish.

Plutonium-239 concentrations in plankton and fish collected in McNary Reservoir were extremely low, ranging from below detection limits (approximately 0.00005 d/m/gm fresh weight) to about 0.002 d/m/gm fresh weight.

Sampling of periphyton in the vicinity of the seepage springs at the 100-N reactor show that $^{60}Co$ is the radionuclide present in highest concentration, about 20 pCi/g dry wt.

The biota in McNary Reservoir are exposed to a changing, and much lower, ambient level of radionuclides in their environment. A true effective half-life cannot be determined since radionuclides are still available from the sediments, from 100-N reactor effluents, and from the residual radioactivity in the organism in the food-web.

Current laboratory studies are directed toward the determination of transfer rates among the various components of the ecosystem.

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Harrison, F. L., 1969, Accumulation and Distribution of $^{54}Mn$ and $^{65}Zn$ in Freshwater Clams. In- Symposium on Radioecology (D. J. Nelson and F. C. Evans, eds.), USAEC-Conf.-670503, pp. 198-220.

## A Conceptual Model of Radionuclide Transfer in Columbia River Biota

J. M. Thomas, C. E. Cushing and L. L. Eberhardt

We believe that several long-term programs are at a point where a substantial statistical evaluation can result in models useful in answering quantitative questions concerning nutrient cycling and radioecology needed for compliance with NEPA. Of the several candidate programs, our first efforts were expended to assess the program entitled "Factors Affecting Biogeochemical Cycling."

Figure 3.15 is an attempt to show some of the components and the complexity of the aquatic ecosystem in McNary Reservoir. We have indicated where additional data is needed (heavy boxes) for each component. The additional complexity introduced by considering interrelationships between dissolved and suspended matter and sediments is shown in the inset. This is the least understood portion of the model. It should be emphasized that Figure 3.15 represents what we define as major probable pathways for elements and/or energy even though other paths might be included for particular situations. The inset portion of the model may appear to be overly detailed; however, the components are real and if the system is to be understood they should be studied and/or models attempted. Some sections (i.e., the sediments as related to dissolved matter) need immediate experimental attention. As

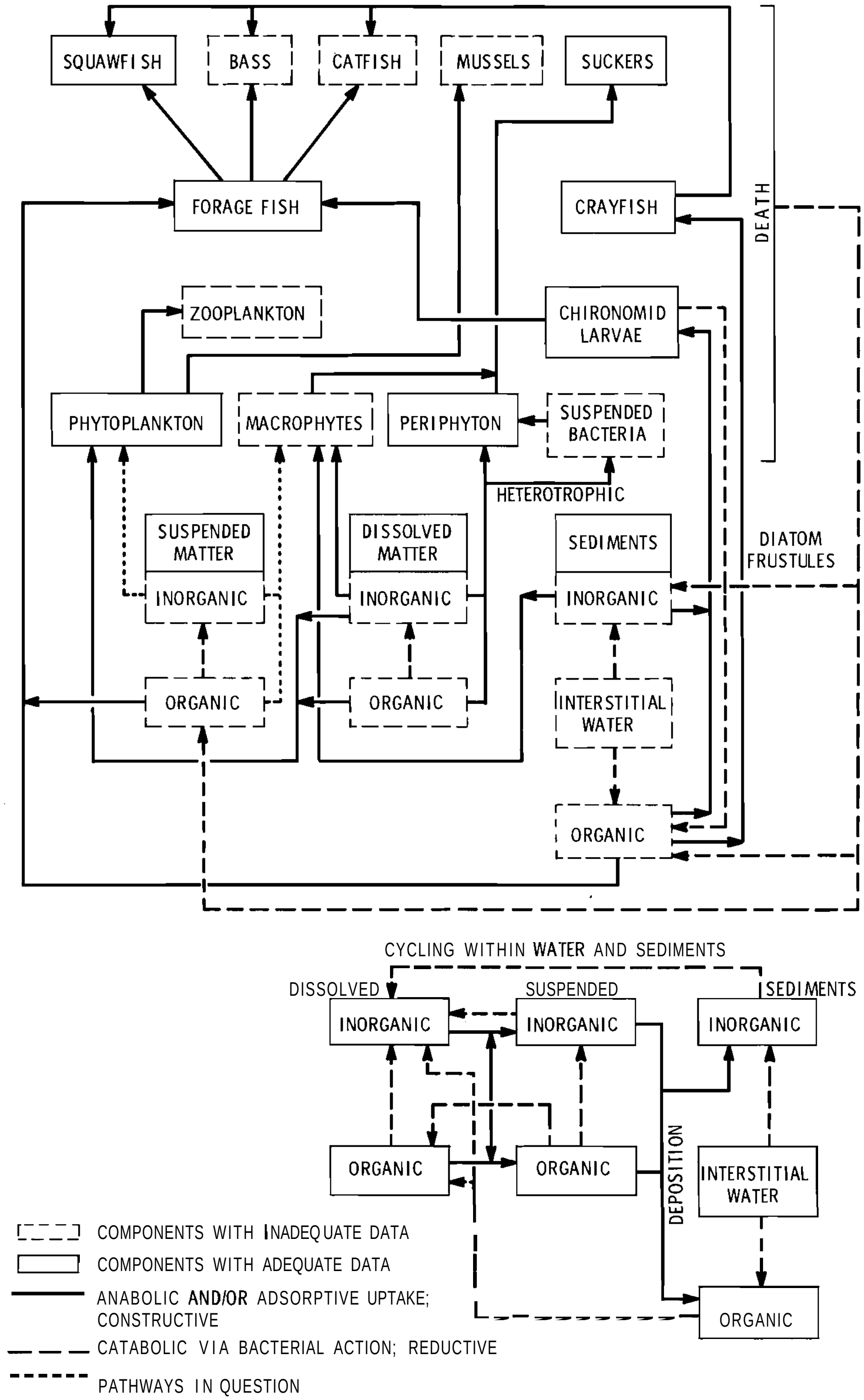



**FIGURE 3.15. Probable Major Pathways for Transfer of Radionuclides in the Columbia River**

field and laboratory studies proceed in conjunction with modelling efforts, new ideas as to structure will undoubtedly evolve. We also stress that the level of understanding we do achieve should be applicable to cycling of substances other than radionuclides.

Our previous Annual Reports and publications give some idea of the data available. Additional current measurements are recorded elsewhere in this Annual Report.* Unfortunately, much of the data collected was not in large enough blocks nor did it extend over a sufficient period of time to be useful in estimating some of the values needed in Figure 3.15. In these cases other values based on related experimental evidence will be used.

We have identified available sources of rate data both on the Hanford reach and elsewhere on the Columbia River. Some studies were designed to estimate rates while others may or may not be useful for this purpose. Some specific areas of weakness identified thus far, and useful for planning are:

1) Often only gross measures of radioactivity are reported (whole animal as opposed to tissues, or combined measures of suspended and dissolved material).
2) Initial appraisal of the literature shows that little or no stable element data is available on suspended sediments, and but little more on sediments.
3) We lack expertise in the area of aquatic microbiology, but we should design and carry out relevant laboratory and field experiments on the role of bacteria. Reference to Figure 3.15 shows that bacteria are crucially involved with many of the interrelationships.
4) The lack of detailed information on the components in the inset of Figure 3.15 and their direct relationship to the lower trophic levels of biota. This area should receive the highest priority for experimental attention if understanding of the system is of paramount importance.

Experiments designed to investigate these and other deficiencies will not all be easy to carry out nor will results be forthcoming in a short time frame.

We intend to attempt some models of the gross features of Figure 3.15 when rate data have been evaluated. Seasonal data available for some components with and without Hanford reactors operating may allow some deterministic "curve fitting" and assessment or criticism of current field efforts concerned with reactor siting problems. Both models and a quantitative assessment of data from reactor pre-operational, operational, and post-operational periods will be investigated from the point of view of sampling. In addition, the conceptual model in Figure 3.15 will be formulated in matrix form to give us an additional perspective for obtaining needed data.

* See pages 92 to 95 for periphyton studies and pages 84 to 89 for McNary Studies.

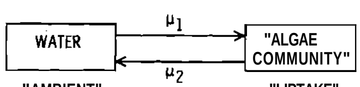
Modelling of Radionuclide Cycling by Periphyton

C. E. Cushing, J. M. Thomas and L. L. Eberhardt

Studies of uptake and retention of $^{65}Zn$ by periphyton communities have been in progress at this laboratory for some time (Annual Report, 1971) and we are now in the process of examining the data in terms of their fit to mathematical models as well as initiating similar studies using $^{137}Cs$.

Early results revealed several basic aspects of $^{65}Zn$ uptake and retention: 1) the uptake process is mainly adsorptive in nature, 2) absolute uptake is directly related to initial ambient concentrations, and 3) uptake involves a competition for divalent cation adsorption sites with other divalent cations, i.e., $Mg^{++}$.

The model in Figure 3.16 was formulated and solution of differential equations led to the two simple exponential expressions shown. Five sets of experimental data were fit using these equations. In addition, the retention rate ($\mu_2$) was estimated independently by fitting an exponential decay model to data obtained when unspiked river water was circulated through the system. Examples of the fits obtained are shown in Figures 3.17 and 3.18. Subsequent calculations using the ambient equation and definitions shown in Figure 3.16 gave estimates of $\mu_1$, the uptake fraction, which ranged from 0.021 to 0.148 $hr^{-1}$. Estimates of $\mu_2$ from the ambient data gave values from 0.008 to 0.012 $hr^{-1}$, suggesting remarkable consistency. However, independent estimates based on retention slopes (i.e., after unspiked river water was




AMBIENT (nCi/ml) = $Y_1 = A + B\ e^{-CT}$

UPTAKE (CPM) = $Y_2 = B[1-e^{-CT}]$

WHERE:

- A = $\lambda\mu_2/(\mu_1+\mu_2)$
- B = $\lambda\mu_1/(\mu_1+\mu_2)$
- C = $\mu_1+\mu_2$
- $\lambda$ = THE INITIAL SPIKE (nCi/ml)
- $\mu_1$ = FRACTION OF $^{65}Zn$ IN WATER TRANSFERRED TO ALGAE PER UNIT TIME PROVIDED TIME UNITS ARE SMALL
- $\mu_2$ = FRACTION OF $^{65}Zn$ IN/OR ALGAE TRANSFERRED BACK TO WATER PER UNIT TIME PROVIDED TIME UNITS ARE SMALL

FIGURE 3.16. Preliminary Model of Closed Lotic Microcosm

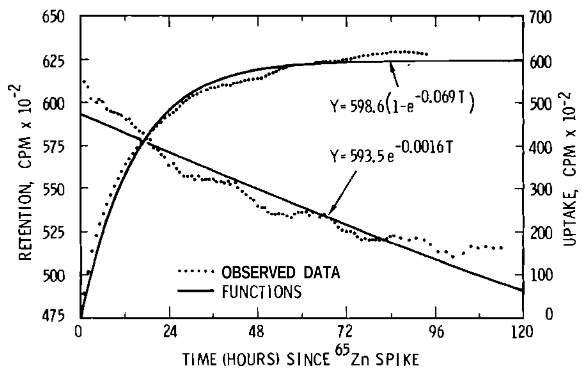



FIGURE 3.17. Exponential Models of Uptake and Retention

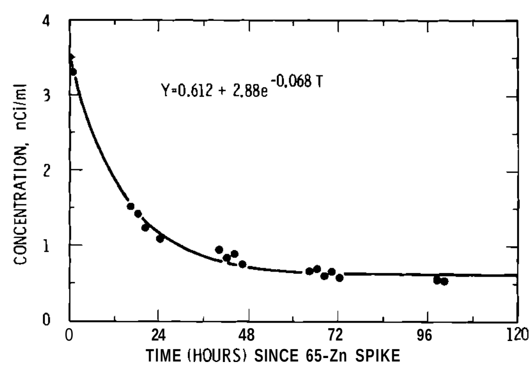



FIGURE 3.18. Loss of $^{65}Zn$ from Water - "Ambient"

added) were from two to eight times lower. Because of this result and the pattern of positive and negative deviations of the data from the uptake and retention models (Figure 3.17), we decided to attempt to fit a different model to the retention data.

We assumed $\mu_2$ to be an expression of "average" loss from a periphyton community because the population contains a mixture of dead organic material, heterotrophic organisms, and autotrophs which are usually dominant. This supposition led to the derivation of the following equation when the loss rates of individual components are assumed to be from a gamma distribution:

$$Y = D\ [(1+T/E)^{-F}]$$

retention by algae (1)

We have used Equation (2) below, derived by Eberhardt and Nakatani (Proc. Second National Symposium on Radioecology CONF-670503, USAEC, WASH.) for fitting "uptake" but have not as yet obtained a mathematical derivation wholly in accord with circumstances of the experimental conditions in this work.

$$Y = D[1-(1+T/E)^{-(F-1)}]$$

"uptake" from "spiked" river water (2)

Figure 3.19 illustrates the results obtained when these equations were used and also shows cyclic deviations

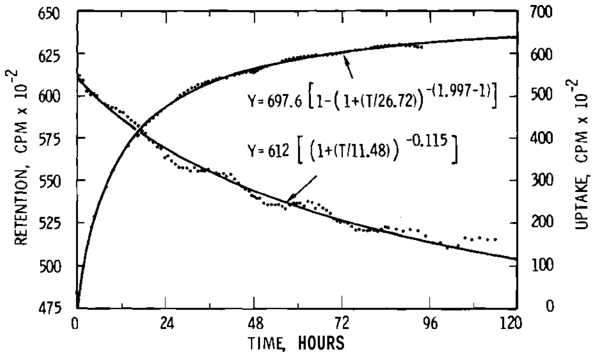



FIGURE 3.19. Power Function Models of Uptake and Retention

from predicted values. Most of the oscillatory behavior has been traced to a combination of electronic and thermal circumstances and has been corrected. Moreover, the fits using Equations (1) and (2) are much better than those obtained using the previous models (compare Figures 3.17 and 3.18). Our current research is directed at assessing the usefulness of the parameters in estimating rates, devising appropriate expression(s) for "ambient" concentrations, and demonstrating the validity of Equation (2) or a counterpart.

We are currently analyzing data where a chenille like cloth was used to present an inert simulated community to study adsorption and retention of $^{65}Zn$ and $^{137}Cs$. Other experimental manipulations will include varying temperature (the "impact" situation), water velocities and chemistry ("outflow problems") and compartmentalizing the communities by using photosynthetic inhibitors and antibiotics.

## $^{65}Zn$ Uptake by Columbia River Periphyton from Sediments

R. M. Emery and J. M. Gurtisen

Accumulation rates of $^{65}Zn$ by periphytic algae were studied using 8-ft simulated water columns. These columns were prepared with 6 in. of sediment (Columbia River) at the bottom containing a $^{65}Zn$ spike. The overlying water was either vertically mixed (with air) or allowed to stabilize through thermal stratification Cultures of Columbia River periphyton (on glass slides) were exposed to two zones within the column: an upper lighted zone, and a lower darkened zone.

Results indicate that periphyton (mainly the diatom Melosira) can concentrate from 2 to 4 orders of magnitude more $^{65}Zn$ than those concentrations present in the associated water mass. This accumulation is rapid even when the vertical transport mechanisms (to move $^{65}Zn$ upward out of the sediment) are minimized in the stable water column. Apparently photosynthetic activity plays a large role in $^{65}Zn$ uptake because levels of accumulation are much greater in the lighted zone of the column under both stable and mixed conditions (Figure 3.20)

Since the uptake of $^{65}Zn$ by periphyton is partially dependent upon the amounts of $^{65}Zn$ available from the water an accumulation factor was calculated for each period of exposure. The expression for this accumulation factor ($F_a$) is

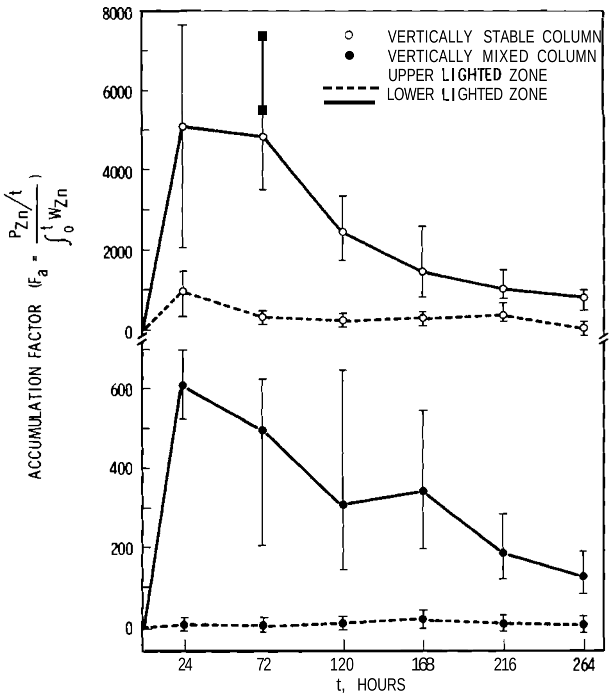



FIGURE 3.20. Accumulation of $^{65}Zn$ by Periphyton Under Conditions of a Vertically Stable and Vertically Mixed Water Columns. Plotted Points Represent Means of Four Replicates with Ranges Indicated by Vertical Lines

$$F_a = \frac{P_{Zn}/t}{\int_o^t W_{Zn}},$$

where $P_{Zn}$ is the level of $^{65}Zn$ accumulated by the periphyton over time period t, and $W_{Zn}$ is the level of $^{65}Zn$ in the surrounding water integrated over the same time t. Accumulation factors were initially high over the first 24 hr and gradually declined in the following 240 hr (Figure 3.20). This appears to be a saturation process accompanied with initial supersaturation.

One of several conclusions which are indicated by these results is that since the absence of light limits the uptake of $^{65}Zn$ by periphyton the possibilities of springtime scouring enhancing $^{65}Zn$ accumulation in Columbia River algae appears to be reduced. Algae growing in euphotic regions before spring runoff occurs probably do not substantially increase their $^{65}Zn$ burden during spring scouring because the associated turbidity (i.e., light limitation) would greatly reduce accumulation of $^{65}Zn$ by the algae - even if more $^{65}Zn$ were made available by this scouring action.

Also evident in Figure 3.20 is that the accumulation factor of $^{65}Zn$ in the stable column is about ten times greater than in the mixed column. This happened because more $^{65}Zn$ was available under mixed conditions than was available when the column was stable (causing a smaller ratio between $P_{Zn}$ and $W_{Zn}$). Reductions of $^{65}Zn$ accumulation at higher levels of availability is also probably associated with an upper limit of saturation which is determined by the number of binding sites on the surface and inside the algal cells.

Similar studies indicate that a 1-in. over-layer of natural (unspiked) river sediment inhibits the vertical transport of $^{65}Zn$ by the periphyton remain about the same. Any differences in accumulation can be accounted for by reduced levels of available $^{65}Zn$ caused by this layer of unspiked sediment. The upward movement of $^{65}Zn$ from the spiked sediment into the unspiked layer show that vertical transport occurs relatively fast. A calculated vertical flux for this action is 13.0 $\mu Ci/m^2 \cdot day$ when the underlying sediment contains 1.196 $\mu Ci$ $^{65}Zn/gm$.

## Study of the Behavior of Plutonium and Americium in an Aquatic System

R. M. Emery and D. G. Watson

Studies to determine the ecological distribution of Pu and Am in U-Pond (a Pu process waste pond on the Hanford Reservation) were initiated in July 1973. Field sampling techniques were developed to collect representative samples of sediments, water and biota. A block design is being used to allow for statistical analyses of Pu/Am distribution when sufficient sample sizes are attained. An extensive dock system is being placed in the pond to facilitate sampling without disturbing the pond bottom. Specially designed traps for collecting benthic organisms (primarily odonate and dipteran larvae, gastropods and amphipods) have been placed in the pond. These traps are expected to collect the sizable quantities of these organisms needed for Pu/Am analysis. To prepare these samples, a freeze-drying system is being employed. A trailer-laboratory will be installed at the pond site by late December. This facility will be used. to process and examine field samples as well as perform continuous-flow bioassays to more specifically identify the pathways of Pu/Am in this aquatic ecosystem. This project is now moving out of the organizational-developmental stage and into an intensive program of sampling and analysis.

Within a few months, the first results concerning the distribution of Pu and Am in this aquatic ecosystem should be available.

Aquatic Studies at Gable Pond*

C. E. Cushing and D. G. Watson

Studies of the aquatic biota in Gable Pond, a low level radioactive waste pond, were begun in 1972 to investigate the distribution and levels of radioactivity in the aquatic food-web. Initial results revealed that the distribution and level of radioactivity in the sediments varies with location; in general, higher levels were found in the northwest end and lower levels in the southeast end of the pond.

To investigate this in more detail, five transects with four stations along each one were established to determine the pattern of radionuclide concentration in the sediments. Thermoluminescent dosimeters placed on the surface of the sediments at each station gave average and maximum dose measurements of 50 mr/day and 230 mr/day, respectively. The sediment analyses confirmed the 1972 data, but revealed that areas of high concentrations are also present at other places, mainly near the center of the transect. A good deal of variation has been encountered in these samples and may be related to differences in the depth distribution of the radionuclides in the sediment and to the difficulty in obtaining uniform samples at each site. Core samples taken at the center of each transect show that over 85% of $^{137}Cs$. $^{95}Zr$, and $^{60}Co$ is in the upper 2 in. of sediments, and that $^{137}Cs$ accounts for over 90% of the gamma radioactivity in the upper 2 in.

A detailed radioanalysis of alpha emitting radionuclides in various biota and sediments was performed on samples collected on May 29, 1973; results are shown in Table 3.10. The highest concentrations found were in the sediments collected near the center of the pond. Snail samples include the shell; concentrations of alpha emitters would probably be higher if only the flesh were analyzed

In conjunction with the sediment studies, investigations of the differential uptake of radionuclides by goldfish were begun. On May 25, 1973, 300 goldfish (obtained from an offsite commercial dealer) were placed in each of two pens to evaluate the rate and maximum levels of radionuclides taken up by the fish. One pen was placed over sediments with high radioactivity; the other over low levels. Data analyzed to date are shown in Table 3.11. Samples of filamentous algae and vascular plants, major food items of the goldfish, collected adjacent to each pen verified that radionuclide levels were markedly different at the two sites - highest levels were associated with the higher sediment radionuclide concentrations. Levels of $^{137}Cs$ are still increasing in the fish over the higher level sediments; levels have essentially stabilized in the fish over the lower activity sediments. $^{95}Zr$ and $^{60}Co$ apparently approached

* ARHCO Intercontractor Support

TABLE 3.10. Concentrations (pCi/g Dry Weight) of Alpha Radionuclides in Biota Collected on May 29, 1973

| Organism | $^{238}Pu$ | $^{239-240}Pu$ | $^{241}Am$ |
|---|---|---|---|
| Snails | $28.56 \times 10^{-4}$ | $3.32 \times 10^{-2}$ | $4.64 \times 10^{-2}$ |
| Algae | $13.7 \times 10^{-3}$ | $2.41 \times 10^{-1}$ | $2.55 \times 10^{-3}$ |
| *Potamogeton richardsonii* | $11.47 \times 10^{-3}$ | $1.27 \times 10^{-1}$ | $9.10 \times 10^{-2}$ |
| *Myriophyllum verticillatum*(?) | $3.56 \times 10^{-2}$ | $6.14 \times 10^{-1}$ | $5.19 \times 10^{-1}$ |
| *Potamogeton filiformis*(?) | $13.27 \times 10^{-3}$ | $4.13 \times 10^{-1}$ | $3.46 \times 10^{-1}$ |
| Sediment A[a] | $4.76 \times 10^{-4}$ | $1.13 \times 10^{-2}$ | $8.60 \times 10^{-3}$ |
| Sediment B[a] | $8.85 \times 10^{-2}$ | 1.56 | 1.46 |

a. Sample A collected near shore in northwest end; Sample B collected nearshore on west-side of pond.

TABLE 3.11. Radionuclide Concentrations (pCi/g Dry Weight) in Experimental Goldfish[a]

| Date | Northwest End | | | Southeast End | | |
|---|---|---|---|---|---|---|
| | $^{137}Cs$ | $^{95}Zr$ | $^{60}Co$ | $^{137}Cs$ | $^{95}Zr$ | $^{60}Co$ |
| 6/7/73 | 126.1 | 6.73 | 0.12 | 129.3 | 6.23 | 0.17 |
| 6/26/73 | 286.0 | 2.43 | 0.17 | 147.3 | 1.02 | 0.08 |
| 7/11/73 | 286.6 | 3.96 | 0.17 | 200.4 | 3.98 | 0.53 |
| 7/23/73 | 377.8 | 5.93 | 1.17 | 265.0 | 5.76 | 0.28 |
| 8/10/73 | 487.3 | 7.66 | 0.38 | 214.2 | 4.68 | 0.14 |
| 8/30/73 | 531.6 | 4.75 | 0.10 | 246.0 | 4.26 | 0.31 |

a. Each figure is a mean of 8 fish.

equilibrium quite rapidly at both sites at essentially the same concentration. In 2 months, the experimental goldfish had attained body burdens of about the same magnitude as that of a single wild goldfish collected on July 12, 1973.

To study the uptake of radioactive isotopes by aquatic birds through natural foods, six adult hen mallard ducks with broods were placed in the pond on June 20, 1973, and an additional 97 adult mallards were introduced on August 8, 1973. These birds were marked and rendered flightless. $^{137}Cs$ concentrations in the muscle and carcass of the young birds from the first planting averaged 86 and 45 pCi/g dry wt, respectively, on July 24, 1973. $^{95}Zr$ concentrations in the muscle and carcass were near unity and $^{60}Co$ concentrations were less than one.

## Fall Chinook Salmon Spawning near Hanford - 1973

D. G. Watson

Fall chinook salmon spawning in the Hanford reach of the Columbia River was estimated by four aerial surveys conducted between October 15 and November 13. This is a continuation of a study that was started in 1947 to determine the effects of the plutonium production reactors on this fish population; and it has been continued to observe changes that may be evident after the closure of all but one of the reactors in 1971.

Between Richland (river mile 339) and Priest Rapids Dam (river mile 396) a total of 2,965 salmon redds (nests) were observed. The spawning areas used in previous years were again the major sites for spawning. In the area near Ringold (river mile 348-358) spawning generally was earlier than in the remainder of the river. This may be due, in part, to the large number of fish returning to the Ringold area as a result of the salmon rearing program by the Washington Department of Fisheries at their Ringold facility. The adult salmon return to the Ringold station was very heavy this year although there was no significant increase in the numbers of salmon spawning in this region of the Columbia River.

The total spawning in the Hanford reach was substantially greater than that observed in 1972 (Figure 3.21). This was due in part to better weather conditions during the times when aerial surveys were made and to the generally greater numbers of fall chinook salmon entering the middle section of the Columbia River. Adult fall chinook salmon counts at McNary Dam the first dam downstream of the Hanford reach were 49,307 and 71,494 in 1972 and 1973, respectively. The brood year for this year's returning adults was very good, with about 4,500 redds observed in the Hanford section of the river and the upstream passage of over 79,000 adults at McNary Dam.

