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RESEARCH AND DEVELOPMENT
in
ENVIRONMENTAL SCIENCES
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RESOURCES MANAGEMENT

By

D. W. Pearce

Environmental and Radiological Sciences

May 1967

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INTRODUCTION

Restoration and maintenance of the quality of our environment has been a subject of increasing emphasis and concern at all levels of government during recent years. In particular, the Federal Government has focused much legislative attention on this major national problem in the past two years. Many significant reports have been prepared to provide background and guidance toward the achievement of a more desirable level of the quality of our environment.

All sectors of our society are vitally involved in this enormously complex social, economic and technical problem. Efficient planning and wise management of our natural resources require a much broader and more fundamental understanding than we now have of the dynamic relationships which couple all elements of resource systems to their eventual use for the benefit of mankind. In addition to this understanding, effective means for implementation of resource management plans must be available.

With so many recent, descriptive and comprehensive reports defining the problems, the interrelationships of air-water-land resources as they are inseparably involved, the needs for systems approaches toward solutions coupled with many nontechnical factors, it would be both presumptuous on our part and redundant to attempt to summarize the overall problem here. Each report contains many similar specific and general recommendations for approaching the myriad of problems.

The House Subcommittee on Science, Research and Development, which held hearings last July-September 1966, under the chairmanship of Rep. Emilio Q. Daddario, on "The Adequacy of Technology for Pollution Abatement" made nine major recommendations in its report:

"(1) Scientific activities in ecology and related fields should be immediately expanded to provide: (a) Baseline measurements in plant and animal communities and the environment. (b) Continued monitoring of changes in biosphere. (c) Abilities to predict the consequences of man-made changes. (d) Early detection of such consequences. (e) Knowledge of the environmental determinants of disease.

"(2) Ecological surveys and research should be centralized as to management in some one science-based Federal agency. The scientific activity should be performed (whether in Government Laboratories or under contract by local universities and research institutes) in geographical regions which correspond generally to natural environmental boundaries.

"(3) To place pollution abatement on a comparable basis with other national technology programs, systems analysis and management capability should be established within the Federal government. This approach should be used along with the 'planning, programming, budgeting' technique to organize both near and long-term Federal research and operational efforts in pollution abatement...

"(4) An abatement extension service should be established by Federal funds to provide information and technical advice to local governments, regional compacts, and industry. A continuing survey of operating practices and successful industrial abatement methods should be undertaken to identify new and better technology as quickly as possible. The service could contract locally for the performance of its functions and become at least partially self-supporting through fees.

"(5) To stimulate the acquisition and development of new technology, Federal contracts for research, development and demonstration should employ a cost recovery principle where commercial success occurs. Return of the ownership of the technology to the private sector for exploitation should be a part of contracting policy.

"(6) The Federal government should undertake the analysis to identify and separate those abatement action programs which are well supported by facts, and for which practical answers are available, from those problem areas where more R&D is needed. A public information program should make these differences clear to the Nation so that installation, enforcement, and research can each proceed on a logical timetable. Actions to decrease pollution should continue even though the ultimate criteria cannot be set at this time.

"(7) The Congress should endeavor to review its broad authorizations and appropriations for water, reclamation, transportation and conservation in the context of environmental quality goals. The diversity of executive agency missions places an added responsibility on the legislative branch to avoid conflicts in large-scale engineering projects.

"(8) The scientific and engineering community should respond to the challenge of the pollution problem as a major opportunity to serve a public need. Work in this field should be recognized as interesting, rewarding, and important. Proposals for organization, funding, and schedules which will assure the participation of excellent technical personnel in adequate numbers should be the joint responsibility of government and private sector research and development leaders.

"(9) The level of Federal funding for research, development, and demonstration projects to improve environmental quality should be increased from the present \$30-million to \$300-million within the next five years."

Many of these recommendations must be implemented through experienced, adequately-sized, multidisciplinary research teams working over an extended period in an integrated manner. As such an organization with considerable competence demonstrated in environmental sciences and pollution abatement research, Battelle-Northwest has a significant role to play in the implementation of these recommendations.

The purpose of this report is to summarize briefly the accomplishments, capabilities and facilities of Battelle-Northwest in this area.

BATTELLE-NORTHWEST BACKGROUND AND ORGANIZATION

The Battelle Memorial Institute was created through the will of Gordon Battelle, Ohio industrialist, for the encouragement of creative research and the advancement of science. The Institute began operations in 1929 at Columbus, Ohio, with an original staff of 30; the Columbus Laboratory has now grown to more than 2,400 persons. In the Institute's early days, it was believed that the precepts of the founder would be implemented best by introducing to industry the advantages of contract research. It was soon demonstrated that this was so and that research done by an outside research institute could increase a company's profits... and Battelle was on its way to becoming the world's leading contract research institute.

Additional laboratories have been acquired or established in various parts of the world (Frankfort and Geneva) and at other locations in the United States. In January 1965, a major addition was made with the establishment of Battelle-Northwest, the Pacific Northwest Laboratory division of Battelle Memorial Institute, formerly the Hanford Laboratories operated for the Atomic Energy Commission by the General Electric Company. These laboratories comprise an installed facility assessed at over \$85,000,000, with an annual budget in excess of \$40,000,000 and staffed by about 800 professional people in a total organization of 2,150 (Appendix A).

In the early days of the Hanford project, very little was known of the interaction of radiation with materials of any kind. The laboratories were established to study just such interactions to assure safe operation of the Plant and the expansion of its capabilities. Therefore, a wide range of scientific research and engineering was soon well established in various components of the plant organization.

The production and separation of the Hanford product created immediate and pressing problems in environmental protection, but these were quickly recognized, and releases of radioactive materials to the environment were minimized by well-advised management. Purposeful disposals were carried out conservatively while the necessary research progressed.

In the beginning, even the composition of the various wastes produced by the plants was not well known. Mechanisms of distribution in the

environment (in air, water and underground) posed real problems for observational and experimental research. Methods of chemical analysis were needed. The meanings of the findings needed integration and translation into terms of biological effects and derived limits.

For these reasons, Hanford personnel soon became authoritative in the behavior and significance of radioactive materials in the environment, and individuals were frequently called on for counsel and leadership both nationally and internationally.

The facilities at Battelle-Northwest are operated for the Atomic Energy Commission under a prime contract. In addition, under a Use Permit Contract Battelle-Northwest has been authorized to use these facilities for its own account and in support of contract research activities with other federal agencies, state and municipal governments and industries.

Battelle-Northwest has twelve research departments in its line organization (Appendix B). Seven of these research staffs are directly involved in some aspect of environmental sciences or engineering:

- Biology
- Chemistry
- Physics and Electronics
- Environmental and Radiological Sciences
- Environmental Health
- Engineering Development
- Mathematics

Integration of such research organizations into multidisciplinary teams for maximum effectiveness has been demonstrated frequently during the past two decades in the conduct of broadly-based research programs; a prime example was in the radiological sciences. This program included specialization in biology, biochemistry, atmospheric physics, hydrology, geology, geochemistry, soil sciences, micromeritics, instrumentation, waste treatment (gaseous, liquid and solid) processes and engineering, and low level analysis. Although these properly emphasized the radiation interest, the methodology was frequently applicable to a wide range of materials. Within recent years the program demands have led more and more to the establishment of specific programs in basic ecology.

In January 1966, we were asked by the Atomic Energy Commission to supply certain information to the Library of Congress regarding our research and development capabilities and facilities in environmental pollution research. The summary indicated that about one-fifth of our current research activities--or about \$7 million annually--is devoted to that general area.

During the past year significant research programs in the broader fields of environmental science were undertaken for sponsors other than the Commission under our Use Permit contract. These have included regional air resource and water resource studies, research in weather modification, desalination and marine sciences.

ACCOMPLISHMENTS, CAPABILITIES AND FACILITIES

The following sections briefly describe more specifically the principal accomplishments, capabilities and facilities in environmental sciences of Battelle-Northwest and its predecessor technical organizations. For clarity, the descriptions are presented from programmatic viewpoints, rather than from organizational, under the following categories.

- Life Sciences
- Environmental Sciences
 - Meteorology and Aerosols
 - Geology, Seismology and Hydrology
 - Waste Treatment and Water Quality
 - Environmental Chemistry
 - Environmental Health
- Instrumentation
- Systems Analysis and Economics
- The Technical Library

Selected bibliographies of related research are in Appendix C.