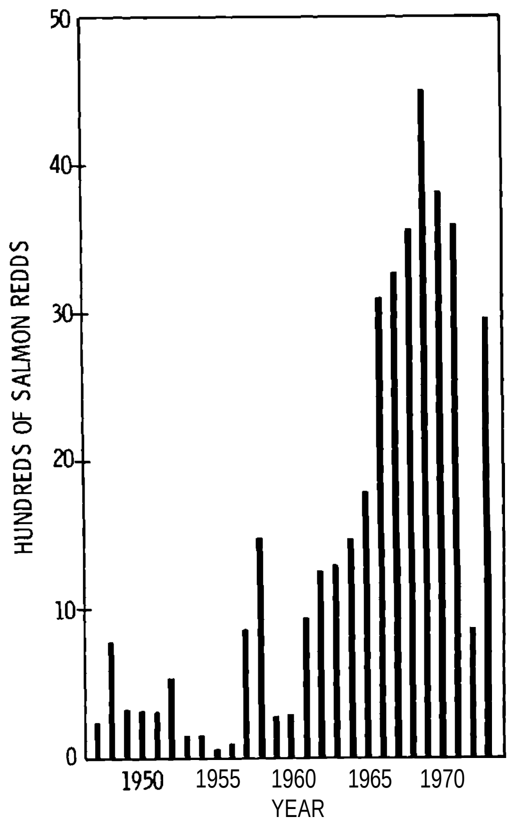



FIGURE 3.21. Fall Chinook Salmon Redd Census - Hanford

### Feeding Experiments with Aquatic Insects

D. A. McCullough and C. E. Cushing

Experiments were conducted to determine the ingestion (feeding) rates and assimilation efficiencies (percent utilization of carbon during passage through the gut) of three immature aquatic insects: *Simulium* sp. (Diptera) and *Hydropsyche* sp. (Trichoptera) from Rattlesnake Springs and *Tricorythodes minutus* (Ephemeroptera) from Deep Creek, Oneida Co., Idaho.

Digestion time (the time required for a portion of food to pass through the gut) for *Simulium* was estimated several times and ranged from 45 to 60 min. By feeding *Simulium* *in situ* (in the natural stream) on a slurry of carbon powder, it was found that particle sizes from 1 to 50 μ could be filtered.

Ingestion rates of the three insects were measured using bacteria, diatoms, and finely ground watercress labelled with $^{14}C$ and $^{51}Cr$. Assimilation efficiencies were determined using a dual-isotope ($^{14}C$ and $^{51}Cr$) technique, and by an ash-ratio technique.

Grazing on diatom-covered slides was found to be insignificant as a method of feeding for *Simulium* and

Hydropsyche. Both species were able to filter suspended food from the water, but ingestion rates varied considerably depending upon experimental conditions. In certain filter-feeding animals, food availability is determined by food concentrations and current speed, and the ingestion rate is further limited by the mechanical efficiency of the feeding mechanism. Within limits, a sub-optimal current speed can be compensated for by an excess of food.

Ingestion rates of Simulium were studied using three different experimental feeding chambers in which current speed could be controlled; current velocities in Rattlesnake Springs were also measured where Simulium occurred. The natural distribution of Simulium is limited to sites where current speed exceeds 19 cm/sec because energy requirements can not be satisfied in slower currents. The concentration of food in the laboratory experiments exceeded that in the stream by about 10 times. Experimental ingestion rates of Simulium on bacteria and diatoms at current velocities of 6 cm/sec varied from 0.023 to 3.04 µg/mg/hr. Simulium maintained in an artificial channel containing small gravel (15 to 20 mm avg. diameter) with a current rate approximating natural conditions (19 cm/sec) ingested diatoms at a rate of 4.5 to 6.9 µg/mg/hr. These higher ingestion rates are attributed to the more natural current speeds, but were still below normal rates due to interference with feeding by increased turbulence in the artificial system.

Intestion rates of finely ground watercress by Simulium in a circular stream channel where the larvae attached to large smooth stones were much higher, 43 µg/mg/hr. Ingestion rates calculated from gut weight and digestion time of in situ Simulium ranged from 82 to 116 µg/mg/hr, depending upon the size of the larvae. Since the guts of the experimental animals were packed with watercress after 45 min of feeding, it appears that the density of natural seston is greater than that of the experimental foods.

Simulium assimilation efficiencies, calculated from experiments using dual-labelled diatoms, ranged from 54.3 to 65.7%. Efficiencies determined by the ash-ratio method with in situ animals were much less, ranging from 7.6 to 31.8%. There appear to be many more variables associated with the ash-ratio method and at present, the dual-label technique is superior.

Ingestion rates of diatoms by Hydropsyche ranged from 3.7 to 25.6 µg/mg/hr. Water turbulence appeared to have less effect on ingestion rates of the Hydropsyche larvae than for Simulium. Assimilation efficiencies calculated from the dual-label experiments ranged from 45.9 to 49.1%.

Digestion time for T. minutus is approximately 7 min. Ingestion rates of diatoms from a single experiment was 338.3 µg/mg/hr. Assimilation efficiencies for diatoms ranged from 20.7 to 43.9% and was 35.6% for watercress.

## PUBLICATIONS AND PRESENTATIONS

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## MARINE SCIENCES

- BIOENVIRONMENTAL EFFECTS OF EFFLUENTS DISCHARGE FROM NUCLEAR POWER PLANTS TO COASTAL WATERS
- FATE AND EFFECTS OF OIL ON MARINE COASTAL ECOSYSTEMS
- PHYSICAL AND RADIOLOGICAL CHEMISTRY OF OCEAN SOLUTIONS
- GEOCHEMICAL OCEAN SECTION STUDY

# • MARINE SCIENCES

*PNL efforts in the marine sciences are geared towards a better understanding of man's impact upon the environmental quality of the oceans. Radioactivity, anthropogenic pollutants, oil, and thermal discharges are waste products of an industrial society which enter the marine environment. The physical, chemical and biological interactions of these additions are being characterized to predict their potential detrimental effects in the oceans. The basic chemical and mixing processes in the ocean are being investigated to understand and determine anthropogenic additions to the marine environment interact and disperse.*

*Research on the thermal resistance of selected marine organisms and the effects of crude oil on marine intertidal communities are being conducted at the Marine Research Laboratory, Sequim, Washington.*

## • BIOENVIRONMENTAL EFFECTS OF EFFLUENTS DISCHARGE FROM NUCLEAR POWER PLANTS TO COASTAL WATERS

### Thermal Resistance of Marine Organisms

J. R. Vanderhorst, C. W. Apts, J. A. Lichatowich and R. Y. Ting

This reporting year marks a significant transitional period for marine thermal studies in that emphasis is being shifted from the short-term, single species exposures to longer term community exposure. Consistent with this shift, studies during the year have emphasized exposure of embryonic and juvenile life stages of animals and has included development of background on the interaction of temperature change and differing salinity. Data on the mortality of economically or biologically important organisms acutely exposed to rapid temperature increases serves as a needed endpoint for the special case where marine organisms are entrained and pass through nuclear power plant cooling condensers. Moreover, examination of the mortality endpoint for differing life stages helps to pinpoint susceptible stages, and, accompanied by a knowledge of the seasonal availability of those stages, assists in determination of plant operating impact. On the other hand, the community response to a continuing elevated temperature and to temporal thermal envelopes in apparatus designed to produce controlled experimental conditions will allow evaluation of not only the longer term effects of plant operation on resident organisms but also potential effects of plant shutdown at various stages of community succession. Thus, for example, elevated temperatures may re-order biological succession by providing some community members optimal growth phases at critical periods at the expense of others. By the same token the supportive community members from lower trophic levels may allow upper trophic levels to reach a magnitude of production, that, given a reduced primary production rate as dictated by lowered temperatures (simulated plant shutdown), leads to an inevitable "crash" of upper trophic levels potentially generating decreased species diversity and community adaptability.

First, we consider data selected from the short term studies of rapid thermal increase applied to differing life stages of key resident species. In subsequent discussion we will point out the state of development of our community studies.

The flatfishes (Pleuronectidae) form the dominant portion of the commercial fishery for bottom fishes in the northwest. Members of the family are demersal and spawn in the lower portion of the water column. As a built-in aeration device, necessary to the survival of the eggs, the eggs are buoyant and rise to the surface water layers. Hence, during the development process they are in all strata and could be expected to be entrained by cooling condenser intakes. Since death is not immediately (within seconds) recognizable, a slightly different form of bioassay has been employed than for the critical thermal maxima (CTM) reported for fishes.

Eggs of the rock sole (*Lepidopsetta bilineata*) were obtained from surface plankton tows (Sequim Bay, Washington) for use in bioassays. Collection of the eggs in this manner has produced eggs, in our experience, at a surprisingly homogeneous stage of development. Thus, the eggs typically hatch in 4 to 5 days after collection. For these tests, the eggs were allowed to stand in the flowing seawater system for a period of 12 to 24 hrs before use. Ten eggs were placed by pipette into each of several 100 ml pyrex beakers containing 80 ml of seawater at 8°C (ambient) or distilled water-seawater dilutions as indicated. In turn, the beakers were placed in a heating mantle provided with a rheostat to control the rate of temperature increase. After exposure to the thermal change the eggs were placed in an incubator at 8°C and observed for mortality. Mortality was definable by opaqueness and lack of buoyancy in higher concentrations of seawater. In the freshwater dilutions, of higher levels, the criteria of buoyancy was lost since the eggs typically were either low in the water column or rested on the bottom of beakers. Reported mortality is accumulative for four observational days.

Eggs were exposed in two block designs. In the first, treatments were rates of temperature increase and blocks were final temperatures above ambient. Means of three replicate exposures are presented on Table 4.1. Trends for rate of increase are not apparent but the apparent function of mortality to maximum temperature above ambient forms an unbroken trend at each rate of increase. Statistical criteria are being evaluated for the data to be included in an open literature report. The second design uses percentage of seawater as treatments and final temperature above ambient as blocks. Data on the percentage of mortality for three replicates of each experimental unit are presented on Table 4.2. That data will also be included as part of our open literature report.

Many species of shrimp have been demonstrated to be especially sensitive to toxicants and plant effluents. Normally a part of the benthos in estuaries and the open ocean, they undergo seasonal migrations which can make them vulnerable to entrainment with consequent exposure to rapid thermal change. In our studies, exposure of the coon stripe shrimp (Pandalus danae) has followed critical thermal maxima (CTM) methodology earlier reported for fishes and has been in block design. Experimental treatments were the rates of temperature increase and the blocks were based on size of shrimp. Size classes were established using wet weight as the criterion for classification. Blocks for "large" and "small" classifications are not yet complete. CTM values for the collected data are presented on Table 4.3. The apparent increase in CTM with increase in rate change will be statistically validated.

TABLE 4.1. Interaction of Rate of Temperature Increase and Maximum Temperature in Rock Sole Egg Mortality

| Rate °C/min | Percent Mortality/Temperature Above Ambient[a] 18 | 20 | 22 | 25 |
|---|---|---|---|---|
| 0.5 | 16 | 26 | 83 | 96 |
| 1.0 | 13 | 33 | 53 | 96 |
| 2.0 | 0 | 13 | 46 | 86 |
| 5.0 | 26 | 26 | 56 | 83 |

a. Ambient temoerature was 8°C; other temperatures expressed in degrees C.

TABLE 4.2. Interaction of Salinity and Temperature in Rock Sole Egg Mortality[a,b]

| Percent Seawater | Percent Mortality/Temperature Above Ambient 15 | 18 | 20 | 22 | 25 |
|---|---|---|---|---|---|
| 20 | 83 | 87 | 93 | 80 | 97 |
| 40 | 13 | 50 | 57 | 20 | 30 |
| 60 | 23 | 67 | 90 | 10 | 33 |
| 80 | 0 | 10 | 30 | 80 | 50 |
| 100 | 0 | 7 | 17 | 34 | 87 |

a. Temperature expressed in °C. Ambient temperature is approximately 8°C. Temperature rate increase from" ambient is 2°C/min in each case. Each data point is mean of three replicates.
b. Salinity is a function of seawater concentration with 100 percent seawater equaling approximately 30 p.p.t.

**TABLE 4.3. Critical Thermal Maxima n for Coon Stripe Shrimp (Pandalus danae)**

| Rate of Increase[a] | Size of Shrimp[b] Large CTM (n) | Medium CTM (n) | Small CTM (n) |
|---|---|---|---|
| 0.5 | | 27.5 (n) | |
| 1.0 | | 27.8 (n) | |
| 2.0 | 28.6 (10) | 28.2 (10) | 27.7 (10) |
| 6.0 | 31.8 (10) | 29.6 (10) | 28.4 (10) |

a. Rate of increase expressed in degrees C/min.
b. Large >9 grams; medium 4-7 grams; small 1-2 grams.

In accord with the idea of catalogueing critical thermal maxima for representative northwest species we now have, in addition to earlier reported values, the determinations for the 23 conditions and/or species included on Table 4.4.

**TABLE 4.4. Critical Thermal Maxima (CTM) for some Common Pacific Northwest Species**

| Species | Rate of increase | Acclimation temperature | CTM °C mean | (n) |
|---|---|---|---|---|
| Pacific Herring (larvae) | 7 | 10 | 29.21 | 15 |
| Pacific Herring (larvae) | 2 | 10 | 29.26 | 3 |
| Mysids | 7 | 10 | 29.96 | 10 |
| Mysids | 2 | 10 | 29.90 | 5 |
| Pacific Sand Lance | 10 | 10 | 28.75 | 10 |
| Pacific Sand Lance | 2 | 10 | 27.96 | 5 |
| Coho salmon | 6 | 10 | 31.80 | 10 |
| Coho salmon | 2 | 10 | 30.06 | 5 |
| Shiner perch | 6 | 10 | 33.63 | 10 |
| Shiner perch | 2 | 10 | 30.74 | 5 |
| Three-spine stickleback | 6 | 10 | 32.97 | 10 |
| Three-spine stickleback | 2 | 10 | 32.00 | 5 |
| Silver spotted sculpin | 6 | 10 | 28.07 | 10 |
| Silver spotted sculpin | 2 | 10 | 27.42 | 5 |
| Staghorn sculpin | 6 | 10 | 32.33 | 10 |
| Three-spined stickleback | 2 | 20 | 34.90 | 5 |
| Three-spined stickleback | 6 | 20 | 35.85 | 9 |
| Shiner perch | 0.5 | 10 | 29.65 | 4 |
| Sand sole | 1.0 | 10 | 28.37 | 10 |
| Staghorn sculpine | 0.1 | 10 | 32.2 | 20 |
| Shiner perch | 1.0 | 10 | 31.08 | 10 |

## ● FATE AND EFFECTS OF OIL ON MARINE COASTAL ECOSYSTEMS

### Nonnuclear Effluents: Effects of Crude Oil on Marine Intertidal Communities

J. R. Vanderhorst, R. M. Bean and R. Y. Ting

In response to the USAEC's interest in the environmental effects of nonnuclear effluents, a new study has been initiated to study the impact of crude petroleum on marine communities. To make such as assessment, there is need for a common denominator which will allow comparison of effluents from differing sources of power generation. Methodologies employing the mortality endpoint for impact evaluation have tended to develop along unique lines for each type of effluent studies. Thus, for radionuclides, a dose-response, or clinical approach, has been used extensively. A critical thermal maxima, or temperature at death for a given temperature rate, is a prominent methodology used for thermal effluents. For soluble toxicants, there is a long history of procedural development which has evolved into determinstions of lethal exposure concentration. These are commonly expressed as TLM (median tolerance limit) or $LC_{50}$ (lethal concentration).

Studies of crude petroleum in the marine environment presents unique problems. Petroleum is a complex material, composed primarily, but not exclusively, of hydrocarbons which differ widely in volitility, molecular weight, water solubility and toxicity. Furthermore, each crude oil tends to be unique with respect to both physical properties, and relative abundance of the various hydrocarbon compound types. Thus, it has been a common experience that the means used to expose biological systems to petroleum, and the type of petroleum used, can have a profound influence on the toxic responses induced. It is therefore essential that the methods of treatment be adequately characterized using analytical/chemical techniques in order to establish casual relationships between treatment and biological response. To this end, Battelle's study constitutes a combined chemical/biological approach to environmental assessment.

Our most intense biological effort for the first year's work will be in development of satisfactory community level endpoints. We have placed a "field" of 100 concrete blocks at the mean low tide level adjacent to the Battelle Marine Research Laboratory at Sequim, Washington. Preliminary experience, supported by Battelle, leads us to believe that within a few months, we can expect the blocks to accumulate "communities" of fauna and flora indigenous to the bay and intertidal zone. At the time of this writing (October 26, 1973), blocks have been colonized predominately by a form of green algae with a scattering of "starts" of brown algae. A few limpids are on the blocks. Since the "field" has been in place for a period of just over one month, we feel that the succession is proceeding quite well. Blocks, bearing the communities, will be selected with a two-stage process for use as experimental units in the cascading bioassay facility described below. The selection process will be roughly as follows: from the total field, the blocks will be classified based on criteria involving numbers of species, numbers of specimens and presence of certain "key" species. From the blocks so classified, a random selection will be made for communities meeting the minimal criteria. Once selected, the blocks will be exposed in a flow-through oil delivery system for periods of several months.

The initial phase of laboratory effort has been to construct a flow-through system for block exposure and to determine levels of oil and water inflow which result in lethal and nonlethal conditions for chinook salmon. A prototype of the system was constructed using Battelle internal development funds and some preliminary chemical characterization has been accomplished. The community bioassay system consists of a positive displacement pump for oil delivery, head box and dripper arm water delivery apparatus, a mixing tank provided with stirrers and skimmers, a settling tank provided with skimming baffles and three serially arranged treatment tanks. The advantage offered by the cascading design is that maximum flexibility in method of oil treatment is available. Chronic exposure to sublethal concentrations of oil for long periods of time can be readily accomplished with the equipment. Alternatively, simulated "spills" of oil can be carried out under conditions of controlled depuration. In addition, secondary treatments can be applied after initial introduction of toxicant. Community adjustments to these conditions, which approximate important "real world" conditions may be quite different in each case, and in the long run, must be independently studied. Particularly with oil, where time and physical processes may markedly affect the observed toxicity, the use of such a flexible design is compelling.

The immediate goals of the chemical characterization work are to determine the critical operating variables in the flow-through equipment which will produce desirable treatment conditions. Progress along these lines has already been made as a result of the Battelle-funded work. Stirring speed and water flow rate have been isolated as important variables as well as to metered oil inflow. In addition to determination of total oil content of treatment water by infrared spectroscopy, work continues on the development of a working definition of "soluble" oil through application of millipore pressure filtration techniques. To adequately characterize low-level chronic oil treatment regimes, development of cryogenic flame-ionization gas chromatographic techniques for analysis of trace quantities of soluble, volatile hydrocarbons in seawater are currently under development. Longer range analytical goals include studies on oil droplet size distributions, establishment of criteria for the study of "weathering" of oil, and analysis of biological tissue for evidence of chronic accumulation. Studies in these areas should greatly assist in interpretation of biological response data.

For Further Information on Chemical Analysis, Fate and Effects of Oil on Marine Coastal Ecosystems:

Bean, R. M. and J. W. Blaylock. Determination of Soluble Aromatic Hydrocarbons in Suspension of Petroleum in Seawater. See Environmental Chemistry Section, pp. 35 to 37.

## • PHYSICAL AND RADIOLOGICAL CHEMISTRY OF OCEAN SOLUTIONS

### Cobalt-60 Distribution in Sediments Along the Washington Pacific Ocean Shoreline

D. E. Robertson and W. B. Silker

During the 27 years of plutonium production reactor operations at Hanford hundreds of thousands of curies of intermediate and long-lived radionuclides have been discharged to the Pacific Ocean via the Columbia River. These radionuclides include $^{54}Mn$, $^{55}Fe$, $^{60}Co$, $^{65}Zn$, $^{90}Sr$, $^{137}Cs$, $^{152,154,155}Eu$ and traces of transuranium elements. These radionuclides entered the ocean in particulate forms associated with the suspended load of the river, and were transported along the continental shelf with the prevailing coastal sediment transport regime. Previous studies have indicated that most of these radionuclides ($^{54}Mn$ being an exception) remain rather firmly bound to the sediments during their residence in the ocean, and are very slowly leached into solution by the ambient seawater. Thus, tremendous quantities of radioactively tagged Columbia River sediments are present in the continental shelf and adjacent abyssal regions.

It is of interest to locate the eventual repositories for these radionuclides in the ocean or shoreline regions of fine sediment accumulation, so that studies of their ultimate biogeochemical fate in the marine environment can be made. Although previous studies have contributed to a better understanding of the distribution and movement of radionuclides associated with offshore continental shelf sediments, very little data are available characterizing the radionuclide distribution in shoreline sediment deposits. To evaluate the shoreline areas as possible sinks for the radioactive sediments, a surveillance of Hanford origin radionuclides along the Washington shoreline between the mouth of the Columbia River and Taholah was conducted in June 1973. This study was also of a timely nature because it provided important baseline data for the environmental radioactivity assessment of future power reactor sites near Grays Harbor and other coastal regions.

Sediment cores of 45 to 90 cm in depth were collected by hand at low tides at 20 locations along the beaches and in Baker Bay, Willapa Bay and Grays Harbor (see Figure 4.1).

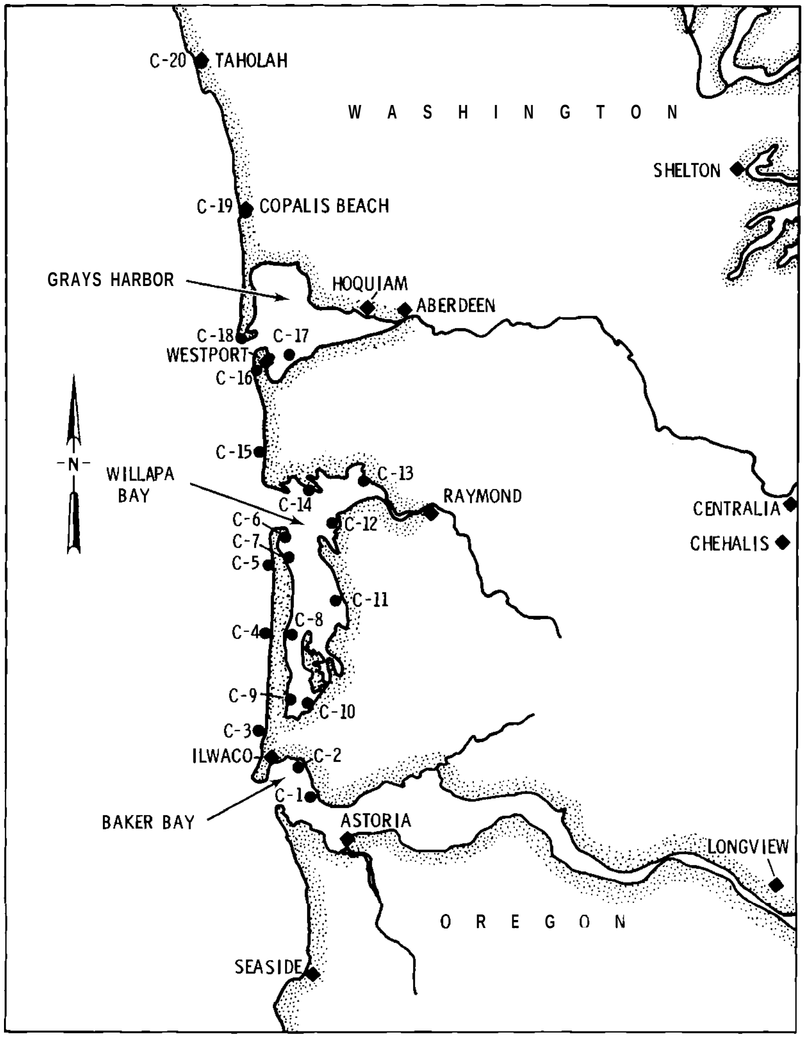


FIGURE 4.1. Sediment Cores of 45 to 90 cm in Depth at Low Tides at 20 Locations Along the Beaches and in Baker Bay, Willapa Bay and Grays Harbor

The sediment cores were frozen immediately after collection, and upon return to the laboratory the cores were sectioned, oven dried, and 200 to 600 gm aliquots were placed in the plastic Petri dishes of standardized counting geometry. The sediment samples were counted for 300 to 1000 min on highly sensitive dual coincidence gamma-ray spectrometers.

Cobalt-60 was ubiquitous in all surface sediments, and is the best indicator radionuclide for evaluating sediment transport, since it can be detected in extremely low concentrations and is almost exclusively of Columbia River origin. In Baker Bay at the mouth of the Columbia River, $^{65}Zn$, $^{137}Cs$ and $^{152-155}Eu$ were easily detectable in the sediments, and inside Willapa Bay very low concentrations of these radionuclides could be detected by counting a 1500 g sediment sample (contained in a Marinelli beaker) for 1000 min on a 17% efficient Ge(Li) diode detector.

The $^{60}Co$ distribution in sediment cores collected along the Washington Coast is shown in Table . Concentrations are highest in Baker Bay sediments; $^{60}Co$ levels were rather homogeneous in the sediments to a depth of 10 to 15 cm, but decreased to nondetectable levels at a depth of 25 to 30 cm. This would indicate that sedimentation rates are relatively slow at this location, but that the top 10 to 15 cm of sediments have become mixed by physical or biological processes. This tidal flat did contain a heavy population of the mud clam, Mya arenaria, and

TABLE 4.5. Concentrations in Sediment Cores Collected Along the Washington Pacific Ocean Shoreline

(concentrations in dpm/g dry sediment)

| C-1 | |
|---|---|
| 0 - 2.5 cm | 0.43 |
| 2.5- 5 " | 0.35 |
| 5 - 7.6 " | 0.35 |
| 7.6-10 " | 0.34 |
| 10 -12.7 " | 0.33 |
| 12.7-15 " | 0.38 |
| 15 -17.8 " | 0.22 |
| 17.8-20 " | 0.045 |
| 20 -23 " | 0.012 |
| 23 -25 " | <0.002 |

| C-2 | |
|---|---|
| 0-10 cm | 0.66 |
| 10-20 " | 0.069 |
| 20-30 " | 0.004 |
| 30-40 " | <0.002 |
| 40-50 " | <0.002 |
| 50-61 " | <0.002 |

| C-3 | |
|---|---|
| 0-10 cm | 0.028 |
| 10-20 " | 0.039 |
| 20-30 " | 0.032 |
| 30-40 " | 0.027 |

| C-4 | |
|---|---|
| 0-10 cm | 0.024 |
| 10-20 " | 0.025 |
| 20-30 " | 0.029 |
| 30-38 " | 0.023 |
| 38-46 " | 0.023 |

| C-5 | |
|---|---|
| 0-10 cm | 0.017 |
| 10-20 " | 0.030 |
| 20-30 " | 0.025 |
| 30-40 " | 0.022 |

| C-6 | |
|---|---|
| 0-2.5 cm | 0.063 |
| 2.5-5 " | |
| 5-7.6 " | |

| C-7 | |
|---|---|
| 0-5 cm | 0.025 |
| 5-7.6 " | 0.042 |
| 7.6-10" | 0.031 |
| 10-15 " | 0.034 |
| 15-20 " | 0.020 |
| 20-25 " | 0.005 |
| 25-30 " | 0.002 |
| 30-35 " | 0.002 |
| 35-40 " | <0.001 |

| C-8 | |
|---|---|
| 0-12 cm | 0.006 |
| 12-25 " | 0.004 |
| 25-38 " | <0.001 |
| 38-50 " | <0.002 |
| 50-58 " | <0.001 |
| 58-79 " | <0.001 |

| C-9 | |
|---|---|
| 0.2.5 cm | 0.21 |
| 2.5-5 " | 0.18 |
| 5-7.6 " | 0.11 |
| 7.6-10 " | |
| 10-15 " | |
| 15-20 " | |
| 20-25 " | |

| C-10 | |
|---|---|
| 0-5 cm | 0.14 |
| 5-10 " | 0.020 |
| 10-15 " | |
| 15-20 " | |
| 20-30 " | |
| 30-40 " | |

| C-11 | |
|---|---|
| 0-2.5 cm | 0.17 |
| 2.5-5 " | -- |
| 5-10 " | 0.069 |

| C-12 | |
|---|---|
| 0-5 cm | 0.037 |
| 5-10 " | 0.037 |
| 10-15 " | 0.030 |
| 15-20 " | 0.007 |
| 20-30 " | <0.002 |
| 30-40 " | <0.002 |
| 40-50 " | <0.002 |

| C-13 | |
|---|---|
| 0-2.5 cm | |
| 2.5-5 " | |
| 5-7.6 " | |

| C-14 | |
|---|---|
| 0-2.5 cm | |
| 2.5-5 " | |
| 5-7.6 " | |

| C-15 | |
|---|---|
| 0-10 cm | 0.0095 |
| 10-20 " | 0.010 |
| 20-30 " | 0.0095 |
| 30-40 " | 0.010 |

| C-16 | |
|---|---|
| 0-10 cm | 0.0091 |
| 10-20 " | 0.0076 |
| 20-30 " | 0.0087 |
| 30-40 " | 0.0055 |

| C-17 | |
|---|---|
| 0-2.5 cm | |
| 2.5-5 " | |
| 5-7.5 " | |

| C-18 | |
|---|---|
| 0-10 cm | 0.012 |
| 10-20 " | 0.0084 |
| 20-30 " | 0.0090 |
| 30-38 " | 0.0096 |

| C-19 | |
|---|---|
| 0-10 cm | 0.0076 |
| 10-20 " | 0.0082 |
| 20-30 " | 0.0084 |
| 30-40 " | 0.0079 |

| C-20 | |
|---|---|
| 0-10 cm | 0.0057 |
| 10-20 " | 0.0062 |
| 20-30 " | 0.0038 |
| 30-43 " | 0.0041 |

about 1 kg of clams was collected for radionuclide analysis.