ENVIRONMENTAL SCIENCES

Meteorology, Aerosols and Off-Gas Treatment

The meteorology group has emphasized the investigation of those mechanisms of the atmosphere which most significantly affect the distribution and magnitude of contact with a pollutant; they are thus of concern not only to local industry but also to any enlarging manufacturing community and more recently to the national space program. The work has emphasized those areas which yield results of significance today and has anticipated those likely to be of significance in the future. For these reasons, the major studies in the research units have been atmospheric diffusion and dispersion as related to meteorological variability, deposition of airborne materials and their contribution to surface contamination, resuspension and translocation of deposited materials by the atmosphere, meso-scale dispersion up to several hundred miles, dosage estimates and the relationship between plume arrival time and the vertical wind profile, and washout depletion by the action of rain and snow.

A major strength of the meteorology group lies in the experience of certain senior members and their participation in activities at the Nevada Proving Ground. These ranged from active meteorological consultation to the full-time leadership of the methods development and monitoring group for several Test Series. Experience in deriving the techniques and coordinating the work of aerial and ground teams has since been applied by the Battelle-Northwest group at Cape Kennedy and Vandenberg Air Force Base to a problem in the space program.

A particulate and gaseous waste research group studies the field of micromeritics to gain understanding of aerosol behavior, including transport mechanisms and techniques for valid sampling of air containing particles.

A chemical engineering group studies the process plants for improvement in the cleanup of their gaseous effluents to be disposed to the environment.

From these three fields of study, the results have application in other areas such as the spread of chemical and biological materials, dispersion of fumes associated with advanced missile systems, air and ground exhaust problems and normal industrial pollution problems.

At Battelle-Northwest diffusion and dispersion are studied through release of various tracer materials to the atmosphere followed by sampling the dispersed plume on extensive horizontal and vertical grids. Supporting meteorological measurements are made simultaneously.

To investigate the dispersion of material from a low release, samplers are positioned along arcs concentric about the source and centered on the azimuth of the prevailing wind. The spacing between samplers along any arc insures the definition of the cross section of the cloud. In addition to the ground level network, meteorological towers are located on the four inner arcs out to 3200 meters. For elevated source experiments, and most useful for night-time conditions, another grid system is centered on the 125-meter Meteorology Tower (Figures 1 and 2).

Facilities for micrometeorological work consist of the instrumented 125-meter Tower at the source, a 24-meter Portable Mast and a 62-meter Mast instrumented for detailed measurements and an array of remote stations, which measure the wind velocity over a large area within and

FIGURE 2. *Smoke Emitted From a Ground Source Exhibits the Effect of Wind Shear in the Neighborhood of the High Tower.*

around the grid. Measurements of temperature, dew point, wind direction and speed are obtained with refined instrumentation and on short cycles at 15-meter intervals on the high Tower.

The 24-meter Portable Mast is instrumented with sensitive micrometeorological equipment for similar measurements at six levels selected to suit the needs of the experiment. The data are recorded both on printed and punched paper tape. The 62-meter Mast is instrumented to obtain wind velocity and temperature measurements at various heights and at averaging times as low as 1 second (Figure 3).

Additional measurements are available from the Radiotelemetering Stations on and near the extremities of the 600 square mile reservation. The integrated data from these outlying stations are automatically radioed to a central control and printout station. The interval of interrogation can be varied from five minutes to one hour or the data may be called in on demand (Figure 4).

Measurement of meteorological parameters and tracer concentrations can be extended far beyond the range of the fixed sampling by means of two instrumented aircraft equipped with monitors and sensors.

Techniques have been extended to the use of multi-tracers, permitting determination of diffusion parameters from multi-sources and evaluation of the behavior of tracers with different physical and chemical properties.

The complexities associated with rain scavenging experiments have been studied and definitive experiments are being conducted by meteorology and chemistry groups. Scavenging tests have been conducted at several elevations on the reservation, at the top of a mountain nearby, and at a site in the Cascade Mountains. In some of the scavenging and fallout studies, the interest has been largely in the atmospheric mechanisms; towers are used for release of nonradioactive tracers and samplers downwind collect precipitation that falls through the plume (Figure 5). Experimental designs are ready for incloud scavenging tests and continental-scale tracking experiments will provide data on stratosphere-troposphere exchange.

One unit of the Meteorology group provides technical services for the research groups and for the plant generally in weather forecasting,

Neg 26219-3

FIGURE 3. Instrumentation at the Lowest Levels on a Portable Mast

Neg 36419-13

FIGURE 4. *A Wind-Powered Meteorological Data Telemetering Station (White Bluffs across the Columbia River in the background)*

Neg 0670779

FIGURE 5. *Preparing the Samplers and the Tracer Source for the Mast for a Measurement of Scavenging by Falling Snow in the Cascade Mountains*

climatology and river forecasting. In addition they carry out research in synoptic meteorology. With the facilities and equipment described, many experiments over a wide range of conditions have been completed. In addition, the techniques have been applied by Battelle-Northwest personnel at Cape Kennedy and Vandenberg Air Force Base. As far as is known, these are the most extensive studies using ground sources and a common experimental design. A basis is thus determined for extrapolating diffusion estimates by accounting for the differences in meteorology and surface characteristics at other sites.