The $^{60}Co$ distribution on the seaward sandy coastline beaches gradually decreased going northward from Seaview (Sta. C-3) to Taholah (Sta. C-20), a distance of approximately 125 km; $^{60}Co$ concentrations were about 5-fold higher at Seaview than at Taholah. The sand on the shoreline beaches is predominantly derived from the Columbia River. The $^{60}Co$ was rather homogeneously distributed through the top 46 cm of sand, as would be expected since surf action can mix the sand to depths of several meters during storms. If we assume that the beach sand became tagged with $^{60}Co$ during its transit through the lower Columbia River, that the $^{60}Co$ remains associated with the sand during its residence on the beaches, and that the $^{60}Co$ transport from Hanford was reasonably constant between about 1955 to 1970 (the period when the majority of the reactors were in operation), we can estimate the northward movement of the beach sands from the Columbia River estuary to Taholah. Based on the decay of $^{60}Co$, the beach sands took approximately 14 years to move from Seaview (Sta. C-3) to Tahola (Sta. C-20), giving a northward transport rate of approximately 9 km per year. This is a reasonable value compared to previous estimates of sediment transport along the shelf.

Within Willapa Bay the $^{60}Co$ concentrations were relatively low, with the highest concentrations found in sediments at the extreme south end of the bay (Sta. C-9). The sediments at Sta. C-9 were extremely fine, compared to the more sandy areas in the central and northern regions of Willapa Bay, and their relatively high $^{60}Co$ contents indicates that this is an area of fine sediment accumulation in the bay. Tidal action within Willapa Bay is very intense and the accumulation of fine sediments appears to be restricted to the south end of the bay.

Since substantial concentrations of $^{65}Zn$ have been reported in oysters from Willapa Bay, it was surprising to find such low radionuclide concentrations in the sediments. The $^{65}Zn$ concentration in Willapa Bay sediments near Sta. C-6 in June 1973 was approximately 0.02 D/M/gm dry sediment. In the early 1960's Willapa Bay oysters contained about 100 to 300 D/M $^{65}Zn$/gm wet weight, and in June 1973 contained about 1 D/M $^{65}Zn$/gm wet weight. It appears that the oysters efficiently filtered out the plankton and fine detrital matter, which contained $^{65}Zn$, as this material was flushed in and out of the bay by the tides. These fine particulates apparently were never accumulated in the bay sediments, except possihly in the southern end of the bay, which is not an oyster growing region. Oysters were collected from various locations within Willapa Bay for radionuclide analysis. Zinc-65 is still, by far, the most predominant radionuclide in the oysters, but $^{54}Mn$ and $^{137}Cs$ could also be detected in extremely low concentrations.

During the years of reactor operations it is estimated that approximately 5,000 Ci of $^{60}Co$ have been discharged to the Pacific Ocean from the Columbia River, of which about 2,000 Ci presently remain after radioactive decay. If we assume that the Washington shoreline sandy beaches are 100 km long by 1 km wide by 2 m deep and that the average $^{60}Co$ concentration in the beach sands between Stations C-3 and C-20 is 0.02 D/M/gm, we can account for approximately 40 Ci of $^{60}Co$ presently dispersed along the Washington beaches. This would account for roughly 2% of the total $^{60}Co$ presently in the Pacific Ocean from Columbia River origin. Willapa Bay, with an area of approximately 158 $km^2$ at mean lower low water and an estimated average $^{60}Co$ concentration in the sediments of 0.03 D/M/gm extending to a depth of 10 cm, presently contains about 4 Ci of $^{60}Co$ dispersed in its sediments or about 0.2% of the present estimated inventory.

It is obvious that the majority of the sediment-associated radionuclides are located somewhere along the continental shelf or adjacent abyssal regions. It is postulated that the finer continental shelf sediments off Washington (which contain the highest concentrations of radionuclides) are being transported northward and eventually slump down the Quinault Canyon, the bottom of which may be an important sink for the radioactive sediments.

## Temporal Variations of Oceanic Fallout

W. B. Silker

Several opportunities arose during 1973 to measure the temporal variations of the concentration of $^{7}Be$ in surface waters of the world's oceans. The NOAA Ship Researcher occupied essentially the same position (29°N, 70°W) on the Atlantic Ocean from mid-March until mid-July. The initial average $^{7}Be$ concentration averaged 220 dpm/$M^3$, then increased to 530 dpm/$M^3$ by early June, and further rose to 730 dpm/$M^3$ by mid-July. On another track along 35°N between 50°W and 70°W, $^{7}Be$ concentrations increased from 190 dpm/$M^3$ in mid-April to 310 dpm/$M^3$ in late May. These increases are greater than would be predicted from air-to-sea transfer based on air concentrations measured at Richland, Washington or the 80th meridian stations. Part of this increase could reflect advection of surface water from an area of higher fallout to the point of measurement or reflect precipitation and wind changes which relate to the magnitude and rate of transfer of the atmospheric aerosol across the air-sea interface.

Some evidence has now been accumulated which suggests that the Atlantic Ocean receives more $^{7}Be$ at a given latitude than the Pacific. For example, during April in the open ocean at 40°N, the concentration in the Atlantic was 350 dpm/$M^3$ while that in the Pacific was 200 dpm/$M^3$ of $^{7}Be$. A similar difference in concentrations was found in 1970 at the pre-GEOSECS station in the Atlantic and at stations off the Pacific Coast.

## Latitudinal Variations in Surface Water Concentrations of $^{7}Be$ in the Eastern Pacific Ocean

W. B. Silker

Past observations have shown a region of high concentrations of $^{7}Be$ in surface waters of the eastern Pacific Ocean at 8 to 10°N latitude. During 1973 samples were collected along three additional tracks through the region of interest in February, March and June

The February and June legs were traversed along 110°W longitude, and in both instances minimum surface concentrations occurred at 8°S, with maxima observed at 8°N in February and 5°N in June. The maximum $^7$Be concentration in February was 10-fold greater than the 8°S minimum, and this difference increased to 20-fold by June. Samples taken during March along a track at 95°W longitude revealed the minimum concentration occurring at the equator. At the same time the northern hemisphere maximum was sharply centered at 4 to 5°N and was 10 times higher than the equatorial concentration. Another maximum was detected in the southern hemisphere at 4°S; although it was of lower amplitude it was readily discernible. These double maxima may have arisen from double intertropical convergence zones, which have been observed to flank the equator in limited regions of the tropical belt.

These observations confirm that the belt of high fallout at 5° to 10°N latitude is a permanent feature and that some seasonal geographical variations occur in both location and magnitude of air-to-sea transfer processes.

## Latitudinal Variation of $^7$Be in the South Pacific Ocean

W. B. Silker

Results from analysis of samples collected during three east-west transects in the eastern South Pacific Ocean are shown in Figure 4.2. Included are results obtained during the same time of year in 1971 when some of the same areas were sampled. The striking agreement of the concentrations measured 2 years apart again confirms the year-to-year constancy of oceanic $^7$Be deposition at a given location.

The $^7$Be concentrations along the open ocean portions of the tracks at 15°S and 22°S latitude were quite uniform, but decreased significantly at the near shore stations due to either strong coastal upwelling or the influence of the Peru current.

The track along 30°S provided the opportunity to examine, in detail, the influence of the cold Peru current on oceanic fallout. The $^7$Be concentrations decrease regularly as

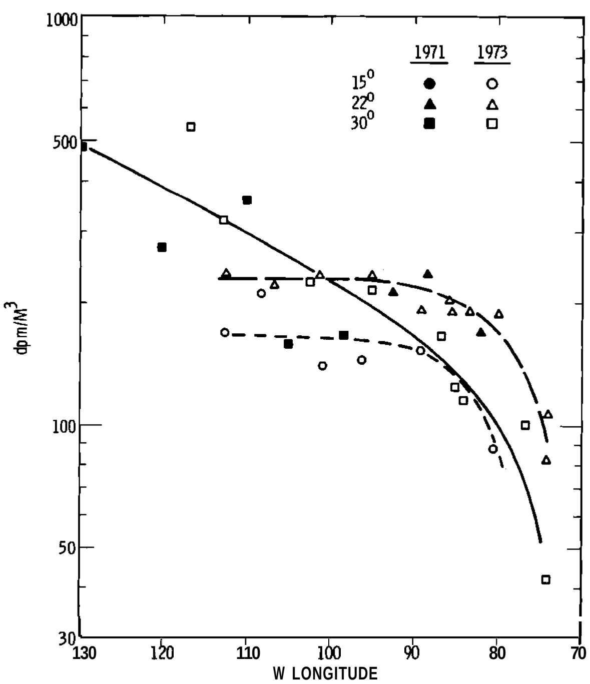


FIGURE 4.2. $^7$Be in South Pacific Ocean

one progresses from 130°W, the westernmost boundary of the current, to the South American coast. The surface concentrations of $^{7}Be$ in the ocean is believed to reflect precipitation scavenging of the atmospheric aerosol, hence the decrease of $^{7}Be$ across the 30°S track would indicate a corresponding decrease in rainfall. Indeed within the region of the Peru current conditions of very low rainfall have been reported, and from these data for $^{7}Be$ concentrations the magnitude of the difference of rainfall between 130°W and the South American coast appears to be at least a factor of 10.

## Measurements of Plutonium in Seawater

W. B. Silker

Analytical efforts in the oceanographic field have been extended to include measurement of plutonium isotopes concentrated by the aluminum oxide and filters employed in field sampling. Plutonium is removed from the sample by acid leach, isolated and purified by standard ion exchange techniques, electrodeposited and measured by alpha spectrometry. Yields, as measured by recovery of added $^{236}Pu$ tracer, are somewhat variable, but generally range from 60 to 80%. A zero blank was measured on the filters and the alumina for $^{238}Pu$ and on the alumina for $^{239}Pu$. A blank value of 0.002 dpm $^{239}Pu$ per filter was found.

Data resulting from plutonium analysis of library samples that had been previously analyzed for cosmogenic and fission product radionuclide concentrations are given in the accompanying table. Soluble $^{239}Pu$ concentrations in the Sargasso Sea at 36°N and 68°W ranged from 0.69 to 0.89 dpm/$M^3$ in the mixed surface layer and decreased within the thermocline to 0.50 dpm/$M^3$ at a depth of 100 m. A much lower $^{239}Pu$ concentration (0.05 dpm/$M^3$) was found in a surface water sample collected near LiJi Island in the South Pacific Ocean. Approximately one-third of both the $^{238}Pu$ and $^{239}Pu$ in this sample was found in the filterable fraction.

The plutonium concentrations in the Atlantic Ocean are consistent with those of other investigators. The $^{238/239}Pu$ ratio at the 0, 15 and 30 m depths agree with reported northern hemispheric ratios. Relatively less $^{238}Pu$ existed at 75 and 100 m levels which were within the thermocline. These smaller ratios suggest that the plutonium at these levels was injected prior to the interhemispheric transfer to the northern latitudes of $^{238}Pu$ from the failure of the SNAP-9A device in 1964. Although the $^{238/239}Pu$ ratio in the samples from the Southern hemisphere was of the predicted magnitude, the measured concentrations, while lower than might have been expected, probably reflect the sampling position which is located in a previously identified zone of relatively low fallout (see Table 4.6).

TABLE 4.6. Plutonium Concentrations in Ocean Water

| | Sample Location | | Depth | Tracer | dpm $^{238}Pu$ / $M^3$ | dpm $^{239}Pu$ / $M^3$ | $238/239_{Pu}$ |
|---|---|---|---|---|---|---|---|
| | Lat. | Long. | M | Yield % | | | |
| $Al_2O_3$ | 36°N | 68°W | 0 | 66.0 | 0.118 | 0.688 | 0.17 |
| $Al_2O_3$ | | | 15 | 73.8 | 0.081 | 0.706 | 0.11 |
| $Al_2O_3$ | | | 30 | 59.4 | 0.123 | 0.889 | 0.14 |
| $Al_2O_3$ | | | 75 | 26.6 | 0.041 | 0.654 | 0.06 |
| $Al_2O_3$ | | | 100 | 100.4 | 0.022 | 0.497 | 0.04 |
| $Al_2O_3$ | 22°S | 179°W | 0 | 57.4 | 0.013 | 0.036 | 0.36 |
| Filter | | | 0 | 47.1 | 0.005 | 0.015 | 0.33 |

## Elevated Heavy Metal Concentrations in Antarctic Seals and Penguins

D. E. Robertson, L. A. Rancitelli, R. W. Perkins and A. W. Erickson

A study of 16 trace elements in Antarctic seal and penguin liver tissues indicates very high concentrations of mercury, cadmium and selenium. The mercury and cadmium concentrations in these animals are comparable to the high levels of these elements reported in northern hemisphere seals. Our highest observed total mercury concentration, 120 ppm, in liver tissue from a male leopard seal is as great, or greater than that observed in humans who died from chronic exposures. The heavy metal content of these animals is apparently related to their diets and to unusual physiological accumulation and retention characteristics of these metals in the seals and penguins. The selenium concentrations were found to be linearly related to the mercury plus cadmium levels in the liver, and selenium may thus serve as both an accumulation accelerator and detoxifying agent for heavy metals.

## • GEOCHEMICAL OCEAN STUDY SECTION

### Mercury Distribution in the Western Atlantic Ocean Based on Analyses of GEOSECS Seawater Samples

D. E. Robertson

Tremendous quantities of mercury are being mobilized into the environment by man's activities. The oceans represent an important sink for this toxic heavy metal, and since Hg is so readily assimilated by the marine food chain, it is imperative that we understand the biogeochemistry of mercury in the marine environment. A first step in this understanding is a knowledge of the geographical and vertical distribution of mercury in the oceans. These data help to elucidate the natural variations of Hg in the oceans and thus permit a more intelligent assessment of the potential Hg contamination of the marine environment.

Seawater samples from 22 Atlantic Ocean GEOSECS stations have been analyzed for Hg by the highly sensitive cold-vapor atomic absorption technique described in this section of the annual report. Over 1000 seawater samples, blanks and standards have been analyzed to provide the data to characterize the distribution of Hg in the western side of the North and South Atlantic oceans from the Greenland Sea to the Antartic Ocean. The GEOSECS seawater samples were acidified to pH 1.5 with high purity HCl and are stored in polyethylene bottles. The sample storage was shown to result in some Hg leaching from the polyethylene bottles, which contributed to the uncertainty of the data; however, the systematic large-scale variations in the Hg distribution in the Atlantic Ocean are certainly apparent. The Hg distribution in four of the GEOSECS station is shown in the accompanying table, which illustrated the extremes in the concentration variations which exist. The Hg distribution in the western basin of the Atlantic Ocean is characterized by extremely low concentrations (2 to 40 nanograms Hg/liter) in much of the ocean between about 15°N to 35°S. A large core of water of relatively high Hg concentrations (80 to 400 nanograms Hg/liter) exists between about 25°N to 50°N.

The source of the high Hg levels in this region is not known. From hydrographic data it appears Mediterranean Water at these latitudes is flowing over the mid-Atlantic ridge into the western basin of the Atlantic Ocean. If Hg is diffusing from the active spreading centers on the active spreading centers on the mid-Atlantic ridge, the overlying water flowing over the ridge could contain relatively high Hg levels, which would spread into the western basin where the highest Hg levels have been observed. Also going northward into the Greenland Sea the Hg concentrations in the Western Atlantic Ocean tend to decrease which would be expected from the above diffusion-mixing model for Hg (see Table 4.7).

TABLE 4.7. Mercury Distribution in Four Atlantic Ocean Geosecs Stations (Hg concentrations are in nanograms/liter)

| Station 3 51°01'N 43°01'W | | Station 27 42°00'N 41°59'W | | Station 58 27°00'S 37°01'W | | Station 76 57°44'S 66°03'W | |
|---|---|---|---|---|---|---|---|
| Depth (m) | Hg | Depth (m) | Hg | Depth (m) | Hg | Depth (m) | Hg |
| 19 | 105 | 7 | 86 | 13 | 12 | 13 | 15 |
| 28 | 107 | 27 | 147 | 58 | 13 | 27 | 9 |
| 59 | 118 | 72 | 150 | 86 | 13 | 53 | 16 |
| 105 | 102 | 102 | 172 | 118 | 3 | 73 | 61 |
| 136 | 137 | 141 | 202 | 158 | 7 | 94 | 39 |
| 182 | 99 | 181 | 108 | 197 | 3 | 119 | 49 |
| 232 | 126 | 252 | 154 | 237 | 12 | 144 | 17 |
| 274 | 100 | 319 | 114 | 278 | 5 | 159 | 45 |
| 329 | 137 | 390 | 53 | 323 | 2 | 186 | 25 |
| 377 | 122 | 461 | 76 | 377 | 2 | 235 | 37 |
| 441 | 109 | 530 | 71 | 426 | 4 | 284 | 37 |
| 464 | 137 | 599 | 62 | 466 | 8 | 385 | 36 |
| 575 | 106 | 672 | 55 | 527 | 3 | 496 | 22 |
| 577 | 103 | 738 | 49 | 595 | 4 | 597 | 10 |
| 636 | 126 | 770 | 80 | 667 | 5 | 695 | 25 |
| 813 | 128 | 801 | 66 | 735 | 10 | 797 | 23 |
| 959 | 108 | 831 | 52 | 805 | 5 | 899 | 35 |
| 1083 | 109 | 879 | 99 | 874 | 9 | 988 | 25 |
| 1177 | 108 | 932 | 62 | 945 | 4 | 998 | 48 |
| 1376 | 116 | 1000 | 68 | 1015 | 9 | 1047 | 36 |
| 1575 | 124 | 1150 | 51 | 1085 | 12 | 1097 | 39 |
| 1725 | 114 | 1242 | 90 | 1153 | 10 | 1110 | 15 |
| 1920 | 109 | 1268 | 72 | 1188 | 19 | 1145 | 61 |
| 2160 | 80 | 1441 | 218 | 1336 | 10 | 1198 | 52 |
| 2356 | 79 | 1640 | 258 | 1461 | 12 | 1238 | 31 |
| 2595 | 98 | 1832 | 232 | 1632 | 10 | 1375 | 9 |
| 2890 | 109 | 2029 | 290 | 1786 | 17 | 1530 | 77 |
| 3089 | 165 | 2231 | 380 | 1934 | 9 | 1697 | 9 |
| 3368 | 101 | 2435 | 1370 | 2085 | 8 | 1704 | 20 |
| 3630 | 112 | 2630 | 160 | 2235 | 9 | 1830 | 21 |
| 3896 | 106 | 2836 | 117 | 2389 | 31 | 1968 | 9 |
| 4049 | 126 | 3038 | 320 | 2561 | 7 | 2118 | 26 |
| 4150 | 110 | 3239 | 94 | 2736 | 9 | 2373 | 34 |
| | | 3442 | 268 | 2912 | 14 | 2588 | 26 |
| | | 3655 | 50 | 3097 | 36 | 2799 | 30 |
| | | 3855 | 64 | 3273 | 10 | 2969 | 61 |
| | | 4056 | 54 | 3445 | 32 | 3167 | 37 |
| | | 4257 | 58 | 3619 | 8 | 3365 | 33 |
| | | 4388 | 36 | 3798 | 6 | 3562 | 50 |
| | | 4486 | 40 | 3943 | 10 | 3758 | 47 |
| | | 4577 | 28 | 4097 | 13 | 3975 | 62 |
| | | 4678 | 40 | 4248 | 27 | 4179 | 50 |
| | | 4767 | 56 | 4422 | 13 | 4311 | 42 |
| | | 4858 | 54 | 4578 | 12 | 4486 | 44 |

## Trace Element Distribution in the Western Atlantic Ocean by Neutron Activation Analysis of GEOSECS Seawater

D. E. Robertson

The Geochemical Ocean Section Study (GEOSECS) is a multi-institutional program to investigate the geochemical properties of the oceans with the aim of utilizing these constituents to characterize the biogeochemical and physicodynamic processes occurring in the oceans. Unlike the major components of seawater which behave conservatively in the oceans, trace elements vary markedly, both geographically and vertically, because input and removal processes affect a large fraction of the trace elements present. Elucidation of the marine geochemical processes associated with these elements depends upon precise and accurate measurements of the small concentrations in seawater.

Reliable data for the oceanic distribution and behavior of the trace elements must be available in order to understand and predict the fate of radionuclides and heavy metal pollutants which enter the oceans. Surprisingly few usable data are available to model the trace element biogeochemistry of the oceans.

Our laboratory is helping to develop the necessary data for us to characterize the oceanic distribution and the input and removal processes of the oceans' trace elements, by measuring their concentrations in GEOSECS seawater samples. Instrumental neutron activation analysis (INAA) is being employed for the measurement of Zn, Co, Fe, Sb, Sc, U, Cs and Rb. Radiochemical neutron activation analysis is used for measuring As, Ag, Cr, Se and Mn. (Hg and Cd are being measured by atomic absorption techniques.)

The INAA trace element measurements have been completed in detailed depth profiles at four of the most northerly Atlantic Ocean GEOSECS stations. These four profiles located in the Denmark Straits, Greenland Sea and the Norwegian Sea, are most important because in these regions the distinct southward flowing intermediate water masses in the North Atlantic Ocean are formed. Large variations in Zn, Co and Fe concentrations with depth were observed at these stations, but these initial data alone do not allow construction of their general, oceanic distribution. One important finding was that the Co concentrations are at least 10 times lower than previous studies had indicated. We are presently working on a series of depth profiles ranging from the mid-latitudes, through the equatorial areas into southern ocean stations.

Arsenic has been determined at five stations between the Greenland Sea and the Southern Ocean. Contrary to previously reported values, the As concentrations in the western Atlantic Ocean do not show large variations, but are rather constant at about 1.6 μg/liter.

Methods have been developed for the measurement of Ag and Mn, and analyses for these elements at selected stations have been started.

Analytical techniques for the determination of Cr and Se in GEOSECS seawater are presently being developed and will soon be used on seawater samples from selected GEOSECS stations.

## $^{7}Be$ and Fallout Radionuclide Measurements During the Pacific Ocean GEOSECS Expedition

W. B. Silker

During the GEOSECS experiment in the Pacific Ocean, water is being processed from both the surface and at depth to measure both the horizontal and vertical distribution of $^{7}Be$ and other radionuclides. In addition, an air sampler is collecting the marine aerosol and the associated radionuclides from large volumes of air at each primary sampling station.

Measurements of the concentration gradient of $^{7}Be$ within the thermocline will allow accurate measurement of the rates of vertical eddy diffusion within this regime. Determination of the total inventory of $^{7}Be$ within the water columns by integration of the depth distribution curves will provide a measure of the steady-state input across the air-sea interface. This value, when compared with the air concentration of $^{7}Be$ will allow calculation of the air-to-sea transfer coefficient, which will also be applicable to other materials associated with the marine aerosol.

## PUBLICATIONS AND PRESENTATIONS

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# RADIOLOGICAL SCIENCES

- RADIOLOGICAL-HEALTH RESEARCH
- RADIOANALYTICAL PROCEDURES DEVELOPMENT
- FATE AND EFFECTS OF RADIONUCLIDES IN ALASKA

## RADIOLOGICAL-HEALTH RESEARCH

*This project involves a continuation of the environmental study to measure the decline of radioactivity in various population groups and to reduce, compute, analyze and report the environmental information from these new studies.*

### Mechanisms of Environmental Exposure

G. W. R. Endres

Since the shutdown of the plutonium production reactors in January of 1971, the only radioisotope associated with the operation of the Hanford plant which can now be detected in environmental residents is $^{65}Zn$. As a consequence, studies on the mechanisms of environmental exposure have centered around measurements of this nuclide in people and have emphasized in particular the determination of improved values for parameters relating to human uptake and retention of $^{65}Zn$. Several whole body counter examinations were conducted on and data were obtained on several hundred local students who had been similarly examined during May 1971, March 1972, May 1972, December 1972 and spring 1973.

The measurements in the spring of 1973 concentrated on recounting a group of students all of whom were counted during all the previous examinations. There are about 60 such students. Body burdens of $^{65}Zn$ in these subjects are now down to the analytical detection limit of the whole-body counter as determined for a 10 minute measurement time. This limit is approximately 1.0 nCi. Final analysis of the most recent data will be completed after finishing a new calibration of the whole-body counter.

Previous measurements have shown a positive correlation between transport rate of $^{65}Zn$ in the Columbia River and $^{65}Zn$ body burdens in the local school children. These results were given in the annual report for 1972, (J. M. Nielson et al). The average $^{65}Zn$ body burdens varied between 0.8 nCi and 1.9 nCi for the

1972 studies when the transport rate for $^{65}Zn$ in the river was approximately four times the transport rate for the same time period in 1973. The spring run off in the Columbia was the lowest in many years in 1973; this condition undoubtedly further reduced the $^{65}Zn$ source term.

This study will be completed in FY 74 after a new set of calibrations of the measurement system have been made. New calibrations were completed for $^{65}Zn$, $^{137}Cs$ and $^{40}K$ using a plastic phantom and extending body size and weight to that of an adult, since many of the school children are now in high school and near adult in size. New calibrations will be obtained for $^{24}Na$ which was present during measurements conducted when the old Hanford production reactors were operating. The final report on this study will include analysis of all data taken in previous years back to 1967 using an improved computer program and the more realistic calibration data.

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# IRON-55 IN HUMAN POPULATIONS OF THE WORLD

*Marine organisms have been shown to have up to 1000-fold higher specific activities of iron-55 than that in seawater. It was also shown that iron-55 specific activities increase 10 to 30-fold in salmon between mid and northern altitudes. These observations are currently explained on the basis of a different chemical form for fresh iron-55 in seawater and greater dilution of the iron-55 by stable iron at the mid-latitudes than at the northern latitudes. The half-time for iron-55 concentrations in mature harvested salmon at all Latitudes is approximately 10 months, which is comparable to the half-time for the movement of stratospheric debris to the earth's surface.*

## $^{55}Fe$ Concentration and Specific Activities in North Pacific Marine Organisms

C. E. Jenkins and J. C. Langford

The $^{55}Fe$ from nuclear weapons testing which enters the ocean is in a chemical form which is much more readily available for biological uptake than is stable oceanic iron. This property of $^{55}Fe$ results in up to 1000-fold higher $^{55}Fe$ specific activities in marine organisms than is present in seawater. Dilution of $^{55}Fe$ by stable iron from anthropogenic sources or natural sources appears to be responsible for the lower specific activity in mid-latitude marine organisms than in organisms from high latitudes. The half-time for $^{55}Fe$ in harvested salmon from the west coast is essentially the same as the half-residence time for stratospheric radioactive debris. This fact suggests that $^{55}Fe$ reaching the ocean surface is available for biological uptake for a relatively short time. Measurements of $^{55}Fe$ specific activity in the various trophic levels of marine organisms do not give a clear picture of the reason for the much higher $^{55}Fe$ specific activities in certain crustacea and predacious fish than in the phytoplankton. A more detailed food web and chemical form study is recommended to elucidate this apparent anomaly. What we have learned about the behavior of the radionuclide $^{55}Fe$ in the ocean environment may well apply to other fallout radionuclides, and a consideration of this fact should be included in estimating the potential hazard of the release of radionuclides to the marine environment. For example, these data suggest that the release of radioiron from a reactor to the oceans at northern latitudes may have a 10 to 30-fold greater impact than releases of radioiron at mid-latitudes, and this may be true for other radionuclides (Figure 5.1, 5.2).

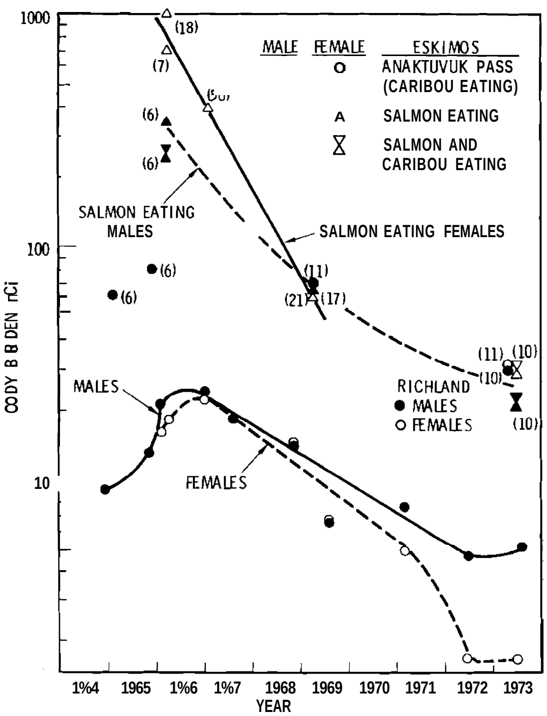


FIGURE 5.1. Total Body $^{55}Fe$ Burden in Adults Alaskan Eskimos and Richland, Washington Residents

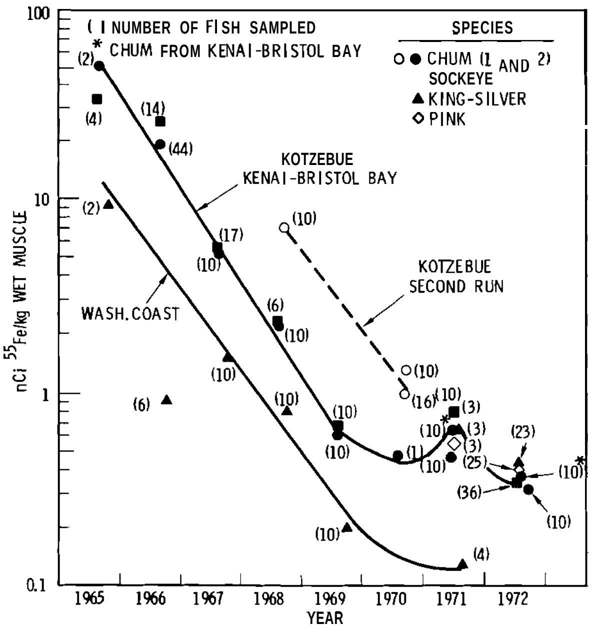


FIGURE 5.2. $^{55}Fe$ Concentrations in Pacific Salmon

## • RADIOANALYTICAL PROCEDURES DEVELOPMENT

*Developments in the past few years have radically changed the requirements of radiochemical separations in radionuclide analyses. Advances in gamma-ray spectrometry, particularly those using multidimensional and solid state Ge(Li) detectors as well as X-ray fluorescence spectrometry have provided selective and sensitive instruments for analysis and have substantially modified the requirements of radiochemical procedures. There is at present an urgent need for procedures which quantitatively separate a radionuclide mixture obtained from natural systems or from one created in the course of elemental analyses such as with neutron activation. The developing techniques are those which divide the mixture into two or three groups or which quantitatively remove an interfering constituent so that the resulting group(s) can be quantitatively measured by instrumental techniques.*

*Procedures have also been developed to measure specific elements such as Hg found to coexist with certain trace radioactive or stable constituents of environmental samples.*

### Determination of Iodine-129 and Iodine-131 in Milk Samples at Sub Picocurie Levels

C. W. Thomas

With the greatly expanding use of nuclear power and the AEC policy that all releases to the environment will be as low as practicable, it has been necessary to review the analytical procedures for radioiodine. There is particular concern for radioiodine in milk, since the air-grass-cow-milk-man pathway is the main route by which man may receive a radiation exposure. Studies have shown that when various forms of radioiodine are fed to cows, that essentially all of this iodine is present as the iodide in milk. Further, these studies indicate that a very small fraction of the radioiodine is bound to organic material and that 97% of the iodine, regardless of its form at the time of ingestion, could be absorbed by anion exchange resin. The following procedure makes use of ion exchange as a vital step in removing iodine from milk and also describes the use of a preservative which allows milk samples to be processed several days after collection, if necessary.

Four liters of milk are collected and preserved by adding 80 ml of formaldehyde solution containing a known amount of iodide carrier and sodium bisulfite. The milk may be passed through a 5 cm high by 2 cm diameter column of Dowex 1 × 8, 50-100 mesh at a flow rate of about 30 ml per minute, or an alternate procedure consists of vigorously stirring a 50 ml water slurry of Dowex 1 × 8, 50-100 mesh with the milk sample for 20 min with a large magnetic stirring bar and decanting the milk after the resin has settled. The resin from either procedure is then washed with water. The iodide is desorbed from the resin as the iodate using a batch procedure with sodium hypochlorite solution. After acidification of the hypochlorite solution, the iodate is first reduced to free iodine by adding hydroxylamine hydrochloride; the iodine is extracted into carbon tetrachloride and then back-extracted into sodium bisulfite solution as iodide. Finally, the radioiodide and carrier are precipitated as palladous iodide which is collected on a preweighed glass fiber filter and dried to a constant weight. The chemical yield is calculated. The $^{131}I$ is determined by a low background beta count and confirmed by following the 8 day half-life. The $^{129}I$ X-rays are measured on the same sample by counting it between two thin sodium iodide crystals after decay of any $^{131}I$ The overall yield for the batch method was 75.4 ± 3.5% and for the column method the yield was 82.1 ± 2.4%. Although the column method was more efficient, it required a longer analysis time, 130 min, compared to a 70-min period for the batch methods.

Using 4 liters of milk samples, $^{131}I$ and $^{129}I$ concentrations of 0.2 pCi/liter were easily measured with a standard deviation of better than ±10%. While detection limits reported as the 30 value of the background do not represent a concentration that can be reliably measured, these limits are commonly used and are therefore considered here. Using the 30 value, the detection limits for $^{129}I$ and $^{131}I$ by this procedure are 0.03 and 0.34 pCi/liter, respectively.

## Magnetic Studies of Centralia Flyash

L. A. Rancitelli and K. H. Abel

The Centralia coals average about 12% ash by weight and at peak capacity the coal burnup rate for the Centralia facility is 960 tons/hr. Therefore 115 tons of ash are being produced (greater than 99% as flyash) and even if the electrostatic precipitators were operating at 99% efficiency this would be a flyash release of over 1 ton/hr.

With the release of such large quantities of flyash to the environment, it is necessary to characterize the physical and chemical properties of the flyash in order to evaluate its environmental significance. One part of this characterization included a magnetic separation and elemental analysis of the original, magnetic and non-magnetic fraction of the flyash. The results of the elemental analysis shown in the accompanying table indicate that a very significant fraction of the transition metals, as typified by Co and

Fe, are separable by this simple procedure. It would also appear from a comparison of the composition of the original and non-magnetic fractions that the magnetic portion of the flyash constitutes only a minor percentage, perhaps 1%.

However, the presence of discrete particles very high in transition metals may pose a threat of environmental contamination especially if these particles are in the respirable range and/or the metals are in or readily converted to a form making them available for environmental interaction (Table 5.1).

TABLE 5.1. Chemical Composition Versus Magnetic Properties of Centralia Precipitator Flyash (ppm except as noted)

| | Original | Magnetic Fraction | Non-Magnetic Fraction |
|---|---|---|---|
| Al(%) | 11.3 | --- | --- |
| As | 5.7 | 8.6 | 7.5 |
| Ba | 1790 | 930 | 1380 |
| Br | 0.66 | 7.9 | 7.3 |
| Cl(%) | <0.1 | --- | --- |
| Co | 26 | 105 | 24 |
| Cr | 69 | 158 | 68 |
| Cs | 2.6 | --- | 2.2 |
| Cu(%) | <0.04 | --- | --- |
| Eu | 3.4 | 7.0 | 3.4 |
| Fe(%) | 3.53 | 45.0 | 3.12 |
| Hf | 25 | 9.4 | 24 |
| La | 86 | 54 | 84 |
| Mg(%) | 1.4 | --- | --- |
| Mn | 570 | --- | --- |
| Na(%) | 1.0 (0.90) | 0.38 | 1.02 |
| Sb | 1.8 | 5.3 | 1.7 |
| Sc | 1.1 | 0.71 | 1.0 |
| Se | 7.2 | 5.4 | 7.1 |
| Sm | 14 | 8.9 | 14 |
| Sr | 3280 | 1670 | 3170 |
| Ta | 8.6 | 5.5 | 8.4 |
| Tb | 3.0 | 2.0 | 2.9 |
| Th | 15 | 7.5 | 14 |
| Ti(%) | 1.7 | --- | --- |
| V | 316 | --- | --- |
| Yb | 12 | 8.7 | 13 |

## Determination of Cadmium in Seawater

J. C. Langford and D. E. Robertson

Cadmium is a heavy metal of considerable interest because of it's potential as a toxic environmental pollutant. Cadmium is a rather volatile element and is released to the environment from ore smelting, fossil fuel burning and in other industrial effluents. Cadmium is of special concern in the marine environment because of its very high concentrations in certain marine organisms, notably shellfish, sea otters, seals and penguins. In order to better understand the marine biogeochemistry of Cd, it is necessary to know its concentrations and its geographical and vertical variations in the oceans. Because of the very low concentrations of Cd in seawater (0.01 to 0.1 μg/liter), previous analytical methods have not possessed adequate sensitivity without preconcentration of Cd from large volumes of seawater. A rapid and simple method of measuring Cd in small volumes of seawater is thus needed, and we have developed a procedure meeting these requirements. This procedure is based on a solvent extraction and atomic absorption analysis utilizing a Perkin-Elmer heated graphite atomizer.

Cadmium is extracted nearly quantitatively from 100 ml of seawater with 10 ml of 1% diethylammonium diethyldithiocarbamate in $CCl_4$. After backextraction into 1 ml of 3N HCl, the backextractant is slowly taken to dryness in a 1.5 ml centrifuge cone. The residue is taken up in 200λ of 1N HCl, and 50λ injections are used for analysis in the atomic absorption graphite furnace. The complete procedure has a yield of 93 + 5% as determined using a $^{115}Cd$ tracer. A reagent and equipment blank of less than 0.01 ng of Cd is achieved, and a linear calibration curve is obtained from 0 to at least 1.5 ng of Cd. The detection limit of the method is about 0.4 ng Cd/liter of seawater. This method will be used to measure Cd in GEOSECS seawater samples and in other environmental oceanographic studies at our laboratory.

## Ultra-Sensitive Method for the Measurement of Mercury in Seawater and Freshwater

D. E. Robertson

The current widespread interest in Hg in the environment stems from the ability of this toxic trace element to enter and accumulate in food chains which eventually involve humans. During the past several years a great deal of information has been generated elucidating the role of Hg in biological systems, but most available methods of analysis have lacked the sensitivity to rapidly and accurately measure low levels of Hg in the hydrosphere. Reliable data on the Hg distribution in the oceans and in rivers and lakes are badly needed to evaluate the natural geographical variations which exist and to assess the anthropogenic contamination of these waters.

To help provide this important information, we have developed the capability of rapidly measuring extremely low concentrations of Hg in small volumes of seawater and fresh waters. The method is based on the cold vapor, UV absorptiometric detection of vaporized elemental Hg. The high sensitivity is achieved by sweeping the Hg vapor through the long dual-beam absorption cells of a Laboratory Data Control Mercury Analyzer.

The method consists of adding 100 ml of seawater or freshwater to a carefully precleaned 250 ml Pyrex glass T/S flask and oxidizing the sample with 2.5 ml of concentrated $HNO_3$, 2.0 ml of 5% $KMnO_4$ and 2.0 ml of 5% $K_2S_2O_8$ at 80°C for 2 hr in a hot water bath. The samples are cooled to room temperature and 1 ml of 12% $NH_2OH \cdot HCl$ is added to reduce the excess $KMnO_4$ and the $MnO_2$ which is formed. The flask is then purged with air to remove any $Cl_2$ gas which interferes with the Hg measurement. Ten ml of 10% $SnCl_2$ is added, the flask is quickly stoppered, and after a 90-sec waiting period the reduced, vaporized elemental Hg is swept from the flask in a stream of $N_2$ gas into the absorption cell of the LDC Mercury Analyzer. The absorption of the UV beam by the vaporized Hg atoms is proportional to the Hg concentration. Quantification is made by comparing the peak height response of the sample with standard curves prepared by spiking seawater and tap water with known quantities of standard Hg solutions.

The minimum detectable concentration of Hg in seawater or freshwater is 0.001 μg/liter. The precision at a concentration of 0.10 μg/liter is ±1.5%, and at a concentration of 0.010 μg/liter is 14%, as determined from replicate analyses. A procedural blank of 0.1 nanograms is experienced. One technician can analyze approximately 48 samples, standards and blanks per day. This procedure is now used for the measurement of Hg in Atlantic Ocean GEOSECS seawater samples, and will be used to measure Hg in a wide variety of freshwater and precipitation samples.

## • FATE AND EFFECTS OF RADIONUCLIDES IN ALASKA

*Comparisons of radionuclide concentrations in rumen contents and muscle tissue of caribou from Anaktuvuk Pass and Kobuk River regions during the 1972-1973 winter season shows that the Kobuk caribou are two to three times higher in $^{137}Cs$ concentrations. Consumption of these animals would produce two- to three-fold higher $^{137}Cs$ body burdens in Anaktuvuk Eskimos than predicted from Anaktuvuk caribou measurements.*

### Radionuclide Cycling in Alaska

C. E. Jenkins, T. P. O'Farrell and J. D. Hedlund

One of the primary objectives of this study is the quantitative definition of the important aspects of radionuclide cycling and their precise role in the steps of transfer of radioelements through the environment and ultimately to man. Equally important is the development of a basic understanding of the ecological factors which influence these transfers. Without a dual approach, in the study of an ecosystem the relative importance of rates of internal circulation, import and export in or between ecosystems may be misunderstood. The major emphasis of this present study is to clarify the steps in the transfer of radionuclides from the environment into Anaktuvuk Pass Eskimos and to determine the cause of the large anomalies observed in their $^{137}Cs$ body burdens in 1969-1970.

To clarify the role that the migratory habits of caribou might have in determining their uptake of radioelements, caribou and lichen samples were collected at Anaktuvuk Pass and in the Kobuk River region for a full seasonal cycle in 1972-1973. In muscle tissue of caribou at the Kobuk winter grounds, $^{137}Cs$ concentrations were consistently two- to three-fold higher than in caribou from Anaktuvuk Pass. A similar pattern was observed for $^{137}Cs$ concentrations in the rumen contents of these animals. Since caribou on the Kobuk winter range utilize numerous mountain passes on their return to their summer range, Anaktuvuk Pass Eskimos could harvest these animals. Consumption of these caribou would result in $^{137}Cs$ body burdens two- to three-fold higher than predicted values. This offers a far simpler explanation for the $^{137}Cs$ anomalies observed in Anaktuvuk Pass residents than a harmonic peak arising from seasonal cycling in lichens, caribou and Eskimos.

Considerable quantities of short-lived radionuclides from recent Chinese nuclear tests were observed on lichens and in caribou. The large sampling of caribou allows tracing the movement of these radioelements through the Arctic food web as a function of season (Figure 5.3).

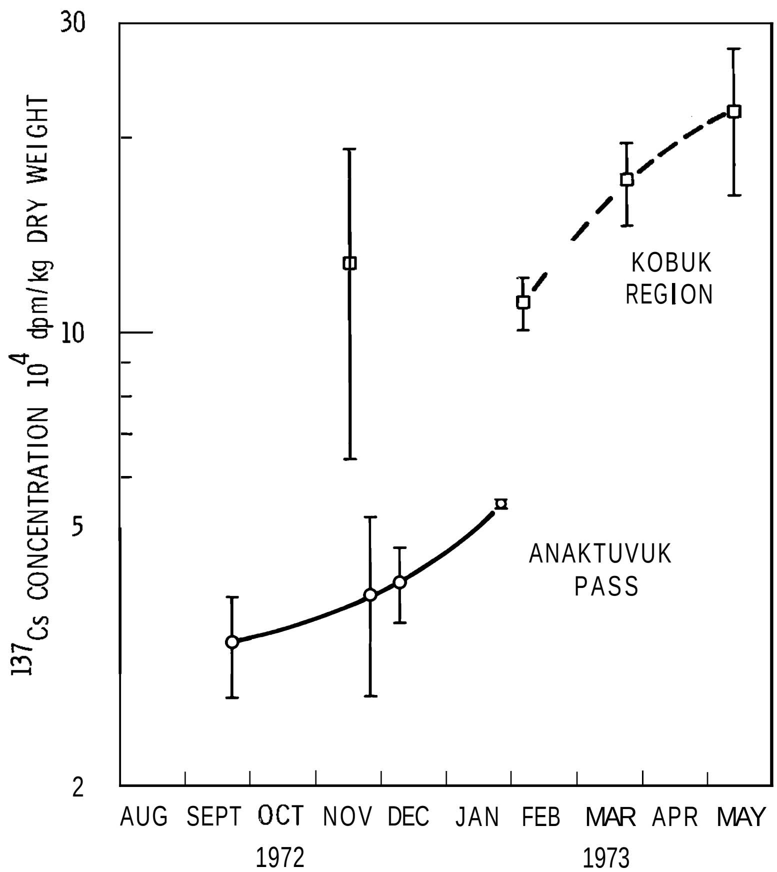


FIGURE 5.3. Average $^{137}Cs$ Concentration in Caribou Muscle Tissue 1972-1973

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Marine Sciences, GEOSECS section, pp. 116 to 119 and Physical and Radiological Chemistry of Ocean Solutions, pp. 108 to 115.

## • TERRESTRIAL ECOLOGY

ENERGY AND WATER RELATIONS
MINERAL NUTRIENTS
MANIPULATED ECOSYSTEMS
CONSUMERS
PRIMARY PRODUCERS
RADIATION STUDIES
MODELLING

*Terrestrial studies continue to contribute ideas and ecological data relevant to nuclear-power plant siting and the management of stored radioactive wastes in the semi-arid steppe region of Washington. These ideas and data are also largely applicable to steppe regions of Oregon, Idaho, and Nevada.*

- *Floristic and faunistic lists*
- *Rare and endangered species*
- *Descriptions of plant communities*
- *Primary productivity*
- *Population dynamics of animals*
- *Food chains to man*
- *Uptake of radionuclides from soils by plants*
- *Transfers of radionuclides from plants to animals*
- *Successional stages in steppe regions*
- *Rooting habits of steppe plants*
- *Burrowing habits of steppe animals*
- *Effects of acute radiation on steppe animals*
- *Mineral cycling*
- *Modelling of ecosystems*
- *Manipulations and stresses in the steppe ecosystem*
- *Microbial activity and decomposition*

*Much of the available information concerning the ecology of steppe ecosystems has been gathered within the boundaries of the Arid Land Ecology Reserve, a place where long-term studies can be initiated with great assurance that the studies will not be interrupted by changing land use priorities. Today the concept of an ecological research area needs to be considered for waste management areas where opportunities are available to study the ecological behavior of radionuclides in the absence of resident human populations. These studies are relevant with the knowledge that rad-wastes will increase as a result of an expanding market for nuclear fueled power plants.*

*The annual report for 1973 reflects the integration of terrestrial ecology studies. Papers are grouped under the headings energy and water relations, mineral nutrients, manipulation studies, consumers, primary producers, radiation studies and modelling.*

*In mid-August, 1973, an extensive wildfire burned through pastures that served as controls for studies of the impact of cattle grazing on the shrub-steppe ecosystem. Three consecutive years of intensive collections have been made on these pastures and provide a firm baseline for evaluating the ecological consequences of burning. Fortunately, a suitable nearby acreage was not exposed to the fire and a suitable "control" has been established to permit the continuation of grassland biome studies.*

*Radiation studies report the continuing studies of the behavior of fallout radionuclides in northern Alaska and the response of small mammals to acute radiation. A technique is described to grow range and crop plants in soil contaminated with plutonium under environmental conditions experienced in the field.*

*Manipulation studies report on the impact of 2 years of spring cattle grazing on perennial grasses characteristic of the shrub-steppe ecosystem and the response of populations of pocket mice to the abundance of a natural food supply regulated by irrigation and herbicide treatments.*

*A simulation model of a cheatgrass ecosystem was developed to illustrate the role of modelling in presenting the multiplicity of environmental factors that occur in an ecological system that ultimately results in plant growth and the maintenance of animal populations.*

## ENERGY AND WATER RELATIONS

### Energy Fluxes in Swards of the Annual Grass *Bromus tectorum*

W. T. Hinds

Energy provides the gradients to move all manner of things about in an ecosystem--the muscle on an ecological skeleton. However, the implications deriving from changes in the amount of incoming energy are not well understood; experiments designed to examine this question have produced conflicting evidence, some indicating an increase in efficiency with increasing energy availability, others a decrease in efficiency (efficiency being the ratio of biologically captured energy to the total energy available). In few cases has the fate of the incident energy been completely determined, and little is known about where or whether any relations remain constant in an ecosystem when the energy available is changed in amount. This question is central to a thorough understanding of ecosystem functioning, so an experiment was designed and carried through last year to provide data on the fate of energy in an ecosystem (including both biological and physical energy transfers and storages). The amount of incident energy was altered by working on steep north- and south-facing slopes on the earth mound described in the annual report for 1971. Small lysimeters described in the past annual reports were used to simulate swards of cheatgrass (Bromus tectorum), providing relatively accurate and precise measurement of biomass production and water use. Meteorological conditions and energy fluxes were measured, including incoming shortwave radiation, net all-wave radiation, heat flux to the soil, and evaporation and transpiration. The fate of photosynthetically fixed carbon was determined by analysis of the plant tissues into crude protein, crude fat, crude fiber, and nitrogen-free extract (NFE) (the proximate analysis scheme routinely used for feed analysis).

Table 6.1 indicates the production of crude protein, fat, fiber and NFE on north- and south-facing slopes during the spring. The clearest differences are in crude protein in shoot tissues at the end of the growing season (23 gm m-' on the north compared to 30 gm $m^{-2}$ on the south). Both exposures began the growing season with 33 gm $m^{-2}$, so evidently shoot tissue protein was translocated to other tissues during the season on the north exposure to a greater extent than on the south exposure. The crude fiber and NFE in seed tissues were both greater on the north exposure, but for all other tissues there were no strong differences (a statistical test of differences was not applicable to the quantities in Table 6.1 because they were calculated from data, producing nonnormality in the distributions of the tabled quantities).

Table 6.2 summarizes the energetics of production on the contrasting slopes (listed under each pair of data is the probability of the difference occurring by chance). Root and seed production were both greater on the north exposure than on the south, but shoot tissue production was not different. Heats of combustion ("caloric content") differed between tissues but not between exposures; as a consequence, the photosynthetically fixed energy differed in the same sense as the production. Total production and total energy fixation were not appreciably different on the two exposures, because the greater magnitude and variability of the shoot tissues overwhelmed the differences in the root and seed tissues. Incident shortwave radiation was very much greater on the south exposure than on the north, so the similar production and energy fixation coupled with more available energy on the south exposure meant the south exposure was much less efficient than the north exposure in converting sunlight energy into chemical energy stored in plant tissues.

**TABLE 6.1. Final Standing Crop and Spring Season Production of Crude Protein, Fat, Fiber and Nitrogen-Free Extract (Ashfree)***

| | | Crude Protein gm m$^{-2}$ | Crude Fat gm m$^{-2}$ | Crude Fiber gm m$^{-2}$ | Nitrogen Free Extract gm m$^{-2}$ | Standing Crop Biomass gm m$^{-2}$ |
|---|---|---|---|---|---|---|
| Initial Conditions | | | | | | |
| Shoots (n=6)** | | 33 ± 3.6 | 3.0 ± 0.30 | 24 ± 2.2 | 76 ± 8.4 | 136 ± 9 |
| Roots | | NO DATA—INSUFFICIENT SAMPLE MASS | | | | 18 ± 2 |
| Final Conditions | | | | | | |
| Shoots (n=13) | North | 23 ± 2.6 | 11 ± 1.9 | 112 ± 8.0 | 201 ± 13 | 350 ± 19 |
| (n=13) | South | 30 ± 2.0 | 11 ± 1.0 | 116 ± 9.3 | 205 ± 14 | 364 ± 16 |
| Seeds (n=5) | North | 14 ± 1.2 | 1.6 ± 0.3 | 20 ± 1.9 | 84 ± 6.3 | 119 ± 7 |
| (n=3) | South | 12 ± 1.1 | 0.9 ± 0.2 | 14 ± 1.5 | 62 ± 6.3 | 88 ± 7 |
| Total Above-ground | North | 37 ± 3.8 | 13 ± 2.2 | 132 ± 10 | 285 ± 19 | 469 ± 20 |
| | South | 42 ± 3.1 | 12 ± 1.2 | 130 ± 11 | 267 ± 20 | 452 ± 17 |
| Roots (n=5) | North | 16 ± 2.0 | 1.0 ± 0.2 | 40 ± 5.0 | 82 ± 9.4 | 139 ± 11 |
| (n=3) | South | 12 ± 1.2 | 0.9 ± 0.2 | 30 ± 4.2 | 70 ± 7.0 | 112 ± 8 |
| Total Above & Below Ground | North | 53 ± 6 | 14 ± 2.4 | 172 ± 15 | 367 ± 28 | 608 ± 23 |
| | South | 54 ± 4 | 13 ± 1.4 | 160 ± 15 | 337 ± 27 | 564 ± 19 |
| Net Production | | | | | | |
| Aboveground Only | North | 4 ± 7 | 10 ± 2.5 | 108 ± 7 | 209 ± 27 | 333 ± 22 |
| | South | 9 ± 7 | 9 ± 1.5 | 106 ± 13 | 191 ± 28 | 316 ± 19 |

* = Numbers following ± are estimated error, not standard error.
** n = Sample size for primary (not calculated) data.

**TABLE 6.2. Net (Ash-Free) Photosynthetic Efficiency of *Bromus Tectorum* on North- and South-Facing Slopes from 13 Lysimeters on Each Slope**

| | Exposure | Root | Shoot | Seed | Total |
|---|---|---|---|---|---|
| Net Production gm m$^{-2}$ ($\bar{x}$ ± SE) | North | 120 ± 11 | 2 4 ± 21 | 119 ± 6.6 | 453 ± 32 |
| | South | 93 ± 8 | 228 ± 19 | 88 ± 6.9 | 409 ± 24 |
| | P | 0.009 | 0.50 | 0.0001 | 0.13 |
| Heat of Combustion kcal gm$^{-1}$ $\bar{x}$ ± SE | North | 4.09 ± 0.083 | 4.36 ± 0.026 | 4.22 ± 0.23 | --- |
| | South | 4.08 ± 0.072 | 4.38 ± 0.010 | 4.23 ± 0.056 | --- |
| Photosynthetic Energy [ixation, kcal m$^{-2}$ x ± SE | North | 491 ± 46 | 933 ± 91 | 502 ± 28 | 1926 ± 106 |
| | South | 379 ± 33 | 999 ± 83 | 372 ± 29 | 1750 ± 94 |
| | P | 0.009 | 0.45 | 0.0001 | 0.09 |
| Incident Shortwave Radiation, kcal m$^{-2}$ x ± SE | North | --- | --- | --- | 29.0 ± 0.06 |
| | South | --- | --- | --- | 40.5 ± 0.06 |
| Net Photosynthetic Efficiency, % $\bar{x}$ ± E* | North | 0.17 ± 0.02 | 0.32 ± 0.04 | 0.17 ± 0.01 | 0.67 ± 0.05 |
| | South | 0.093 ± 0.009 | 0.24 ± 0.02 | 0.093 ± 0.009 | 0.43 ± 0.03 |

* Numbers following ± are estimated errors, not standard errors.

## TERRESTRIAL ECOLOGY

- TERRESTRIAL PLANT ECOLOGY
  - HYDROLOGICAL CYCLING ON THE ALE RESERVE
  - ECOLOGICAL MICROMETEOROLOGY AND CLIMATOLOGY OF THE ALE RESERVE
- GRASSLANDS BIOME
- TERRESTRIAL ANIMAL ECOLOGY
- FATE AND EFFECTS OF RADIONUCLIDES IN ALASKA

The self-regulating tendencies noted by many workers in regard to seed production was very evident in this study. Table 6.3 shows that the average seed weight was only about 10% heavier on the north exposure, although it was shown in Table 6.2 that the north produced more than a third more total seed biomass. The composition of an average seed is listed in Table 6.3 showing that the difference in seed weight was caused primarily by a change in soluble components, probably starches in the endosperm. Crude protein was almost identical--possibly a very important point because studies with wheat (a rather closely related grass) indicate a linear relation between seedling size and vigor and the amount (not percentage) of protein in the seed, without regard to seed size as such.

Average meteorological conditions on the two exposures were not strongly different except in terms of energy partitioning--the ordinary climatological measurements did not detect notable differences, even in air temperatures, as summarized in Table 6.4. All terms in the radiation balance were significantly different (larger on the south exposure), and the estimated radiative surface temperature average was higher on the south exposure (about 40°C compared to about 30°C on the north exposure).

The energy-rich south exposure was subjected to water stresses much earlier than the north exposure, as indicated in Figure 6.1, where total transpired water, the fraction of energy used to transpire water, and soil water content are plotted against

TABLE 6.4. Average Climatological Conditions and Flux Sites on Contrasting North and South Exposures

| | North | South |
|---|---|---|
| Daytime Temperature | 21 C | 22 C |
| Nighttime Temperature | 9 C | 10 C |
| Soil Temperature (60 cm) | 11 C | 15 C |
| Calculated Radiative Surface Temperature | 31 C | 40 C |
| Daytime Vapor Pressure Deficit | 18 mb | 20 mb |
| Nighttime Vapor Pressure Deficit | 5 mb | 7 mb |
| Total Rainfall | 3.3 cm | 3.6 cm |
| Solar Radiation Flux Density | 470 cal $cm^{-2}$ $min^{-1}$ | 650 cal $cm^{-2}$ $min^{-1}$ |
| Net Radiation Flux Density | 190 " " " | 280 " " " |
| Transpiration Flux Density | 66 " " " | 70 " " " |
| Evaporation Flux Density | 34 " " " | 40 " " " |
| Heat Flux Density to Atmosphere | 90 " " " | 160 " " " |
| Heat Flux Density to Soil | 4 " " " | 4 " " " |
| Photosynthetic Flux Density | 3 " " " | 3 " " " |

TABLE 6.3. Average Composition of Seeds from 13 Lysimeters on North and South Exposures*

| Exposure | Crude Protein mg | Crude Fat mg | Crude Fiber mg | Nitrogen Free Extract mg | Average Seed Weight mg |
|---|---|---|---|---|---|
| North | 0.26 ± 0.01 | 0.03 ± 0.005 | 0.38 ± 0.02 | 1.55 ± 0.05 | 2.22 ± 0.05 |
| South | 0.27 ± 0.01 | 0.02 + 0.002 | 0.33 ± 0.02 | 1.45 ± 0.04 | 2.07 ± 0.05 |

"Numbers following ± are estimated errors, not standard errors.

time. An abrupt change in rate of transpiration occurs at about 7.5 cm water content in the profile (∿10% by weight), perhaps indicating a rather sudden decrease in water conductivity that reduces water availability to the plants. The change in transpiration rate occurred near day 30 on the south exposure, and near day 42 on the north exposure, implying that water was readily available to the north exposure for a period about a third longer than on the south exposure. This almost certainly would help to create conditions favorable for a larger seed crop on the north exposure; it perhaps also led to more effective root growth and function, because the north exposure produced nearly a third more root biomass along with the larger seed crop (Table 6.1).

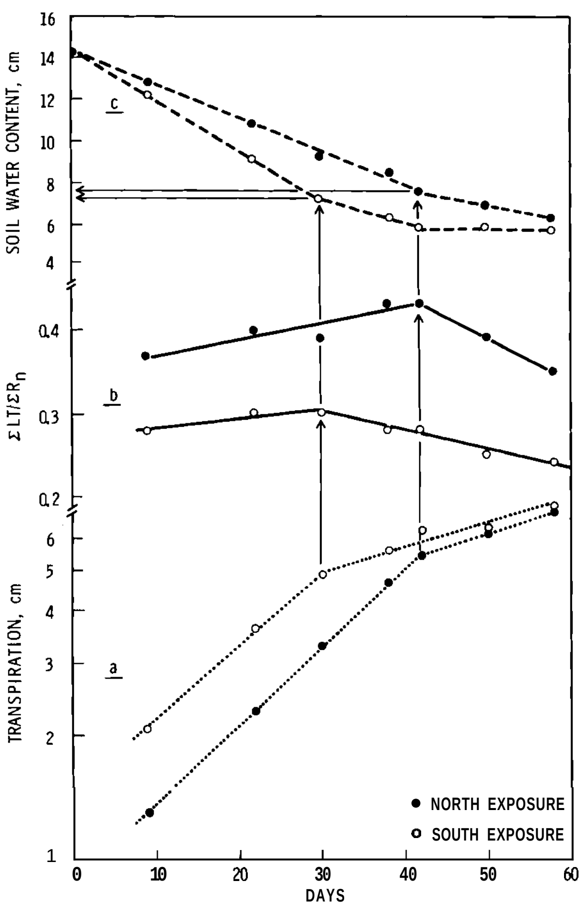


FIGURE 6.1.

a. Total Water Transpired by Bromus tectorum in Lysimeters on Contrasting North- and South-Facing Slopes as a Logarithmic Function of Time During Spring 1972

b. Fraction of Total Available (Net) Radiant Flux Density Used by Bromus tectorum in Lysimeters to Transpire Water on Contrasting Slope Exposure as a Function of Time, Spring 1972

c. Total Soil Water Content in the Profile in Lysimeters on Contrasting Slope Exposures as a Function cf Time, Spring 1972

Ultimately, the transpired water was the same on both exposures, because the rate of transpiration on the south exposure decreased markedly a fortnight before the end of the experiment, becoming significant again only during the last week, following heavy rains. The south exposure community was subjected to water stresses sooner and longer than the north exposure, but was not subjected to higher stresses, because the average soil water content on the south exposure did not decrease below that eventually attained on the north exposure.

The experiment pointed up the following facets relating energy fluxes in Bromus tectorum to energy fluxes in the environment:

1) The ordinary climatological conditions were more similar on the two exposures than energy flux densities: average daytime and nighttime temperatures were only 1 to 3°C different, average daytime vapor pressure deficits were only

2 or 3 mb apart, and so on. The flux densities associated with these measurements were rather more different: solar radiation and net radiation were both about 30% higher on the south exposure, and total water (evapotranspiration) flux was 40% greater on the south exposure.

2) Total water transpired was the same on the two exposures, but the rate of transpiration was considerably higher on the south exposure early in the season (due primarily to the high flux density of solar radiation) and thus the south exposure was subjected to water stresses earlier and longer than the north exposure.
3) Seed size and composition tended to be homeostatic, but total seed biomass and seed number were higher on the north exposure.
4) Composition of plant tissues in terms of crude protein, crude fat, crude fiber and nitrogen-free extract was very similar on the two exposures, except for protein content, which was nearly 20% greater in shoot tissues on the south exposure.
5) Total production and energy fixation tended to be homeostatic, and efficiency, therefore, was inverse to energy income.

## Water Loss Patterns from Grasses and Bare Surfaces

W. T. Hinds

A study was set up in March 1973 to examine water consumption in contrasting communities: native grasslands, old fields, trampled (bare) surfaces, and intact lichen/moss crusts characteristic of native grasslands. The basic tool for the investigation was the small lysimeters described in earlier reports (Annual Reports for 1971 and 1972). Transplants from stands of Bromus tectorum, Agropyron spicatum, and Poa sandbergii were made in mid-March, along with transplant cores from bare surfaces trampled by cattle, and intact cores of lichen and moss surfaces. The lysimeters had been brought to near field capacity before the transplantation was performed.

Water use patterns (averages ± standard errors) for the various surfaces are shown in Figure 6.2. Agropyron used water at the fastest rate, and at the same rate whether clipped (to simulate grazing) or left standing. Bromus tectorum used very nearly as much water as Agropyron, but Poa used only about half as much water (with much less shoot biomass than the other species). The lichen/

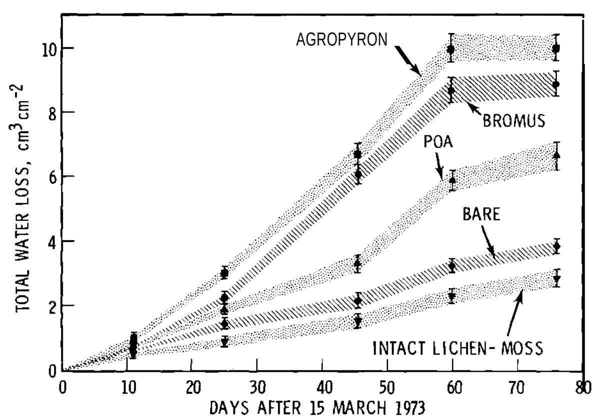


FIGURE 6.2. Total Water Loss from Lysimeters with Transplants of Native Grasses (Agrophron spicatum and Poa sandbergii), introduced Grass (Bromus tectorum), Undisturbed Lichen/Moss Surface and Bare Soil, During the Spring of 1973

moss surface lost less water than the trampled bare surface, suggesting that the intact lichen/moss layer may act as a mulch rather than as an evaporative surface in the drying phase of the annual water cycle of this semi-arid landscape.

## Sagebrush Leaf Water Potentials in Grazed and Ungrazed Grasslands

W. T. Hinds and Betty Klepper

Sagebrush has the reputation of being a strong competitor for water in grasslands, and increased yields of grasses have been consistently achieved if dense overstories of sagebrush are removed. However, the grasslands on the Arid Lands Ecology Reserve are characterized by sparse, rather than dense, stands of sagebrush, typically with a canopy cover of about 3 to 5%. The objective of this study was to determine whether the removal of a substantial fraction of the transpiring surfaces of the grasses (by grazing) would improve soil water relations for sagebrush.

Leaf water potentials of sagebrush twigs were estimated by pressure chamber readings during the spring and summer of 1973 in grazed and ungrazed experimental pastures on the ALE Reserve. Strong diurnal differences were detected in the leaf water potentials, so the results reported here are those observed just before dawn, probably reflecting the greatest degree of hydration attained by the sagebrush each day. Values reported are averages from at least ten samples from each grazing treatment.

The soil water patterns observed during the season are shown in Figure 6.3, along with a plot of sagebrush

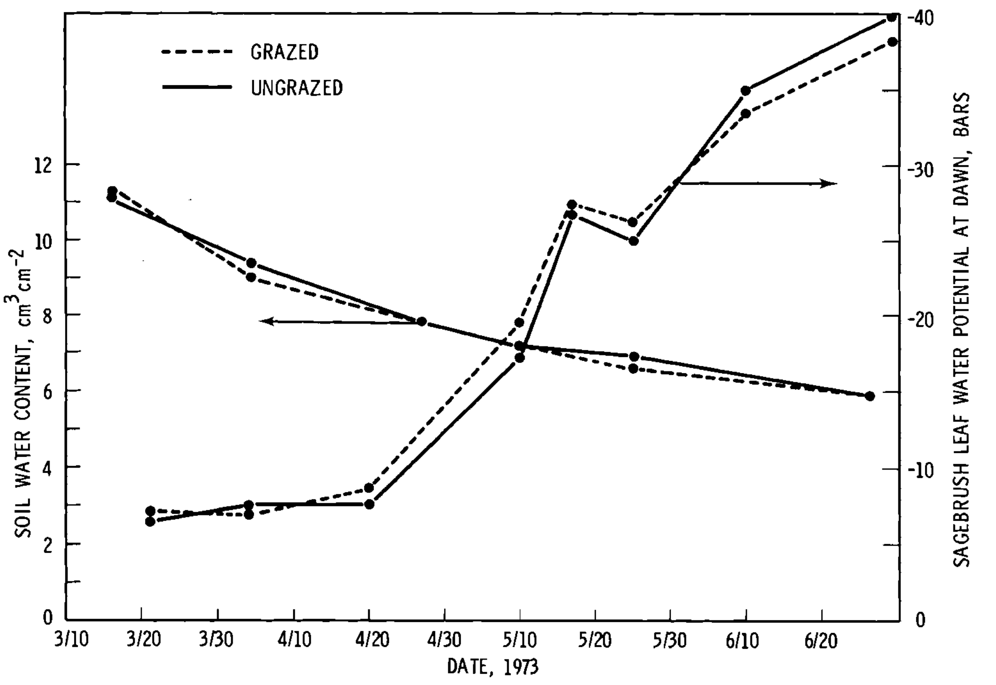


FIGURE 6.3. Total Soil Water Content in the Profile ($cm^3$ $cm^{-2}$), and Sagebrush Leaf Water Potentials (bars), as a Function of Time During Spring 1973

leaf water potentials. There were no detectable differences in soil water content between grazing treatments. A detailed analysis of variance of the soil water data by depth increments and date (from 1 to 10 dm, and from October 1972 through October 1973 by fortnights or months) likewise indicated no detectable effect on the water profile due to grazing. The sagebrush water potentials rarely were statistically different and never were ecologically different.

Although no difference in water relations was detected in this study, clear evidence of the seasonal pattern of sagebrush and soil water relations was obtained. Figure 6.4 demonstrates that in Ritzville silt loam, the water potential in sagebrush leaves decreased at a rate of about a half bar per cm of water lost with more than 8 cm (about 9% by weight) of water in the profile. In drier conditions, sagebrush leaf water potentials decreased at a rate exceeding 16 bars per cm of soil water loss, more than 30 times faster than in the moist conditions, probably reflecting a sharp decrease in conductivity of the soil near that soil water content.

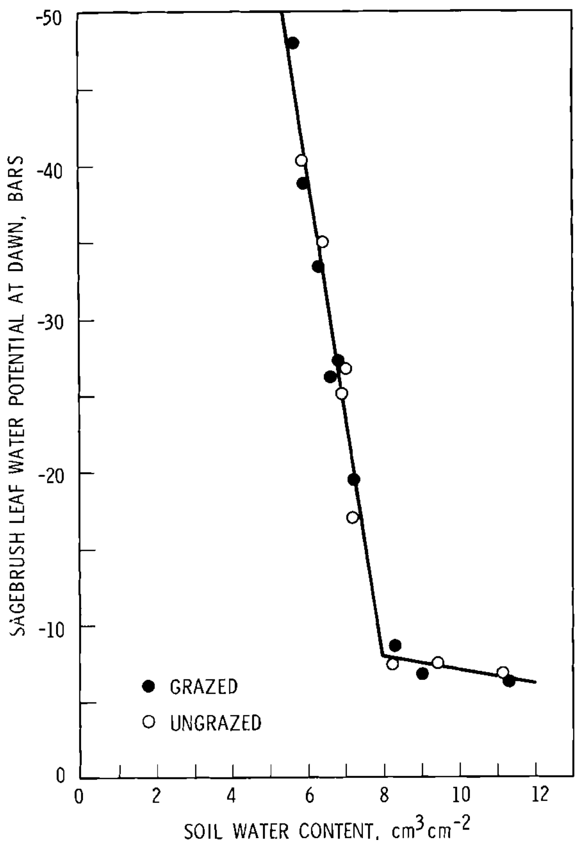


FIGURE 6.4. Sagebrush Leaf Water Potential (bars) as a Function of Total Soil Water Content in the Profile ($cm^3$ $cm^{-2}$), Spring 1973

## Climatology of the Arid Lands Ecology Reserve

W. T. Hinds and J. M. Thorp*

Climatological measurements on the ALE Reserve continued during 1973, in a slightly expanded form to include a few more detailed measurements at significant sites. A relatively detailed report will be included in the Annual Report for 1973 by Atmospheric Sciences Department. The precipitation pattern is presented here because of its intrinsic importance to the ecosystem. Figure 6.5 shows the total winter + spring accumulation of precipitation on the Reserve, illustrating a maximum at mid-elevations and in the mid-section of the Reserve. The water accumulated between October and May in 1972/1973 was nearly identical to that in 1971/1972 at the middle

* Atmospheric Sciences Department

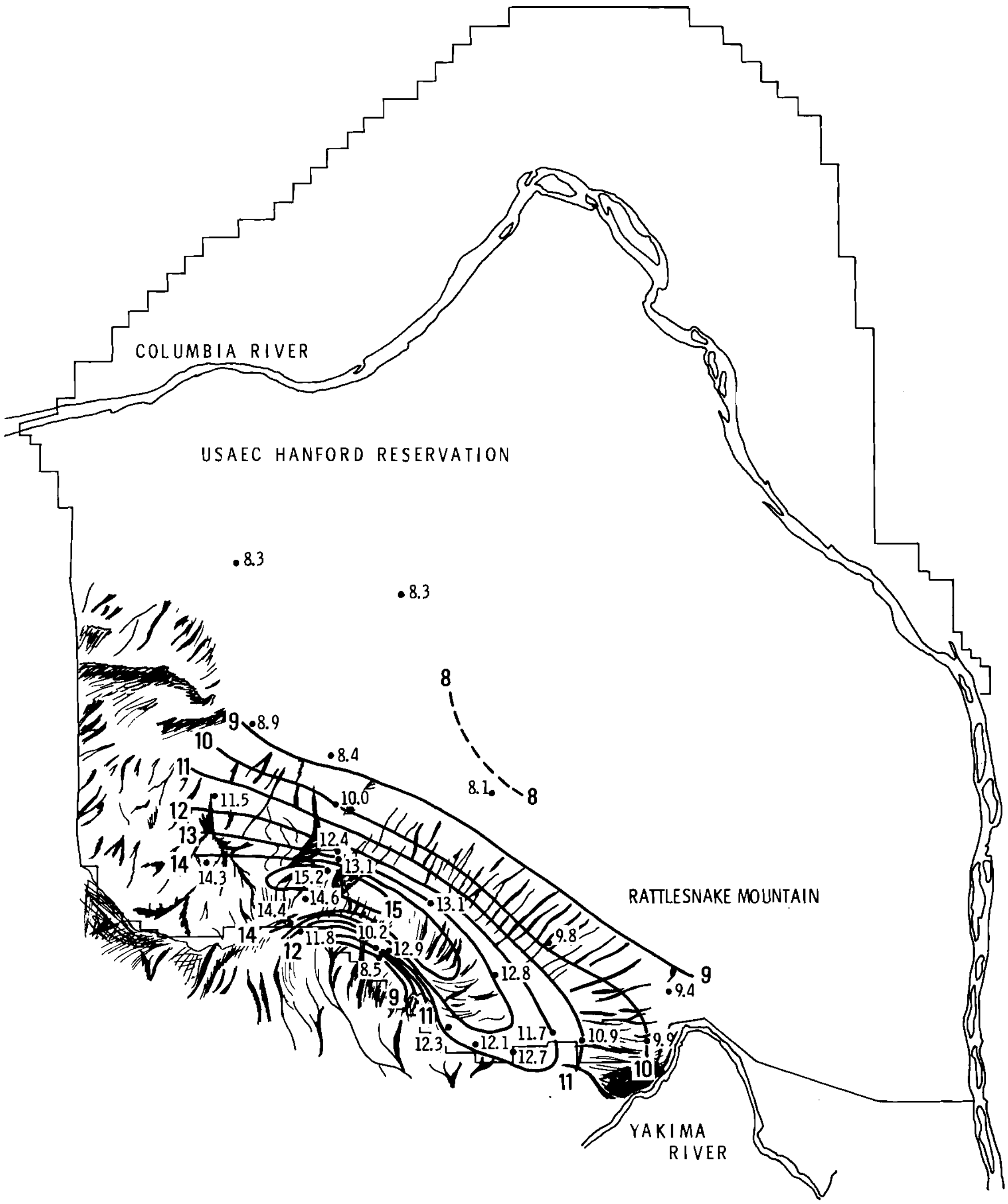


FIGURE 6.5. Arid Lands Ecology Reserve. October 1972 to May 1973 bioyear precipitation (cm of water).

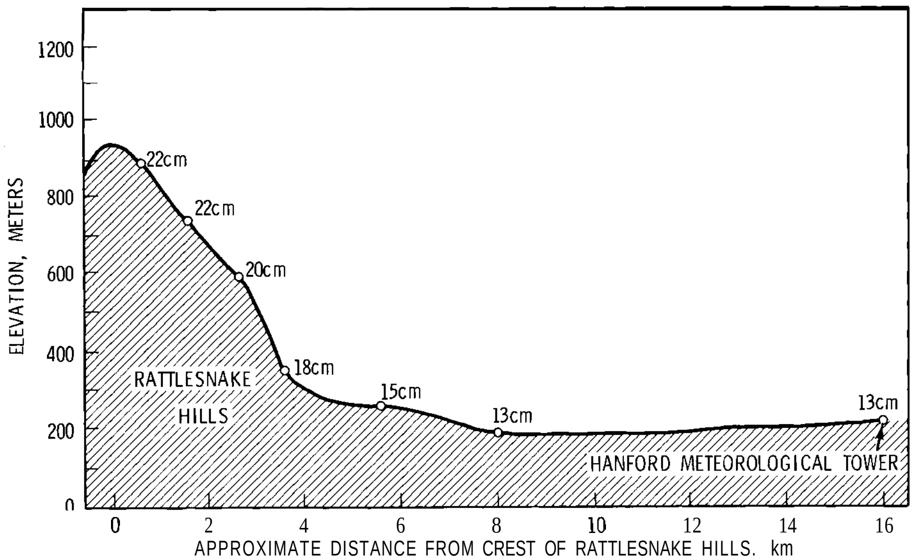


FIGURE 6.6. Five-Year Averages of October to May Precipitation as a Function of Elevation in the Rattlesnake Hills on the ALE Reserve

elevations, but both the lower elevations and the higher elevations received about 25% less in 1972/1973. The 5-year average of October/May precipitation at the mid-section (Benson) transect (see the Annual Report for 1968) is shown in Figure 6.6. The increase of precipitation with elevation is much more rapid at the lower elevations than at the higher elevations. The transition in vegetation type from Sagebrush/Bluegrass (at low elevations) to Sagebrush/Wheatgrass (at higher elevations) occurs at about 17 cm of precipitation.

MINERAL NUTRIENTS

Mineral Content of the Above Ground Biomass of Cheatgrass Communities

J. F. Cline and W. H. Rickard
Technical Assistance: V. D. Charles and H. A. Sweany

The amounts of nitrogen, calcium, phosphorus and potassium were measured in the above ground biomass in two cheatgrass, Bromus tectorum, communities over a 4-year period. The use of these nutrients by the living crop may be regulated by the amounts of the mineral retained in the dead plant material called flat and standing litter. The amount of each mineral retained in the litter was different, indicating different utilization and rate of return to the soil for use by new generations of plants.

As shown by the bar graphs in Figure 6.7, large amounts of nitrogen, phosphorus and calcium are accumulated and held in the flat and standing litter. The relatively low amount of potassium held in the litter as compared to living plants can be partially explained in that potassium is more water-soluble than the other elements and is, therefore, more readily returned to the soil for re-use by plants.

Nitrogen is characteristically scarce in arid land soils and is a limiting factor during years when soil water is not limiting. Figure 6.7 shows that large quantities of nitrogen were held in litter from year to year, indicating з slow cycling of nitrogen and that a complete cycle was multi-year. The nitrogen in the above ground biomass averaged lower at the 1700 ft elevation than at the 1000 ft elevation. This is a reflection of lower average plant yields with lower nitrogen content. The total amount of nitrogen in the above ground biomass varied among the 4 years of study with 1970 showing the lowest values for nitrogen as well as phosphorus and calcium, but not potassium.

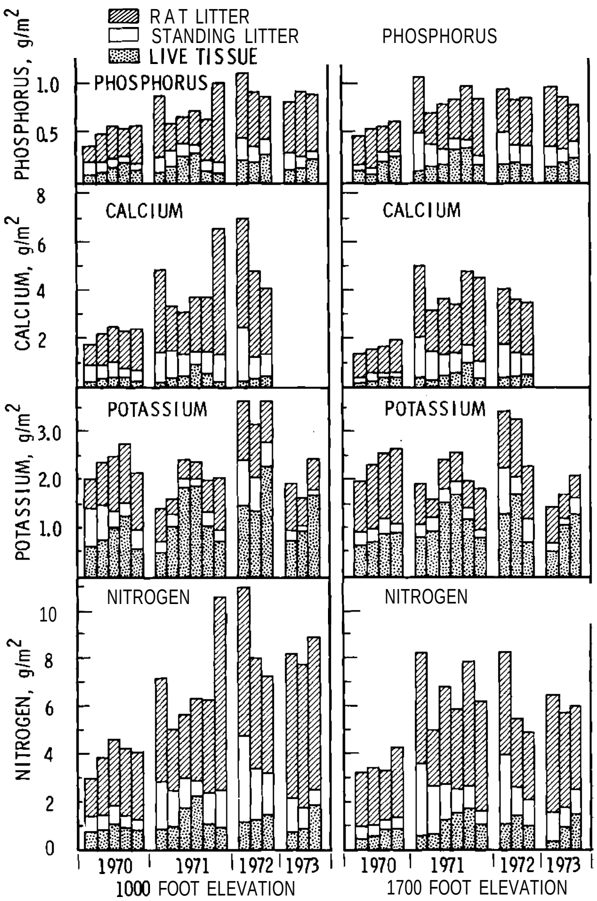


FIGURE 6.7. Average Nitrogen, Potassium, Calcium and Phosphorus Contents of Flat Litter, Standing Litter, and Live Shoots in Cheatgrass Communities at Different Harvest Dates in the Growing Seasons (March, April and May) 1970, 1971, 1972 and 1973

The amount of phosphorus in the above ground biomass was between 5 to 10 times less than nitrogen but showed less year to year variability.

The calcium content of the living crop was low with most of the calcium lodged in the litter.

Potassium seemed to cycle faster than the other elements, and less was retained in the litter.

Data of the kind presented here provide useful insight as to the changes in mineral content of living plants in cheatgrass communities throughout a single growing season and the year to year extremes that result from changing weather conditions. The data also provide some insight as to the magnitude of nutrient uptake of cheatgrass communities growing at different elevations under different climatic conditions. These data are also useful for the validation of mathematical models of mineral behavior in cheatgrass ecosystems.

## Dynamics of Nitrogen and Phosphorus in Agropyron *spicatum*

W. H. Rickard, J. F. Cline and D. W. Uresk
Technical Assistance: V. D. Charles and H. A. Sweany

The ALE Reserve offers an unusual opportunity to assess the impact of cattle on the seasonal and annual changes in plant nutrients on a pristine stand of shrub-steppe vegetation.

Sampling was conducted every 3 weeks throughout the growing season and once during the post growing season. Two pastures were sampled during 1972: (1) grazed - cattle and other herbivores were present during sampling, and (2) control - cattle were excluded entirely. During each sampling period all species were clipped near ground level and separated into live, dead, crown, and litter categories and analyzed for nutrients, Table 6.5

Ten species of plants, including litter, were analyzed in 1972. Figure 6.8 summarizes the annual changes in nitrogen ($g/m^2$) for Agropyron spicatum on the control pasture for live, dead and crowns. The amount of nitrogen increased for the live vegetation from the beginning of the growing season, peaking at 37 $g/m^2$ and then declining for the remainder of the season. The amount of nitrogen in the dead category reached a high of 57 $g/m^2$ during the latter part of March, and then fluctuated throughout the season, but generally remained higher than the nitrogen present in the live herbage. This was primarily due to the amount of standing dead herbage accumulated in the ecosystem. The amount of nitrogen was also dependent upon the transfers of herbage from the live category to the dead, and the amount of dead entering the litter pool. The standing crop of nitrogen for crowns decreased early in the spring during the period of rapid vegetative growth and then peaked at 106 $g/m^2$ when seed production was taking place. Crowns may have acted as a storage reservoir for nitrogen.

Figure 6.9 represents the seasonal dynamics of phosphorus in A. spicatum. The pattern of changes was similar to

TABLE 6.5. Average Nitrogen and Phosphorus Content of *Agropyron spicatum* Expressed as $g/m^2$ Day Weight

Ungrazed 1972

Agsp.

($g/m^2$ ± SE)

| | | 3/6 | 3/27 | 4/17 | 5/10 | 5/31 | 6/19 |
|---|---|---|---|---|---|---|---|
| | | $\bar{X}$ ± 1 SE | $\bar{X}$ ± 1 SE | $\bar{X}$ ± 1 SE | $\bar{X}$ ± 1 SE | $\bar{X}$ ± 1 SE | $\bar{X}$ ± 1 SE |
| Live | N | 8.4 ± 2.0 | 31.2 ± 4.9 | 37.0 ± 5.2 | 35.7 ± 8.8 | ----- | 23.0 ± 2.9 |
| Dead | N | 31.0 ± 5.5 | 56.8 ± 13.6 | 48.9 ± 11.0 | 27.2 ± 6.8 | 53.6 ± 7.5 | 35.0 ± 7.6 |
| Crowns | N | 69.5 ± 10.9 | 28.4 ± 4.3 | 54.8 ± 9.1 | 50.4 ± 11.0 | 105.6 + 6.9 | ----- |
| $\bar{X}$ | | 108.9 | 116.4 | 140.7 | 113.3 | | |
| Live | P | .92 ± 0.22 | 3.09 ± 0.48 | 3.69 ± 0.52 | 4.83 ± 1.18 | ----- | 3.39 ± 0.43 |
| Dead | P | 2.91 ± 0.51 | 3.03 ± 0.73 | 2.53 ± 0.57 | 1.80 ± 0.45 | 3.51 ± 0.58 | 1.92 ± 0.41 |
| Crowns | P | 7.17 ± 1.13 | 6.86 ± 1.04 | 5.30 ± 0.88 | 6.27 ± 1.37 | 11.14 ± 0.73 | ----- |
| $\bar{X}$ | | 11.0 | 12.98 | 11.52 | 12.90 | | |

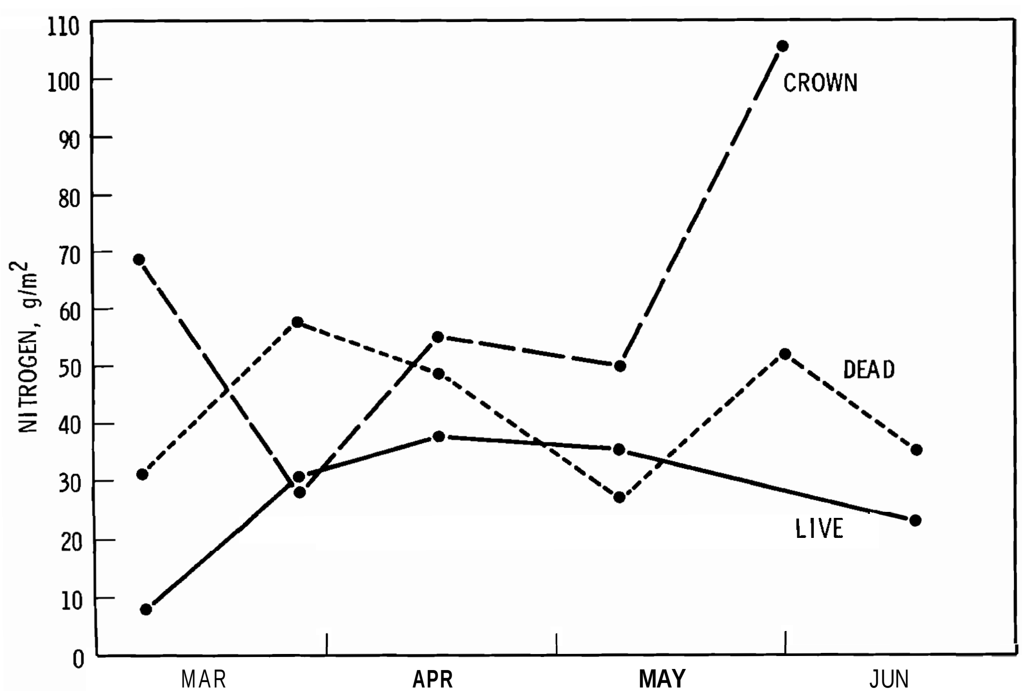


FIGURE 6.8. Seasonal Trends of Nitrogen in *Agropyron spicatum* for each Category of Live, Dead and Crown Biomass

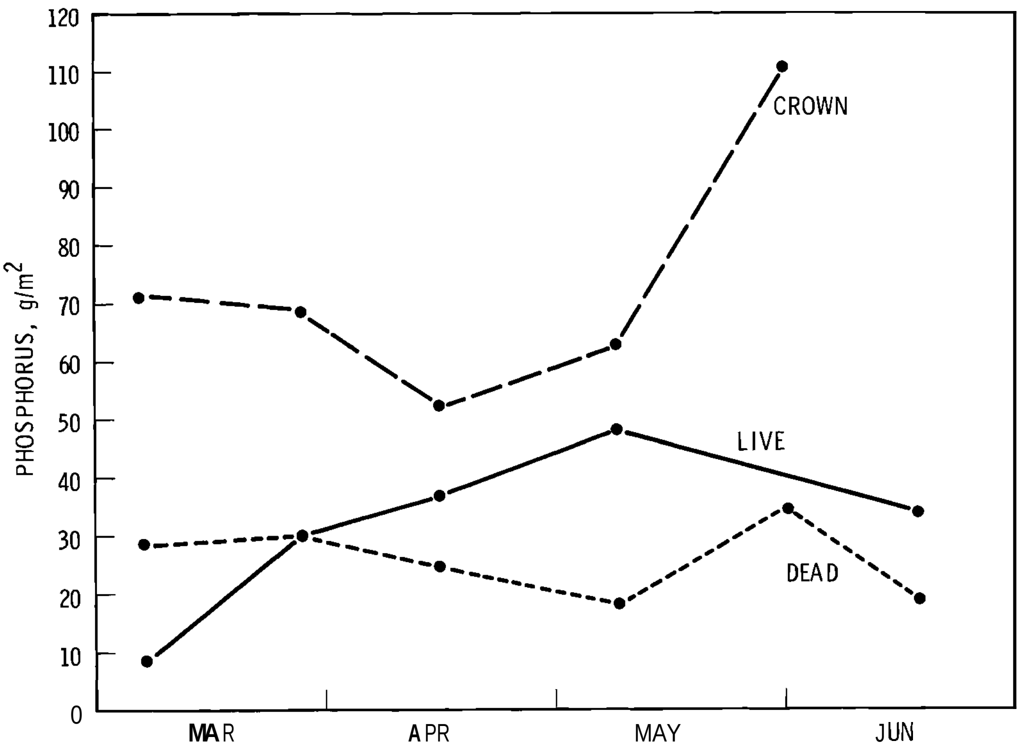


FIGURE 6.9. Seasonal Trends of Phosphorus in *Agropyron spicatum* for each Category of Live, Dead and Crown Biomass Within a Near Pristine Stand of Shrub-Steppe Vegetation During 1972

that of nitrogen. However, the standing crop of phosphorus in the live herbage was much higher than in dead herbage throughout most of the growing season and reached a high of 5 $g/m^2$ during mid-May. Crowns exhibit the highest amount of phosphorus of the three categories throughout the growing season. Phosphorus decreased during the early stages of growth and increased to a high of 11 $g/m^2$ near the time of seed formation.

A base line of nutrient cycling within a pristine stand of vegetation must be established to assess the impact of grazing on these plants. The nutrient changes that occur for each category, seasonally and annually, are important factors in understanding nutrient uptake by plants and transfers to higher trophic levels.

## MANIPULATED ECOSYSTEMS

### Impact of Cattle Grazing on Three Perennial Grasses in the Shrub-Steppe Ecosystem

W. H. Rickard, R. O. Gilbert,
D. W. Uresk and J. F. Cline
Technical Assistance: V. D. Charles

Three species of perennial grasses, *Agropyron spicatum, Poa cusickii* and *Stipa thurberiana*, were subjected to 2 years of moderate spring grazing by cattle on small pastures located on the Arid Land Ecology Reserve. A grazed pasture was allowed to recover without grazing the third year. At maturity, plants were sampled for height of leaves, flowering culms, length of seed heads and clump area (length x width). Data collected on the recovery pasture were compared with an adjacent control plot that has not been exposed to grazing for 30 years or more.

Two consecutive years of grazing reduced the average height of leaves and flowering culms ($a \le 0.01$) for all three species (Table 6.6). The effect of grazing on seed head length was not statistically significant ($a \le 0.05$) for S. thurberiana; however, A. spicatum, having a mean seed head length of 6.6 cm, was significantly greater than the control plot. The number of seed heads per clump for P. cusickii was reduced from 23 to 3 on the control and recovery pastures respectively. Overall, the average number of seed heads per clump was smaller on the recovery than on the control pasture for all three species of plants, although not statistically for A. spicatum which showed a high variance. The proportion of clumps with seed heads was significantly reduced ($a \le 0.01$) on the recovery plot only for P. cusickii. No significant changes ($a = 0.05$) were noted for S. thurberiana nor A. spicatum. The clump area for each species (length x width) was smaller on the recovery plot with A. spicatum being significantly different ($a \le 0.01$) from the control.

Poa cusickii was particularly sought out by cattle and all bunches were grazed down to crown level during each of the two grazing years. The impact of grazing was greater on this species of plant than on the other two for all parameters measured. Continued grazing with the same stocking rate of 7 steers on 9 hectares (moderate grazing) for about 3 months would be detrimental to this species.

### Population Dynamics of Perognathus parvus on Manipulated Shrub-Steppe Ecosystems

T. P. O'Farrell, J. D. Hedlund, R. A. Gies and G. B. Long

Field manipulations were commended in 1970-1971 to test the hypothesis that production of winter annuals, particularly Bromus tectorum, is largely responsible for variability in reproductive performance of the great basin pocket mouse, Perognathus parvus. Three 5.75 hectare study areas were established in shrub-steppe vegetation typically inhabited by Perognathus. The first site was irrigated with an overhead sprinkler system to simulate a year of high natural precipitation and high vegetative growth. An herbicide was applied to the second area to simulate a year of little to no winter annual production. The third area was an unstressed control plot.

Populations of small mammals were sampled on all three sites at biweekly intervals starting in March 1971. Results gathered in 1973 represented the third and final year of the manipulation study. The data are now being reduced and analyzed. Preliminary observations indicate that

**TABLE 6.6. Summary of Morphological Data on Three Perennial Grasses from a Pasture with a 2-Year History of Moderate Grazing Compared with an Adjacent (Control) Pasture Without a Grazing History**

| | Height of Leaves | | | | Height of Flowering Culms | | | | Length of Seed Heads | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | $\overline{X}$ | SE | CV | n | $\overline{X}$ | SE | CV | n | $\overline{X}$ | SE | CV |
| Agropyron (6-6-73) | | | | | | | | | | | | |
| Recovery | 1010 | 24.78** | 0.22 | 0.28 | 367 | 32.54** | 0.52 | 0.31 | 367 | 6.56* | 0.13 | 0.37 |
| Control | 910 | 30.30 | 0.29 | 0.29 | 356 | 38.20 | 0.66 | 0.32 | 356 | 6.18 | 0.14 | 0.43 |
| Poa | | | | | | | | | | | | |
| Recovery | 316 | 13.58** | 0.28 | 0.36 | 36 | 31.08** | 1.05 | 0.20 | | Not Measured | | |
| Control | 336 | 22.42 | 0.33 | 0.27 | 287 | 38.95 | 0.51 | 0.22 | | Not Measured | | |
| Stipa (5-10-73) | | | | | | | | | | | | |
| Recovery | 288 | 22.61** | 0.40 | 0.30 | 300 | 34.85** | 0.45 | 0.22 | 285 | 13.82NS | 0.15 | 0.19 |
| Control | 288 | 28.62 | 0.39 | 0.23 | 337 | 38.09 | 0.41 | 0.19 | 325 | 13.86 | 0.14 | 0.18 |

| | Proportion of Clumps With Seed Heads | | No. of Seed reads Per Clump† | | | | Clump Area (Length x Width) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | n | P | n | $\overline{X}$ | SE | CV | n | $\overline{X}$†† | SE | CV |
| Agropyron (6-6-73) | | | | | | | | | | |
| Recovery | 85 | 0.729NS | 62 | 18.60NS | 2.68 | 1.14 | 85 | 428.24* | 54.74 | 1.18 |
| Control | 76 | 0.724 | 55 | 24.75 | 3.75 | 1.12 | 76 | 581.53 | 72.70 | 1.09 |
| Poa (5-8-73) | | | | | | | | | | |
| Recovery | 48 | 0.229** | 11 | 3.27** | 0.82 | 0.83 | 48 | 285.32NS | 20.68 | 0.50 |
| Control | 48 | 0.854 | 41 | 22.93 | 3.31 | 0.92 | 48 | 294.79 | 24.74 | 0.58 |
| Stipa (5-10-73) | | | | | | | | | | |
| Recovery | 48 | 0.896NS | 43 | 13.93* | 1.65 | 0.78 | 48 | 101.89NS | 11.25 | 0.76 |
| Control | 48 | 0.958 | 46 | 19.43 | 1.86 | 0.65 | 48 | 102.99 | 12.13 | 0.82 |

* Statistically significant versus control at a = 0.05 level.
** Statistically significant versus control at a ≤ 0.01 level.
NS Not statistically significant (a = 0.05).
† Computed for those clumps with at least one seed head.
†† Tests of significance on clump area computed on logs of data due to positive skewness of original scale.

there was no change in the species composition of the three sites over the three years of study. This was unexpected since published results from grassland sites indicate that amendments of water resulting in optimal production of food species and cover can precipitate marked alterations in species composition of small mammals. We did observe dramatic changes in the relative abundance of small mammals on the irrigated plot, but there were few differences between the densities on the herbicide and control plots.

By the third year densities on the manipulated plots were similar even though the production of surplus food was maintained on the irrigated plot. We tentatively conclude that population regulatory mechanisms other than food quantity were operational during the final year of the study. Further analyses of the changes in population characteristics, such as rates of natality, mortality, and dispersal will hopefully give some clue as to the possible mechanisms involved.

## Wildfire in the Shrub-Steppe Ecosystem

D. W. Uresk, W. H. Rickard and J. F. Cline

A natural fire started by lightning on the ALE Reserve on August 13, 1973, at approximately 10:00 AM (P.S.T.) offered an unusual opportunity to assess the total amount of herbage necessary to sustain a continuous grassland fire.

Prior to the burn, data were collected for total plant herbage, including litter on three pastures. The three pastures include the following: (1) Grazed - grazed for 3 years by cattle; (2) Recovery - grazed for the first 2 years and allowed to rest in 1973; and (3) Control - this pasture had not been subjected to grazing since 1943 or fire since 1957 until the natural burn in mid-August.

The total amount of plant material present in each pasture prior to the fire is presented in Figure 6.10. Approximately 433 $g/m^2$ of total herbage was measured on the grazed pasture with 563 $g/m^2$ and 636 $g/m^2$ on the recovery and control pastures, respectively.

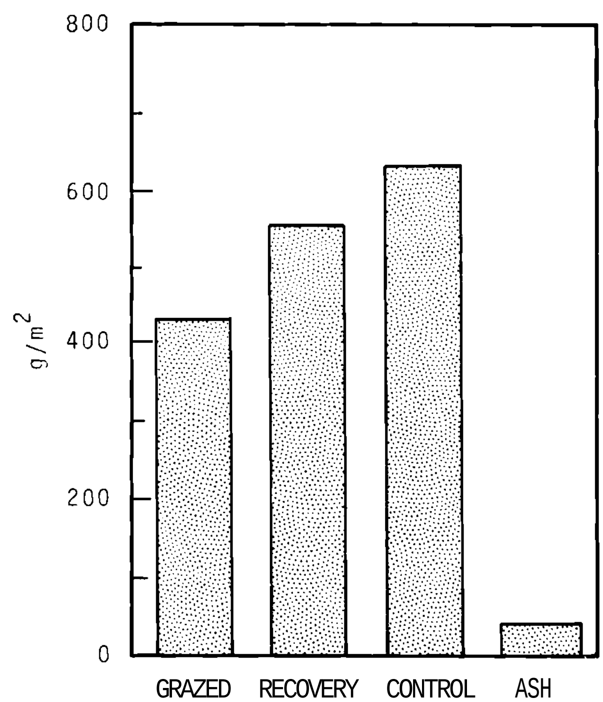


FIGURE 6.10. Total Herbage of Plants ($g/m^2$) on Three Grazing Treatments Prior to a Natural Burn and the Standing Crop of Ash Remaining on the Control After the Burn

When the fire occurred, each pasture had an equal likelihood of burning; however, the control with an additional 73 $g/m^2$ of herbage, was the only pasture that burned. A reduction of plant matter to 563 $g/m^2$, and possibly canopy cover by grazing, reduced the chances of burning under the conditions that were present that day.

Figure 6.10 shows the amount of ash remaining after the burn on the control pasture. A loss of approximately 600 $g/m^2$ resulted from the burn. This is equal to about 2400 $kcal/m^2$ which was released into the surrounding area as heat.

Average hourly wind speeds obtained at the ALE Site, 14 inches aboveground, ranged from 1.2 to 4.8 mph from 8:00 AM to 12:00 PM (P.S.T.) during the time of the fire. The high occurred during 10:00 AM to 11:00 AM with an average wind speed of 4.8 mph. Air temperatures ranged from 48°F to 96°F during these same hours.

In general, fires suppress shrubs and increase the amount of grasses and forbs for the first few years afterwards. However, effects of fire on the plants in relation to soil moisture, intensity of the fire, season of the burn, vigor of plants and nutrients are important factors in the measurement and determination of the response by plants to fire. Burning may be necessary to obtain the most productive ecosystem, since it is a natural phenomenon occurring on the ALE Reserve before man interfered with the role that fire has in ecosystems.

## CONSUMERS

### Analysis of Consumer Food Habits in the Shrub-Steppe Ecosystem

L. E. Rogers and D. W. Uresk
Technical Assistance: M. A. Wise

An ecosystem is a dynamic entity characterized by the continual exchange and redistribution of materials within and between its component parts. This exchange is essential to the stability of the system, but the associated food chains and food webs permitting such transfer also provide a mechanism for distribution of harmful substances inadvertently introduced into the system. Studies pertaining to consumer food habits should provide an interface between existing plant and animal ecology programs and studies concerning the behavior of waste nuclides in an arid ecosystem. The purpose of this report is to outline the techniques available for the assessment of dietary habits of both vertebrate and invertebrate organisms and present some preliminary results of diet analysis.

There are several methods of identifying food habits of native herbivores, but probably the most accurate is a method involving the microscopic identification of material contained within the digestive tract. This method requires a complete reference collection of all plant species present in the study area. Tissues of leaves, stems and reproductive parts are broken up and mounted on glass microscope slides. These slides then serve as reference material for identification of food material contained in the gut of the study species. Microscopic identification of plant species is based on cellular characteristics, primarily epidermal tissues of the plants ingested (Figure 6.11).

Stomach contents from vertebrate consumers are dried and ground to reduce all parts to a uniform size. These samples are then washed and mounted on glass microscope slides. The slides are dried for about three days prior to further processing. Similar methods are employed during analysis of invertebrate food habits except that the entire gut is generally removed and mounted on the glass slide, and the samples are not ground.

Quantification of sampled food material occurs by "reading" about 20 slide locations using 40 to 120 power magnification. A slide location is here defined as that area of the slide delimited by the field of view at a preselected power of magnification. Results may be expressed as frequency of occurrence or as a percent composition for each species. Frequency (number of locations that the species occurred in 100 slide locations) is probably the easiest and most accurate method. Frequency data may be converted to density of particles per location if desired, using existing conversion tables.

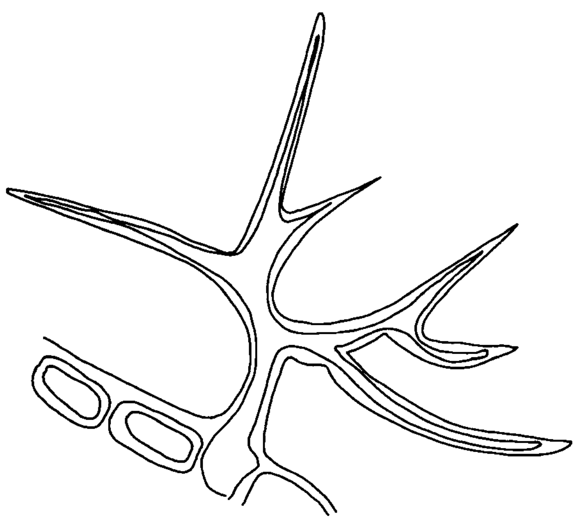

FIGURE 6.11. Showing a Branched Trichome Characteristic of the Annual Forb Draba verna

Table 6.7 shows the dietary composition of the migratory grasshopper Melanoplus sanguinipes (F.) on July 6, 1972. The biennial forb Tragopogon dubius occurred in nearly 50% of the sample points, while the annual forb Microseris laciniata occurred in about 16% of the samples. The annual grass Bromus tectorum and the perennial grass Agropyron spicatum occurred with

TABLE 6.7. Dietary Composition of the Migratory Grasshopper Melanoplus sanguinipes on July 6, 1972

| Plant Species | Common Name | Dietary Composition[a] |
|---|---|---|
| Annual Grasses | | |
| Bromus tectorum | Cheatgrass | 13.8 |
| Festuca octoflora | Sixweeks fescue | 0.5 |
| Perennial Grasses | | |
| Agropyron spicatum | Bluebunch wheatgrass | 11.5 |
| Poa secunda | Sandberg bluegrass | 0.3 |
| Annual Forbs | | |
| Draba verna | Spring draba | 0.2 |
| Holosteum umbellatum | Jagged chickweed | 0.1 |
| Sisymbrium altissimum | Jim Hill mustard | 2.1 |
| Microseris laciniata | Lanceleaf microseris | 15.8 |
| Biennial Forbs | | |
| Tragopogon dubius | Goatsbeard | 49.4 |
| Lactuca serriola | Prickly lettuce | 0.5 |
| Perennial Forbs | | |
| Taraxacum officinale | Common dandelion | 0.4 |
| Crepis atrabarba | Slender hawksbeard | 4.9 |
| Unknown | | 0.5 |
| | Total | 100.00 |

a. Results expressed as percent frequency (number of microscopic locations that a particular species occurred in out of 100 sample points) from a total of 56 grasshoppers.

a frequency of 13.8 and 11.5%, respectively. The migratory grasshopper appears to be polyphagous, selecting a wide range of food materials--as pointed out by earlier workers.

## Insect Ecology Studies

L. E. Rogers
Technical Assistance: N. E. Woodley

Insects are frequently cited as important components of grassland areas, but little is known concerning their role in ecological processes. A study concerning the role of insects in ecosystem functioning was initiated last year (1972) and continued through the present reporting period.

The goals of this study are to ascertain abundance, biomass, trophic structure, and taxonomic composition of insect populations occupying both grazed and pristine areas. The impact of introduced herbivores (cattle) on native consumer populations is of particular interest. Long-term goals involve identifying the influence major insect populations have on critical ecological processes.

Insects are not a particularly visible part of the shrub-steppe system. There are few flying insects and, although some species do occur in the "bare" areas existing between clumps of bunch grass, most are associated with the vegetation dominants--big sagebrush and bluebunch wheatgrass (Figure 6.12). The high summer temperatures and low humidity levels that occur in this area may have resulted in insects selecting those microhabitats offering the greatest buffering against environmental extremes.

Cattle grazing does not seem to have an affect on insect populations associated with big sagebrush (Figure 6.12). This is not surprising since cattle do not generally select this plant as forage material. There are significant differences in the number of insects occupying the "bare" areas. The lower densities in the grazed treatment may be related to trampling and the resulting destruction of the lichen layer. Cattle grazing also appears to have a disruptive influence on insect populations associated with bunch grass--higher densities were found during June and July on the grazed pasture. This may be an artifact, but the same general trend was observed last year. Flying insects will probably never contribute significantly to abundance on either grazing treatment.

Density provides one index as to the "importance" of a particular consumer population, but tends to over estimate populations of smaller organisms. Biomass values provide a better evaluation and are also essential for later energy flow and nutrient cycling analysis. Individual biomass determinations for every sampled specimen would be a time-consuming process. A better method is to determine the relationship between size and weight for each taxonomic group and measure the length of individual specimens as they are identified. Computer processing can then equate size and weight values for all populations. Figure 6.13 shows the relationship between size (body length) and weight for grasshoppers. Regression equations have been established for all major populations on the ALE Reserve.

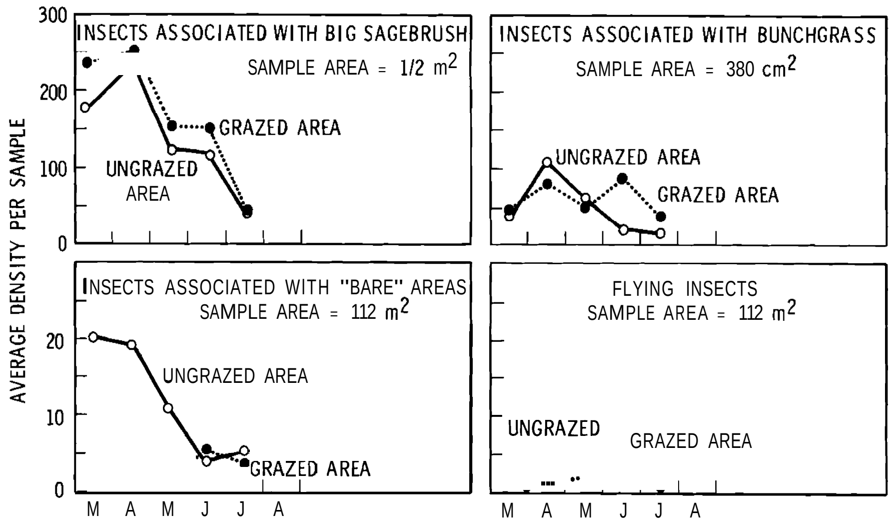


FIGURE 6.12. Impact of Cattle Grazing on Shrub-Steppe Insect Populations

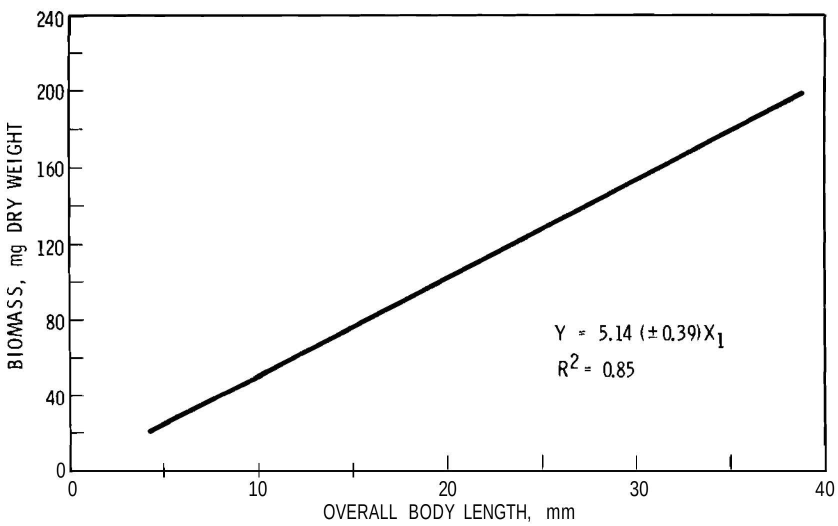


FIGURE 6.13. Relationship Between Length and Biomass for the Grasshopper Population

Nematode Abundance in the Shrub-Steppe Ecosystem

Jim Smolik* and Lee E. Rogers

Nematodes are frequently abundant components of the soil system but are often overlooked unless specific sampling techniques are employed. An effort was made in June of this year (1973) to ascertain the "importance" of nematodes in the shrub-steppe ecosystem.

Soil samples were collected during a period representing the approximate time of peak plant standing crop values. Six samples were selected from

* Cooperating Investigator
South Dakota State University
Brookings, South Dakota

grazed and ungrazed treatment areas to evaluate nematode abundance under both pristine and managed conditions. Separation of nematodes from soil was accomplished using the Christie-Perry method which consists of wet screening followed by Baermann funnel extraction. This method was previously determined to be about 73% efficient..

Highest densities occurred near the soil surface (Table 6.8). This is consistent with preliminary reports from other grassland areas. It appears that food habits are about evenly divided between herbivorous and saprophagous forms. Omnivorous specimens are presently under study and a percentage composition will be calculated for members at each trophic level. Analysis is continuing and we anticipate converting the density data presented here to biomass values This will facilitate comparisons with other soil dwelling invertebrates.

TABLE 6.8. Nematode Abundance in the Shrub-Steppe Ecosystem[(a)]

| Soil Depth[(b)] | Herb-ivores | Omnivores[(c)] | Saprovores | Total |
|---|---|---|---|---|
| | | Grazed | | |
| 0-5 | 1678 | 10 | 1793 | 3481 |
| 5-10 | 1455 | 48 | 1477 | 2980 |
| 10-20 | 363 | 42 | 243 | 648 |
| 20-30 | 210 | 0 | 101 | 311 |
| 30-40 | 105 | 10 | 45 | 160 |
| 40-50 | 102 | 0 | 69 | 171 |
| 50-60 | 61 | 5 | 28 | 94 |
| | | Ungrazed | | |
| 0-5 | 1937 | 69 | 2381 | 4387 |
| 5-10 | 1109 | 60 | 1212 | 2381 |
| 10-20 | 477 | 15 | 281 | 773 |
| 20-30 | 115 | 0 | 92 | 207 |
| 30-40 | 124 | 15 | 103 | 242 |
| 40-50 | 72 | 0 | 70 | 142 |
| 50-60 | 99 | 0 | 38 | 137 |

a. Abundance expressed as the average number of nematodes per 100 $cm^3$ of soil and is adjusted for extraction efficiency.

b. Soil depth expressed in cm.

c. Percentage composition of predators and herbivores presently under study.

We postulate--on the basis of this preliminary sample--that nematodes will be found to constitute a significant portion of the belowground invertebrate biomass in the shrub-steppe ecosystem.

## Association Between *Eleodes humeralis* and Rabbitbrush, Chrysothamnus *nauseosus*

J. K. Sheldon*

A survey of the beetle species Eleodes humeralis was conducted during the summer of 1973. Large populations were found associated with rabbitbrush (Chrysothamnus nauseosus) and were readily collected at night on the foliage where they were feeding. The survey was undertaken to answer two questions. First, are the beetles nomadic within the rabbitbrush community, or is there a tendency to associate with specific plants? Second, what is the density of the beetle population?

The area of study covered approximately 0.13 hectares and contained 34 rabbitbrush plants with volumes of 70 $dm^3$ or greater (length × width × height). Several smaller plants were present, but no beetles were found associated with them.

A total of 485 E. humeralis were collected on rabbitbrush, marked and released on the same plant over a 3-day period. One week later, exhaustive collecting was begun and a total of 455 was obtained for a 4-day period. Of the 455, 113 had been previously marked. Eighty-one of the marked beetles were recaptured on different plants than their original host Twenty-two others were recaptured on the same plant. The average distance travelled for all marked beetles was 8.6 m, while those that left their original host moved an average of 11.9 m. This is probably an underestimate, however, since some beetles had completely left the area of study and were found across a major highway more than 50 m from the bush on which they had been marked.

The population density was estimated using the exhaustive capture technique and a linear regression analysis. The estimated number of E. humeralis within the 0.13 hectare area was 495 or a total of 3808 individuals per hectare.

## Longevity of the Northern Grasshopper Mouse, Onychomys *leucogaster fuscogriseus*, in the Laboratory

J. D. Hedlund and T. P. O'Farrell
Contributor: G. E. Cosgrove

The objective of this experiment was to determine average longevity of Onychomys leucogaster in laboratory colonies. Since working with these animals to observe reproductive performance indicated that they do, in fact, adapt well to life in laboratory, Onychomys could be an excellent test model for long-term experiments which require small mammals having relatively long life spans. In conjunction with the above mentioned objective, having known-age old animals provided an opportunity to examine pathologies which may occur simultaneously with the aging processes.

* Cooperative investigator

The results of this study have shown that the mean age*at death ± SD was for males, 1330 ± 309 days (3.64 years), and for females, 1324 ± 351 days (3.62 years). There appears to be no significant difference in the longevity between sexes overall, but an in depth examination of reproductive performances may provide further information regarding longevity when comparing "physiological age" to chronological age.

Pathologies associated with aging in Onychomys are being examined by Dr. G. E. Cosgrove of the Biology Division, Oak Ridge National Laboratory. Both gross and histopathological diagnoses of decedents have been performed over the past five years. A number of interesting neoplasts have been described and will be included in a summary manuscript which is in preparation.

### Tagging Hanford Deer, *Odocoileus hemionus*

J. D. Hedlund, R. E. Fitzner, G. B. Long and D. T. McCullugh

The 1973 deer tagging operation marked the fifth consecutive year in which mule deer fawns were tagged on the Hanford project. A total of 48 fawns was captured and tagged with tags, one of plastic which is easily identified with binoculars, along with a small metal tag furnished by the Washington State Game Department.

It was noted that many of the does accompanied by fawns are carrying tags from previous years' tagging efforts. These sightings not only exhibit the effectiveness of previous tagging sessions but also provide needed information regarding the age structure of the herd on the Hanford project.

The data for the past five years (Figure 6.14) demonstrates a preference for the islands in the Columbia River or for the riparian vegetation near the shoreline.

At the time of the tagging operation, the river was at minimum flow (<120,000 cfs) and many of the areas which are normally islands essentially became peninsulas. This affected the distribution of the fawning areas as many of the does had already taken the fawns to the mainland. Most of the islands which were still completely surrounded by deep, fast moving water yielded more fawns than past years, again showing the marked preference for the islands as fawning areas. The water surrounding an island provides a barrier for intruders such as coyotes while the fawns are young and relatively defenseless.

The return of tags from sportsmen yields valuable information on the movements of Hanford mule deer from the project to outlying areas. Last fall tag returns indicated movements of deer as far as 20 miles from their original fawning grounds.

Continued tagging operations will better define the composition and distribution of the Hanford mule deer herd.

### Waterfowl Studies

R. E. Fitzner

This paper reports the twenty-first consecutive annual spring survey of

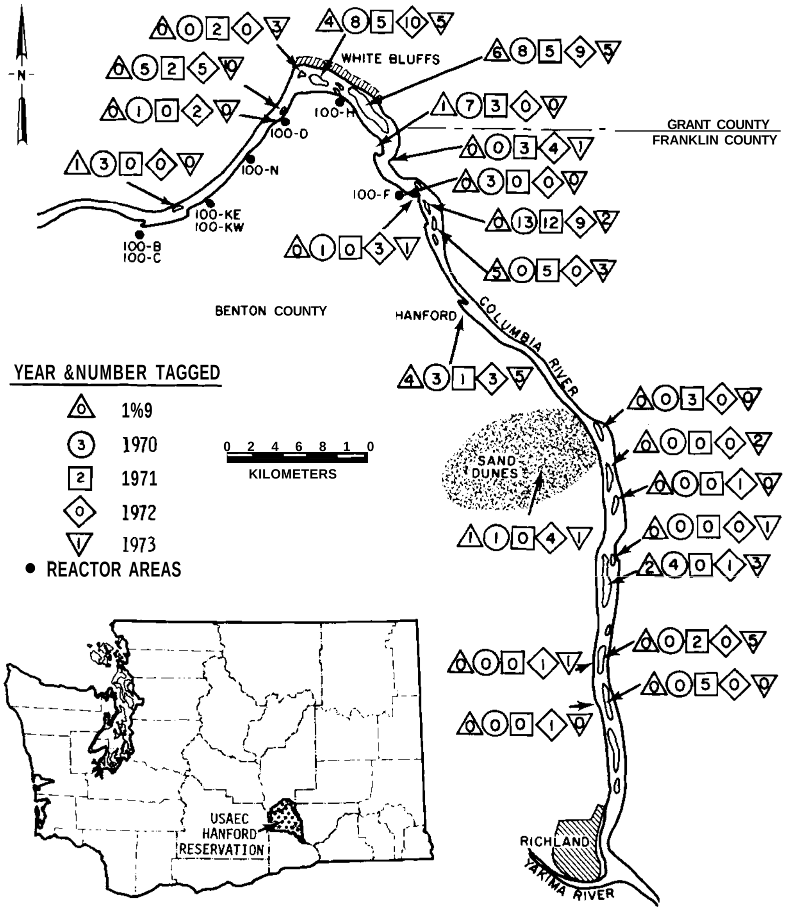


FIGURE 6.14. Hanford Deer Tagging Areas

Canada goose nesting on Columbia River islands and wintering waterfowl abundance during the 1972-73 season on the Hanford Reservation.

A total of 131 goose nests were found of which 116 were successful (Table 6.9). A total of 643 eggs hatched 580 young. This represented a 17% drop in total number of young produced from last year's values and a drop of 30% below an 18-year mean. The decline in number of hatchlings is not due to decreased clutch sizes nor to failure of eggs to produce young successfully, but is due to a decrease in total number of nests.

The decline in nest numbers is attributed to (1) changes in vegetation that have occurred over the years,

TABLE 6.9. Number of Canada Goose Nest and Eggs, Recorded on the Hanford Stretch of the Columbia River, 1973

| | Number |
|---|---|
| Total number of nests | 131 |
| Successful nests | 116 |
| Eggs in successful nests | 643 |
| Young from successful nests | 580 |
| Eggs/successful nest | 5.5 |
| Young/successful nest | 5.0 |

namely an increase in willow thickets that are not used as nest sites, (2) the presence of coyotes on certain islands, and (3) nest desertion as a result of human visitation to nests early in the egg laying period. To improve the island habitat for goose nesting some means of growth suppression of woody vegetation is suggested, realizing that the suppression of woody vegetation would reduce summer forage for mule deer populations. Elevated platforms supporting bowl-shaped platforms 3 ft 8 in. in diameter have been set out on certain islands as one way to circumvent the coyote as a nesting goose predator. Whether or not geese will accept these platforms as nest sites remains to be seen. It is suggested that the number of human visits to goose nests for recording data be reduced and that the survey not begin until a strong affinity is established between goose parents and the incubating eggs.

Aerial surveys of wintering ducks utilizing the Hanford reach of the Columbia River were made monthly during October, November and December, 1972, and January, 1973. A peak population of nearly 70,000 ducks was observed in January 1973. An 8-year mean (1961-1969) records over 250,000 ducks in the Hanford reach of the Columbia River. The decline in duck use of the Hanford reach of the Columbia is probably due to ducks selecting other areas in the region as wintering habitats.

## PRIMARY PRODUCERS

### Impact of Spring Grazing by Cattle on Shrub-Steppe Vegetation

W. H. Rickard, R. O. Gilbert, J. F. Cline and D. W. Uresk
Technician Assistance: V. D. Charles, H. A. Sweany, L. E. Rendall, M. A. Combs, L. F. Nelson and M. J. Harris

A major objective of grassland biome studies is to assess the impact of controlled grazing by cattle on a pristine stand of shrub-steppe vegetation.

During 1973, three 9-hectare pastures were sampled to determine the impact of grazing on herbage yields. The three pastures or treatments included the following: (1) Control - no grazing by cattle; (2) Recovery - grazed by cattle for 2 years and allowed to rest during 1973; (3) Grazed - continuous grazing by cattle for three spring growing seasons. Sampling of the vegetation for biomass was conducted before cattle were introduced, during the grazing period and after cattle were removed.

Three perennial grasses, *Agropyron spicatum*, *Poa cusickii*, and *Stipa thurberiana*, were the major forage plants. *Poa secunda* is a small perennial grass which provided little forage for cattle because of its short growth form and it did not appear to be enhanced or retarded under the present grazing intensity.

Figure 6.15 shows the dynamics of live herbage for perennial grasses on

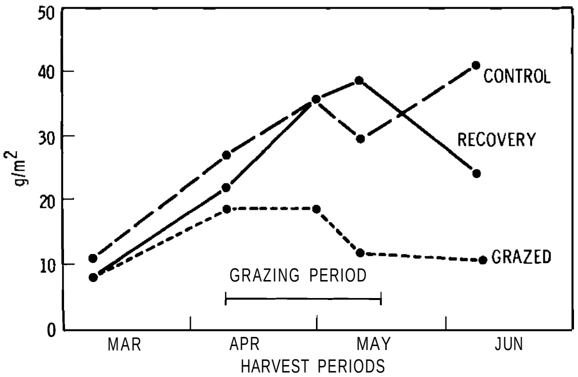


FIGURE 6.15. A Comparison of Live Standing Crop of Perennial Grasses ($g/m^2$) by Harvest Dates on Three Pastures During 1973

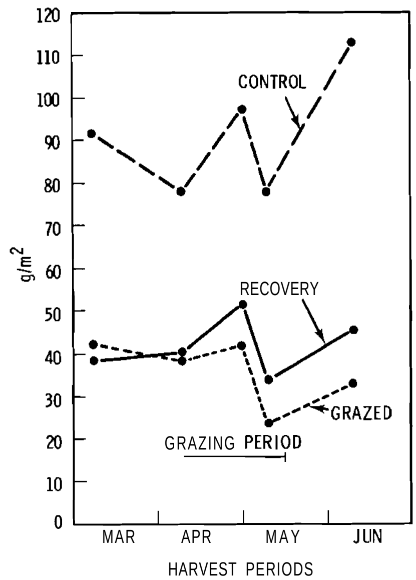


FIGURE 6.16. A Comparison of Dead Standing Crop of Perennial Grasses ($g/m^2$) by Harvest Dates on Three Pastures During 1973

the three pastures. The control pasture steadily increased in live herbage until early May when it decreased slightly and then increased to a high of 41 $g/m^2$ in mid-June. A similar growth pattern is shown for the recovery pasture, reaching a high of 38 $g/m^2$ during mid-May and decreasing for the remainder of the season.

When cattle were introduced on the grazed pasture, there was 20 $g/m^2$ of live herbage. The amount of live herbage remained constant until early May when the biomass decreased to about 11 $g/m^2$ and remained at this level until mid-June. Cattle were removed from the pasture in mid-May shortly after the decline in live biomass.

The amount of dead vegetation was much higher on the control pasture than on the recovery or grazed pastures (Figure 6.16). Most of the standing dead herbage on the control pasture represents several years of accumulation. The amount of dead herbage on the recovery pasture was generally higher than on the grazed, having a high of 53 $g/m^2$ in early May and then fluctuating for the remainder of the season. The recovery pasture represents a realistic estimate of the dead herbage resulting from the current year's growth, because most of last year's growth was removed by cattle.

A comparison of live standing crop ($g/m^2$) of the perennial forbs by harvest dates on each pasture during 1973 is presented in Figure 6.17. A similar growth pattern was observed on all three pastures with the control pasture generally having the highest standing crop throughout the season. Each pasture reached a high in live biomass in early May with the control having 3.9 $g/m^2$, followed by grazed, 3.3 $g/m^2$ and recovery, 3.1 $g/m^2$. The results show that grazing produced various effects on the forbs.

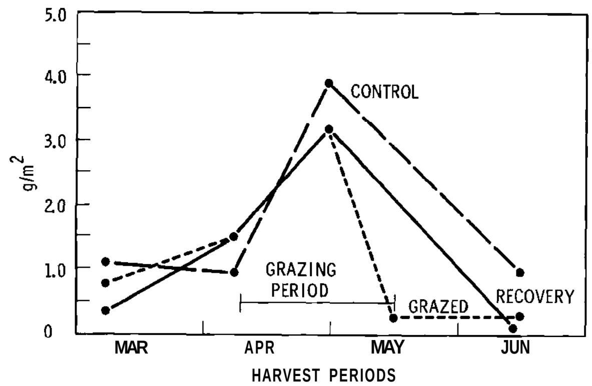


FIGURE 6.17. A Comparison of Live Standing Crop ($g/m^2$) of Perennial Forbs by Harvest Dates on Each Pasture During 1973

Crepis atrabarba, a large perennial forb, was highly selected by the cattle. All plants of this species were grazed to ground level, and it appears that the biomass production has been reduced by the present grazing intensity.

The plants that were not highly selected by cattle include Artemisia tridentata, Erigeron filifolius and Phlox longifolia. E. filifolius was enhanced by grazing and showed a general increase in total standing crop. No apparent changes were indicated in the other two species.

From the data presented, it can be estimated that cattle had consumed or destroyed by trampling about 25 $g/m^2$ of live herbage and 10 $g/m^2$ of dead herbage. These values were estimated from the annual herbage yield of perennial grasses. Approximately 1 $g/m^2$ of the annual yield of forbs was consumed. A dietary analysis would be required to estimate each species of plant consumed and may be an important factor for estimating transfers to higher trophic levels. The estimates presented do not reflect the true consumption of herbage intake by cattle. Other methods would need to be employed to determine the actual intake of the animals.

The use of cattle to manipulate the vegetation and to place stress upon the ecological system broadens the understanding of the function and structure of an ecosystem that would not have been possible otherwise. However, several years of stress on the ecosystem are required to obtain measurements of all possible functions and structures.

## Belowground Plant Biomass in the Shrub-Steppe Ecosystem

J. F. Cline and W. H. Rickard
Technical Assistance: ti. A. Sweany, V. D. Charles, L. F. Nelson, M. J. Harris, M. A. Combs and L. E. Rendall

Belowground biomass is difficult to measure because of the problems associated with taking soil cores in dry soil and the separation of root material from soil particles. However, belowground biomass represents a significant part of the ecosystem. This paper compares belowground biomass at the end of the spring growing season in annual grass communities dominated by cheatgrass, Bromus tectorum, and perennial grass communities dominated by bluebunch wheatgrass, Agropyron spicatum. On the average, more belowground biomass is present in the perennial grass as compared to the annual grass community (Table 6.10). The distribution of belowground biomass in the soil profile is shown in Figure 6.18. The

TABLE 6.10. Average Belowground Biomass in the Surface 0.8 Meter Depth of Soil Profile in Annual and perennial Grass Communities at the End of the Spring Growing Season in 1973. Results are Expressed as Grams per Square Meter Dry Weight (Ash Free)

| Community | | | Biomass $g/m^2$ ($\pm$ SE) |
|---|---|---|---|
| Annual Grass | | | |
| Ungrazed | 1000 ft | elevation | 836 ± 66 |
| Ungrazed | 1700 ft | elevation | 338 ± 20 |
| | | | $\bar{X}$ 587 |
| Perennial Grass | | | |
| Grazed | 1200 ft | elevation | 995 ± 99 |
| Ungrazed | 1200 ft | elevation | 1210 ± 122 |
| | | | $\bar{X}$ 1102 |

greatest amount of biomass is found in the surface decimeter of soil depth. As soil depth increases, belowground biomass decreases. At depths below 3 dm the biomass of the perennial grass community exceeds that of the annual grass community.

These kinds of data would be more meaningful if living root biomass could be separated from dead roots. The living root component of annual and perennial grass communities may not be as different as suggested by the estimates of total belowground biomass.

## RADIATION STUDIES

### Fallout Radionuclides in Northern Alaskan Ecosystems

J. D. Hedlund, T. P. O'Farrell and H. A. Sweany

The objectives of this study are to further define the routes, rates, and amounts of fallout radionuclides in natural ecosystems in northern Alaska. Past and present emphasis

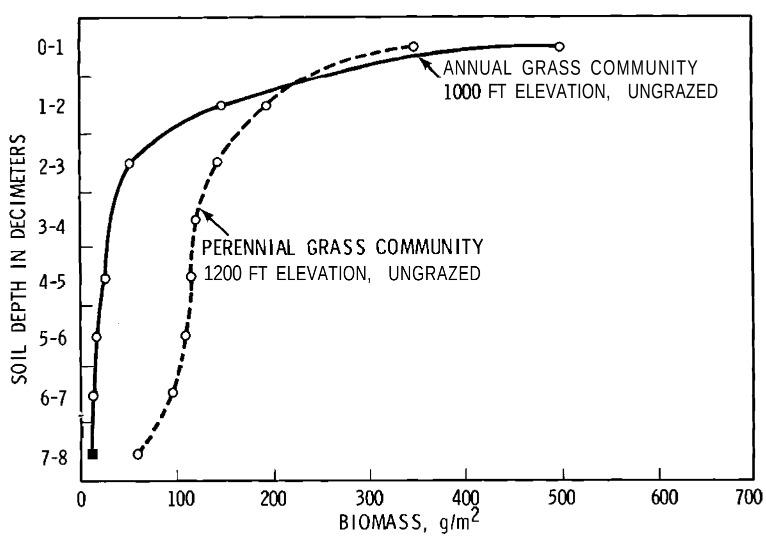


FIGURE 6.18. The Distribution of Belowground Biomass with Depth in Perennial and Annual Grass Communities

has been directed towards the $^{137}Cs$ body burdens of the native residents of Anaktuvuk Pass and the $^{137}Cs$ levels found in the lichen-caribou-Eskimo food chain.

Body burden measurements were made in January and July 1973. These months are the previously observed minimum and maximum body burden periods, respectively. The results of these sampling sessions (Table 6.11) indicate that the body burdens are continuing their downward though stabilizing trend.

At the time of the whole-body counting sessions, samples of caribou, lichens and sedges were obtained and have been analyzed for $^{210}Pu$-$^{210}Po$ as well as for levels of $^{137}Cs$. The results of these measurements are now being examined to determine the necessity of continued surveys of other radioelements in addition to $^{137}Cs$. If the levels of $^{210}Pb$-$^{210}Po$ demonstrate a cyclic pattern similar to that of $^{137}Cs$, it would appear that nuclides other than $^{137}Cs$ may be contributing to the average annual whole body burdens of northern natives The bi-monthly sampling of caribou and lichens on the wintering ranges will continue through May 1974. On initial examination of the results of the caribou flesh analysis, it appears that the levels of $^{137}Cs$ tend to be significantly higher in the caribou taken on the wintering grounds south of the Brooks Range than those taken near Anaktuvuk Pass in the same time period. Further detailed analysis of the levels of radionuclides combined with information on the movements and foraging habits of the caribou should explain the occurrence of these differences.

Through arrangements with the Public Health Service, blood samples from residents of two Alaskan villages were obtained for members of the Radiological Sciences Department.

TABLE 6.11. Body Burdens of Anaktuvuk Pass, Alaska, Residents During 1973

| Age Category | No. | $^{137}Cs$ Body Burdens (nCi) Mean + Standard Error | Range |
|---|---|---|---|
| January | | | |
| Adults (> 21 yrs.) | 32 | 163 ± 13 | 40 - 300 |
| Minors (15–20 yrs.) | 1 | 90 | |
| Children (< 15 yrs.) | 32 | 22 ± 2 | 10 - 40 |
| July | | | |
| Adults (> 21 yrs.) | 30 | 312 ± 22 | 140 - 580 |
| Minors (15–20 yrs.) | 8 | 181 ± 22 | 90 - 260 |
| Children (< 15 yrs.) | 24 | 65 ± 7 | 20 - 160 |

These were analyzed for $^{55}Fe$ content to determine differences, if any, between $^{55}Fe$ levels in the blood of caribou-eating people versus salmon-eating people.

Response to Acute Radiation of Small Mammals

J. D. Hedlund and T. P. O'Farrell

Three species of small mammals, Chinese hamsters, *Cricetulus griseus*, sagebrush voles, *Lagurus curtatus*, and Mongolian gerbils, *Meriones unguiculatus*, were exposed to acute doses of radiation to determine their $LD_{50/30}$ values. The exposures took place in a 2000 Ci $^{137}Cs$ annular source.

Results obtained from probit transformation of survivorship curves shows the $LD_{50/30}$ values for the Chinese hamsters to be 1100 [1094-1190 rad. (95% fiducial limits) Figure 6.191. On initial observation of these results, it appears that there may be significant sex-specific responses to median lethal doses of ionizing radiation.

The second species irradiated, sagebrush voles, were a group of animals reared in the laboratory. These animals, though indigenous to southeastern Washington, were found difficult to maintain in a laboratory colony and mortality was very high in weanlings as well as in adults. The results of the probit transformation of the survivorship curves exhibits a wide range between the lower and upper fiducial limits. The $LD_{50/30}$ value for this species was calculated at 1090 (792-1498). The variability of this value is probably due to non-radiation induced deaths in the lower exposure levels. This assumption may be confirmed after examination of the pathological reports on the decedents.

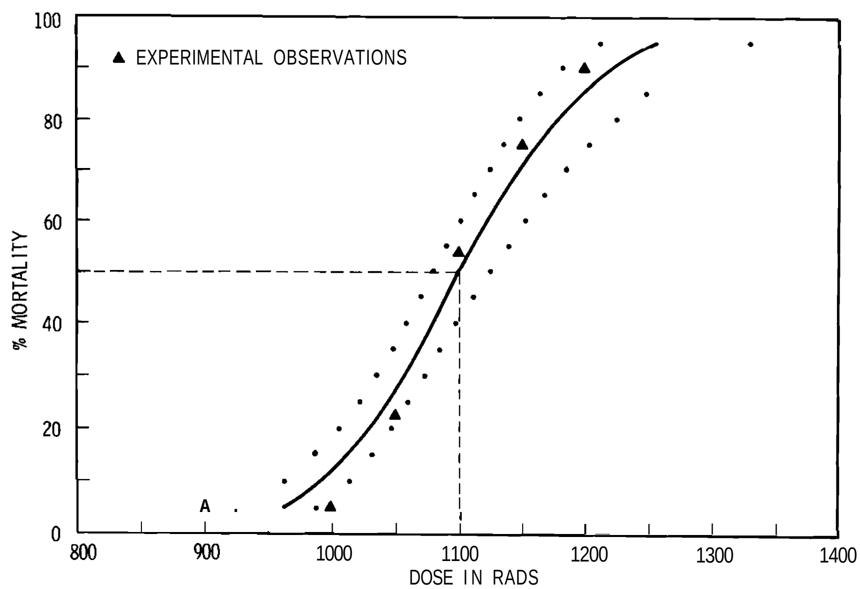


FIGURE 6.19. Response of Chinese Hamsters to Ionizing Radiation

The third species irradiated, Mongolian gerbils, proved to be more resistant to radiation than was expected after surveying recent literature. The calculated $LD_{50/30}$ from our data was 1219 (1128-1875). A second irradiation is now in progress, which will fill in the higher dose levels and will allow a more accurate determination of the actual $LD_{50/30}$.

The results of the irradiation of these three species will be incorporated into previously reported data. Since our data have indicated relatively high resistance to ionizing radiation, these three experiments have added to our already extensive background data which demonstrates the potential benefits of using different species of small mammals as animal models to test the mechanisms responsible for the variation in mode or chronology of radiation death.

Plutonium Uptake in Field Conditions: Experimental Design

W. T. Hinds and J. F. Cline
Technical Assistance: V. D. Charles and H. A. Sweany

Plutonium uptake by plants has in the past generally been studied under controlled laboratory conditions or as an adjunct to releases for other purposes (weapons testing in the past, for instance). Controlled experiments under field conditions are rare or nonexistent. However, field studies are essential to provide realistic out-of-doors data as baselines for laboratory results. Water relations, large plants and mature plants are three conditions that are difficult to study in controlled environments. To remedy this deficiency, an experiment was designed and fabricated to determine the effects of environmental and soil conditions on uptake by important species of plants.

The objectives of this pilot study are as follows:

1) To determine the effect of water relations and nitrogen availability in alteration of plutonium uptake by cheatgrass and mustard in field conditions; and
2) To determine the uptake of large and mature plants of important wild and domestic species.

The isotope of plutonium selected for the study is $^{238}Pu$, which has a relatively short half-life (86 yr) and may have a relatively high biological mobility compared to $^{239}Pu$. The plants will be grown in small lysimeters (described in earlier annual reports) containing plutonium-spiked soil. The small lysimeters will prevent loss of the plutonium into relatively uncontrolled space, and will enable complete removal of the contaminated soil after the period of experimentation is complete. The plutonium will be administered as a nitrate solution containing a total of 1 mCi of plutonium pipetted onto 100 gm of dry soil and thoroughly mixed. The spiked soil will then be placed in the lysimeters on top of clean dry soil at a depth of 12 cm below the top of the lysimeters. The spiked soil will form a layer about 6 mm thick which will be covered by 10 cm of clean soil. Seeds will then be planted in the lysimeters and the lysimeters placed in the soil.

The species chosen for the study were Bromus tectorum (cheatgrass) and Descurainea sophia (Tansy mustard)--two important colonizers of disturbed soils in the Hanford region--and Triticum sp. and Pisum sativum (wheat and peas)--two important crop plants grown in the region. The cheatgrass/mustard experiment will include both normal and optimum (i.e., irrigated and fertilized) growth conditions to emulate conditions found in both field and laboratory conditions.

The experiment will involve 130 lysimeters the first year, ten lysimeters for each of the following treatments:

1) Cheatgrass grown in optimal conditions, early harvest;
2) Cheatgreass grown in normal conditions, early harvest;
3) Cheatgrass grown in optimal conditions, late harvest;
4) Cheatgrass grown in normal conditions, late harvest;
5) Wheat grown in typical agricultural conditions, late harvest;
6) Peas grown in typical agricultural conditions, late harvest;
7) Duplicates of the above conditions without plutonium (controls); and
8) No green plants at all (control to estimate evaporation from soil)

The lysimeters will be weighed periodically to determine water use during the season, and to estimate the necessary amount of water required to keep the optimal cheatgrass, wheat and pea treatments near optimal conditions. The lysimeters will be weighed inside a wind-proof shelter in a jig designed to prevent accidental mishandling of the lysimeters.

Entrance to and egress from the test area will be controlled by a newly constructed fenced enclosure (Figure 6.20) which for this pilot study will be 5 x 13 m X 1.8 m high. The enclosure will be constructed of 1 in. mesh poultry wire stretched between treated cedar posts 2 m apart, and topped by a covering of 2 in. mesh poultry wire. In addition, 1/4 in. mesh hardware cloth will be attached to the posts from 15 cm below the surface to 45 cm above the surface. Small animals will be prevented from climbing over the hardware cloth by lengths of inverted roof gutters. Creeping organisms will be proscribed by 10 cm high lawn edging, and baited live and snap traps will be kept in the enclosure to entice any transgressors from the lysimeters. The green plants will be harvested in June 1974, before large populations of flying insects emerge, and before fire hazard exists for the standing dead material.

FIGURE 6.20. Enclosure to House and Protect Plutonium-Spiked Lysimeters Containing Plants Exposed to Field Conditions

## MODELLING

### Simulation Model of a Cheatgrass Ecosystem

Ronald H. Sauer*

#### MINISIM

MINISIM, the shortened version of the Grasslands Biome simulation language SIMCOMP, was installed on the UNIVAC 1108, and later, on the new CYBER 70 system, with the generous assistance of Dick Olson.

#### ELM - IBP Site

With MINISIM operational, I started gathering data and information necessary to adapt the Grasslands Biome ecosystem model ELM to the ALE site. The version of ELM available in June, 1972 was adapted to only the Pawnee site in Colorado, and was soon found to be inadequate to simulate the annual species and more xeric characteristics of the ALE Reserve. Improvements were made simulating ALE grassland, and new improvements continue to be added to ELM as more is learned and understood about the real and simulated ecosystems.

In the abiotic section it became evident that the algae-lichen crust on the soil surface is very important

* NSF Modelling Liaison, Grassland Biome

in controlling evaporation and transpiration; reasonable simulations were obtained by representing the algae-lichen crust as a 2 cm thick top soil stratum. My primary responsibility in the ELM project in the Grasslands Biome is the primary producer model, and I took advantage of the opportunities afforded me during my visit to Battelle to experiment with several versions of the primary producer model and make many improvements in the sections simulating photosynthesis, shoot to root transfers, shoot death, standing dead loss, and seed growth and germination. My experiences at Battelle were instrumental in developing a new phenological simulation model for ELM. The consumer and decomposer sections of ELM are not site specific and required little change to produce reasonable simulations. Presently, the ALE version of ELM produces reasonably good simulations of the biomass dynamics of the perennial bunchgrass prairie characteristic of much of the ALE Reserve, in a variety of climatic conditions.

ELM - Old Fields

The ELM model was applied to the old field study site as a test of ELM's capacity to simulate annual species. This test proved to be very instructive as unexpected results were obtained in photosynthetic rates, root growth, seed production, soil water content, and consumer (steer) growth. The necessary improvements have been made, and the old field version of ELM produces reasonable simulations under a variety of climatic conditions.

Data Collection

In connection with my modelling activities, I have assisted in data collection with grass clipping on the IBP and old field plots and I have been taking phenology data at the IBP site. Participation in data collection has given me additional insight into experimental and simulation problems, and furthered my opportunities to exchange ideas with the Battelle staff.

Seminars

I presented one departmental seminar on modelling in general in the US/IBP Grasslands Biome, and helped to organize a series of monthly informal modelling seminars. The informal seminars have been successful in initiating communication between biologists and nonbiologists as well as between biologists.

DBER Review

At the recent (17, 18, 19 April) DBER review, I presented the modelling philosophy of the Grasslands Biome. Of particular importance is the distinction I was able to emphasize between inductive modelling, in which the level of understanding advances from the specific to the general, and deductive modelling in which the level of comprehension advances from the general to the specific. The latter has its particular usefulness in identifying inadequate areas of data or theory in the total system, and the former in prediction.

ALE - IBP Data Need Priorities

A goal of systems analysis is to understand ecosystems and ecosystem processes (Smith, 1970). To this end, an ecosystem model, such as the ELM model developed in the US/IBP Grasslands Biome, can be used to identify inadequacies in both data and concepts in ecosystem studies. Figure 6.21 is a box and arrow representation of the biotic components of an ecosystem. The abiotic components, for purposes of this discussion, are considered driving variables. As many species of primary producer and consumer may be visualized as necessary to account for the observed biomass. The decomposer trophic level is based not on species but rather functional groups (litter versus roots) and could be elaborated as necessary.

In the ELM model, attention is focused on the processes that transfer material between the boxes. The validity of the process representations in the model is tested by comparing the model simulation output for the boxes with data values obtained from field collections.

Most data available to date is state variable data, and hence the processes connecting these state variables have been structured by using qualitative descriptions made quantitative with rate constants and intuition. The modeler relies heavily on information from investigators in all fields for such information. For example, the rate of photosynthesis of Bromus tectorum (and other species) is regulated in part by soil water content, soil and air temperature, insolation, nutrients, current phenophase, and leaf area. The simultaneous quantitative relationships between these controls as they affect photosynthetic rate are not available for Bromus tectorum or any other primary producer species on the ALE Reserve. Until this sort of information is available, modelling representations and subsequent ecosystem

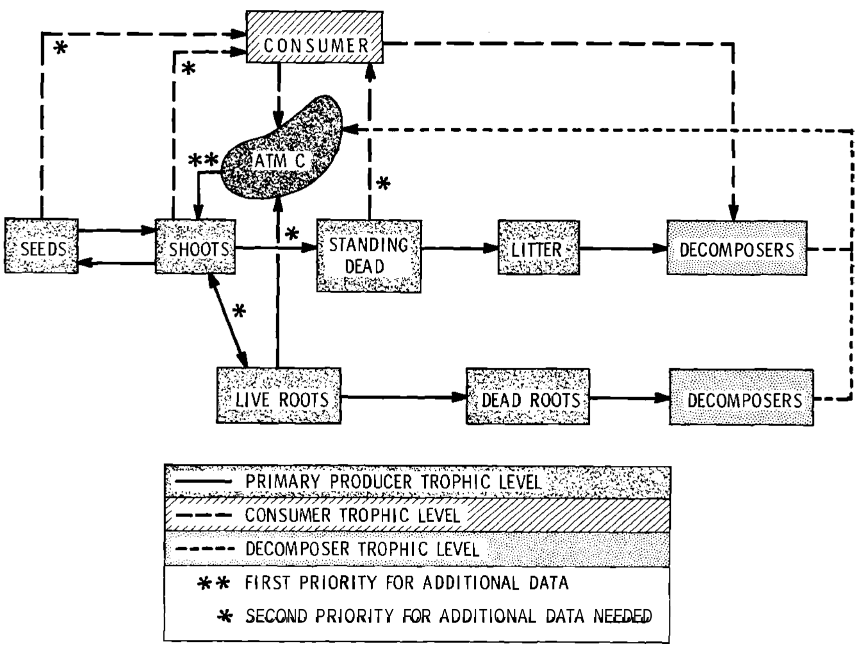


FIGURE 6.21. Simulation Model of Cheatgrass Ecosystem

comprehension will continue to be dependent on insecure foundations. Not represented on the diagram explicitly is the need for more belowground state variable and process data. The belowground system is a very dark part of our understanding, yet it appears to have a large part in total ecosystem regulation. Hence, the belowground system has ** (see Figure 6.21). It would be desirable to stratify the belowground system so that the effect of contrasting characteristics of the soil strata, such as soil water content, could be simulated and thereby studied.

The above comments pertain to the biomass processes and state variables. At another level, the boxes and arrows represent other materials, such as N and P. Here again state variable and process data are wanting, and preliminary models are based on incomplete data and intuition.

Interaction between ecosystem modelling and experimental work can lead to better understanding of ecosystem processes. This is an iterative process in which new experimental results either verify current modelling representations or suggest better representations, and the model indicates which experimental data are most needed.

In summary, the ELM model, as applied to the ALE IBP site and old fields site indicates that more data are needed on photosynthesis as it is regulated by physiological and climatological variables in the principal producer species. Belowground data are also needed, particularly the distribution of the root system of each of the dominant species, and the relationship between root biomass and water absorption capacity. With reliable representations of these elements of the model, other sections can be more effectively studied and understood.

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- **ENVIRONMENTAL IMPACT STATEMENTS**

# ● ENVIRONMENTAL IMPACT STATEMENTS

## Environmental Impact Assessment

The Ecosystems Department, along with other Departments of Battelle, Pacific Northwest Laboratory, has for the past 1 1/2 years been assisting the Directorate of Licensing in the preparation of environmental statements for nuclear power stations. These statements are addressed to the assessment of impact potentially arising from both siting and operation of the nuclear stations. During the 1971 calendar year, most stations that were evaluated were in some stage of completion. In some instances, they had been operating for 1 or more years.

During 1972 and the first half of 1973, effort was addressed chiefly to new power plants. The program was terminated on July 1, 1973. For record purposes, all draft statements reviewed by PNL are listed in Table 7.1, with report status indicated as of December 18, 1973. We anticipate some small-scale continuing effort on Shearon Harris, Monticello, Oyster Creek, and Waterford nuclear plants. These efforts will involve participation in hearings and assistance in the development of nonradiological (e.g., ecological) technical specifications. Copies of the Final Statement are obtainable through the Directorate of Licensing by reference to issue date and docket number.

TABLE 7.1. . Current Status of Nuclear Power Stations Evaluated by PNL 1971-1973

| | Name/Location | Reactor Type[a] | Design Power, $MW_e$ | Type of Cooling | Type Aquatic Environment | Proposed Power Level | | Date of Issue, Final Statement | Docket No. |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Calvert Cliffs 1 and 2<br>Lusby, Maryland | PWR | 800 each | once thru | estuary | 2450<br>2450 | 800<br>800 | 4/6/73<br>4/6/73 | 50-317<br>50-318 |
| 2 | Point Beach<br>Manitowoc Co., Wisconsin | | 454 | once-thru | freshwater (lake) | | | 5/19/72<br>5/19/72 | 50-266<br>50 301 |
| 1 | Pilgrim<br>Plymouth. Massachusetts | BWR | 625 | once thru | marine | 1998 | 655 | 5/72 | 50-293 |
| 4 | Turkey Point 3 and 4<br>Dade Co , Florida | PWK | 760 each | once-thru | ocean | 2097<br>2097 | 760<br>760 | 7/18/72<br>7/18/72 | 50-250<br>50-251 |
| 5 | Maine Yankee<br>Lincoln Co., Maine | PXK | 827 | once-thru | estuary | 2440 | 827 | 7/19/72 | 50-309 |
| 6 | Zimmer<br>Moscow, Ohio | BWR | 80' | tower | freshwater (river) | 2436 | 807 | 9/7/72 | 50 358 |
| 7 | Aguirre<br>Barrio Aguirre,<br>Puerto Rico | PWR | 614 | once thru | ocean | 1785 | 614 | (withdrawn) | 50 376 |
| 8. | Fort Calhoun<br>Washington Co . Nebraska | PWR | 481 | once-thru | freshwater (river) | 1420 | 481 | 8/30/72 | 50-285 |
| 9 | Cooper Station<br>Nemaha Co., Nebraska | BWR | [illegible]8 | once thru | freshwater (river) | 2381 | 778 | 2/9/73 | 50 298 |
| 13 | Monticello<br>Monticello, Minnesota | BWR | 472 | once thru + mechanical tower | freshwater (river) | | | 11/22/72 | 50 263 |
| 11. | Crystal River<br>Crystal River, Florida | PWR | 855 | once-thru | estuary | 2452 | 855 | 5/22/73 | 50 302 |
| 12. | Brunswick 1 and 2<br>Brunswick Co.,<br>North Carolina | BWR | each | once thru | estuary (ocean) | 2436<br>2436 | 821<br>821 | 12/20/73<br>12/20/73 | 50 324<br>50 325 |
| 13 | Hutchinson Island,<br>(St. Lucie 1 and 2)<br>Hutchinson Island, Florida | PWR | 890 | once thru | estuary (ocean) | 2700<br>2700 | 890<br>890 | 6/18/73 | 50-335 |
| 14 | summer | | | once thru | freshwater (cooling lake river) | 2785 | 918 | 1/73 | 50-395 |
| 15 | Rancho Seco<br>Sacramento Co ,<br>California | PWR | | tower | | 2452 | 850 | 3/12/73 | 50-312 |
| 16 | Salem 1 and 7<br>Salem, New Jersey | PWR | 1050 each | once-thru | estuary | 3250<br>3250 | 1050<br>1050 | 4/4/73<br>4/4/73 | 50-272<br>50-311 |
| 17. | Waterford 3 and 4<br>Taft, Louisiana | PXK | 1210 each | once-thru | freshwater (river) | 3580<br>3580 | 1210<br>1210 | 3/22/73<br>--- | 50-382 |
| 18. | Shearon Harris 1,2,3,4<br>Wake Co , North Carolina | PWR | 960 each | once-thru (cooling reservoir) | freshwater (river) | 2785<br>2785<br>2785<br>2785 | 900<br>900<br>900<br>900 | 5/16/73<br>5/16/73<br>5/16/73<br>5/16/73 | 50-400<br>50-401<br>50-402<br>50-403 |
| 19. | Haddam Neck<br>Haddam Neck, Connecticut | PWR | 600 | once thru | estuary | | | 10/73 | 50-213 |
| 20 | Millstone 1 and 2 (M 2) | BWR<br>PWR | 549<br>828 | once-thru<br>once-thru | ocean | 2560 | 830 | 11/25/72<br>11/25/72 | 50-245<br>50-336 |
| 21. | Beaver Valley<br>Whippingport,<br>Pennsylvania | PWR | 888 | tower | river | 2660 | 888 | 7/19/73<br>7/19/73 | 50-334<br>50-412 |
| 22 | Oyster Creek<br>Oyster creek. New Jersey | | | once-thru | estuary | | | --- | 50-219 |
| 23 | Forked River<br>Oyster Creek, New Jersey | PWR | 1250 | once-thru | estuary | 3560 | 1250 | 2/16/73<br>--- | 50-363 |

a PWR - pressurized water reactor
BWR - boiling water reactor

In addition to the effort scheduled above, staff members have produced three topical reports concerned with rationale and approach in the assessment of impacts. These are:

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Hutchinson Island (St. Lucie No. 1, No. 2)
Hutchinson Island, Florida

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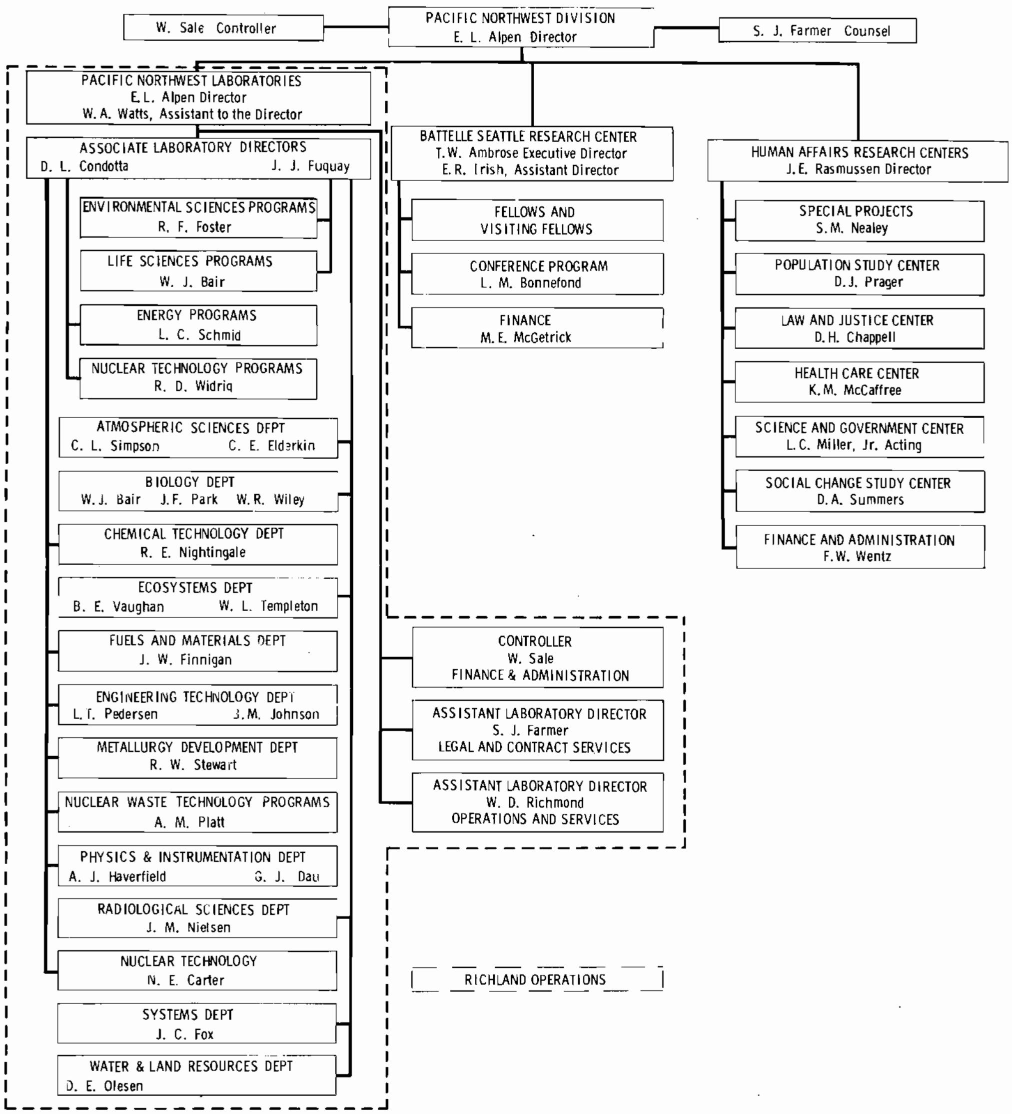

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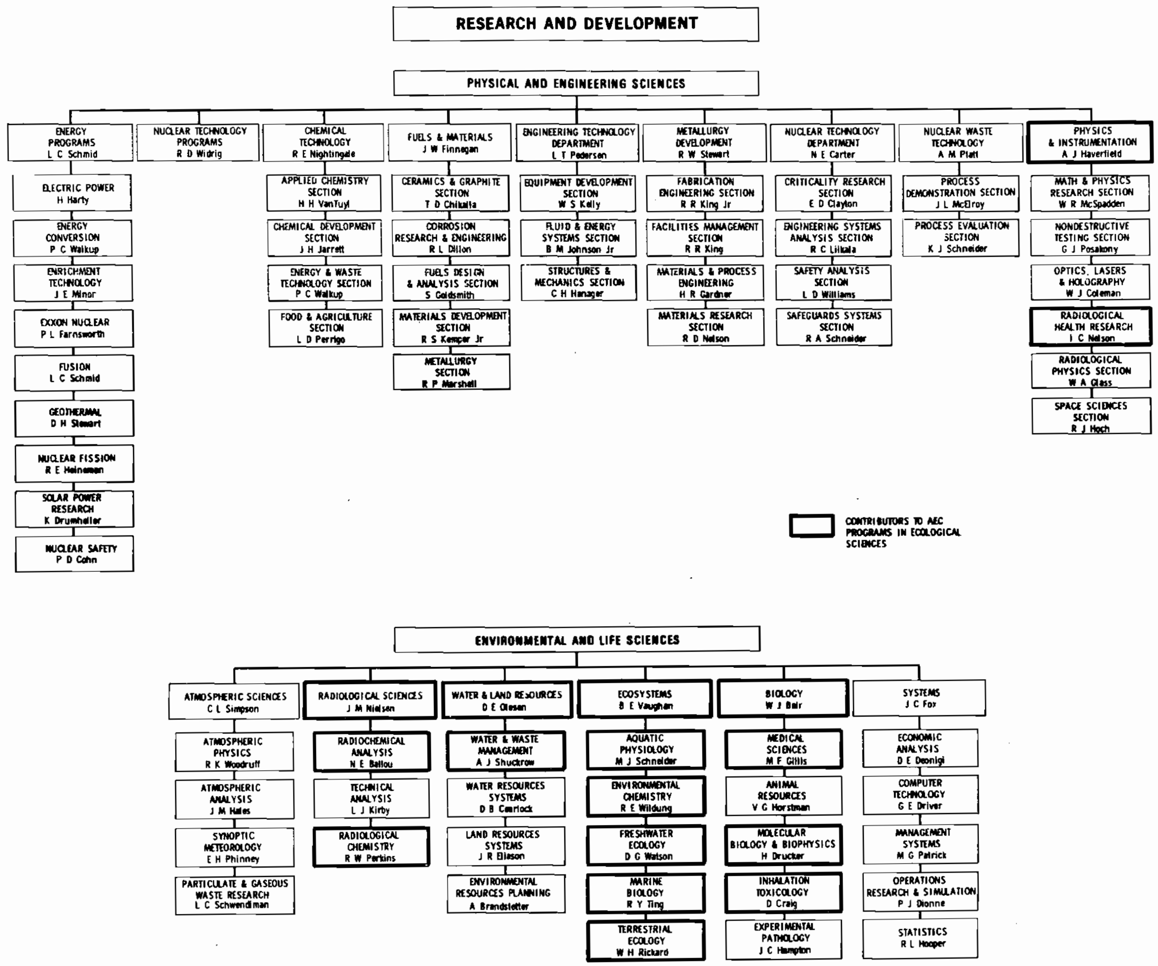
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ENVIRONMENTAL AND LIFE SCIENCES
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Radiological Health Research Section - I. C. Nelson

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Radiochemical Analysis Section - N. E. Ballou

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University of California
Los Angeles, California 90024

Dr. A. F. Bartsch
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Environmental Protection Agency
200 S.W. 35th
Corvallis, Oregon 97330

Dr. Baumgartner
EPA Water Quality Office
Pacific Northwest Water Laboratory
200 South 35th Street
Corvallis, Oregon 97330

Dr. Earl Bell
Sierra Club
1050 Mills Tower
San Francisco, California 94104

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Dr. Albert W. Bove, Editor
Division of Earth Sciences
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Washington, D.C. 20418

Dr. V. T. Bowen
Woods Hole Oceanographic Inst.
Woods Hole, Massachusetts 02543

Mr. E. L. Bowhay
Washington Department of Game
2802 Naches Highway
Yakima, Washington 98901

Gale Bradshaw (DPI)
USAEC
Washington, D.C. 20545

Dr. Grant J. Brewen
Biology Division
Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, Tennessee 37830

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Juneau, Alaska 99701

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Corvallis, Oregon 97331

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Associate Dean of Research
Department of Oceanography
Oregon State University
Corvallis, Oregon 97331

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Dean, College of Veterinary Medicine
Washington State University
Pullman, Washington 99163

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National Science Foundation
1800 G. Street N.W.
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Department of Biological Sciences
University of South California
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Radiation Programs
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Mr. M. Lemeire
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Mr. Burt McConnell
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Dr. William A. Mills
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Oak Ridge National Laboratory
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Dr. Gordon Orians
Professor of Zoology
148 Johnson Hall
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Seattle, Washington 98105

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Lubbock, Texas 47409

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Bureau of Radiological Health
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National Environmental Research Center
200 S.W. 35th Street
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Ecology and Ecosystems Analysis
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Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Dr. John H. Rust
A. J. Carlson Animal Research Facility
950 East 58th Street
Chicago, Illinois 60637

Dr. Walter M. Sanders III Chief
National Pollutants Fate Research Program
Federal Water Quality Administration
Southeast Water Laboratory
Athens, Georgia 30001

Mr. John E. Sater
Arctic Institute of North America
1619 New Hampshire Avenue, N.W.
Washington, D.C. 20009

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Field Representative
National Wildlife Federation
8755 S.W. Woodside Drive
Portland, Oregon 97225

Dr. Vincent Schultz
Department of Zoology
Washington State University
Pullman, Washington 99163

Dr. Jacob Sedlet
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Dr. Allyn H. Seymour
College of Fisheries
University of Washington
Seattle, Washington 98105

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Extension Manager
Division of Technical
Information
USAEC
P.O. Box 62
Oak Ridge, Tennessee 37830

Mr. Bernard W. Shore
Bio-Medical Research Div.
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Lawrence Radiation Lab.
P.O. Box 808
Livermore, California 94550

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Idaho Operations Office
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Dr. Warren K. Sinclair
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

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Air Force Technical
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Florida 32925

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Wildlife Habitat Research
Pacific Northwest Forest &
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P.O. Box F
LaGrande, Oregon 97850

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1130 Fifth Avenue
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Committee on Environmental
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Executive Office Building
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Department of Zoology
University of Tennessee
Knoxville, Tennessee 37916

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U.S. Geological Survey
P.O. Box 4369
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Battelle Columbus Laboratories
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U.S. Department of Interior
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Grasslands Biome
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Laboratory
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National Academy of Sciences
2101 Constitution Avenue
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Ecology Center
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University of Alaska
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Colorado State University
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5200 Gibson Boulevard, S.E.
Albuquerque, New Mexico 87108

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Department of Zoology
University of Georgia
Athens, Georgia 30601

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Oregon State University
Corvallis, Oregon 97331

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Chemical Oceanography Branch
Ocean Sciences Division
Naval Research Laboratory
Washington, D.C. 20390

Mr. Hill Williams
Science Writer, Seattle Times
Fairview N. and John
Seattle, Washington 98109

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County Service Bldg.
318 W. Main
P.O. Box 536
Walla Walla, Washington 99362

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75 Karlsruhe Postfach 36 40
GERMANY

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