Aerosol research studies have fallen into four categories. One series has concerned the nature and quantity of material which would be released in an accident involving nuclear materials such as radioactive fission products from power reactors if the fuel were overheated.

Obtaining a valid sample of airborne particles is difficult in most situations unless the particle size is known and a great deal of information about the sampler probe, flow rate, positioning, and particle kinetics is at hand. Many uncertainties exist in air sampling, and knowledge in depth of particle interactions is necessary before proper evaluation may be made. Turbulent deposition in tubes, impaction on objects of various geometries, and errors in anisokinetic sampling are some of the areas much better understood because of the work of this group.

Particle size and shape are such important parameters in the behavior of particles in any system that a continuing effort is maintained at Battelle-Northwest to upgrade the methodology of particle generation, sampling, and sizing. Particles of essentially single size can now be generated, thus providing a source of particles of known characteristics for precise studies and improved understanding in the field.

An important contribution of the group has been consultation and recommendation regarding air cleaning applications. This work embraces laboratory studies of new concepts and proposed equipment for removing particles from effluents, controlling the release of gases, and field evaluation of air cleaning equipment.

In addition to well-equipped laboratories and instrument rooms, the aerosol research group has a small wind tunnel providing air velocities

up to 30 miles per hour and a 50-foot vertical shaft both used for the deposition and sampling studies. A small laboratory in a remote area is used for work with highly radioactive metals and particles.

Extensive research and development activities have been conducted over the years of Hanford history to provide a control of radioactive emissions from the production plants. The Hanford-developed purification schemes, most importantly the deep bed fibrous filters for removal of aerosols and silver reactors for chemisorption of radioiodine, have resulted in almost complete removal ($>99.9\%$) of these pollutants from the chemical plant off-gases. These designs have been generally adopted in nuclear industry without modification. Strong abilities in the engineering of large-volume gas handling are thus available in these research and development groups.

Highly dependent upon these abilities, the Containment Systems Experiment is a major program which now is being conducted at the Laboratory and which has a high significance in terms of environmental engineering and control. The purpose of the program is to study the effectiveness of reactor containment systems to limit the release of radioactive fission products in case of a reactor accident. The program will include studies of the reduction of fission product concentration within a containment vessel due to natural processes such as deposition on the walls or condensation of water vapor, the effectiveness of engineered safeguards such as water sprays or filters, and the leakage of fission products from containment vessels.

Geology, Seismology and Hydrology

In the earth sciences work, two groupings of activities are highly related. The first of these is concerned with geology, seismology and hydrology while the second deals with the interactions of wastes with the earth materials and the quality of waters. The latter topics are discussed in the next section on waste treatment and water quality.

Because a knowledge of the geology is so fundamental to the progress of all the other work, the rock structures are being thoroughly studied and mapped by both surface and in-well methods. A complete hydrological description of the behavior of surface and subsurface waters is similarly being compiled from field observation and experiment.

Geologic research has been directed toward accurate definition of the regional lithology and stratigraphy and relating these to the occurrence and movement of confined and unconfined ground waters. A number of sophisticated geophysical methods, including advanced seismic measurement and in-hole logging techniques, have been used to obtain this information. Classical geological methods have been important also and the many years of concentrated study have built up a body of knowledge and understanding of basalt flows and interbeds that would be difficult to match.

Field experimentation is an integral part of the overall program. The development, testing and application of new, more accurate methods for obtaining needed field data have received strong emphasis. The ground water monitoring program has supplied a 22 year historical record of comprehensive water and waste movement data which has proved invaluable in research as well as in operations-oriented studies.

Over 400 wells reach into the ground water, many into the basalt bedrock, on the Hanford reservation and these have provided research information, both during and subsequent to drilling. A large number of piezometer banks have been installed in the wells at chosen locations to obtain three-dimensional information on ground water potentials, soil permeability and water movement. In addition, a small-scale well field is available for research purposes. Portable field equipment, including tank trucks, winches, generators, compressors, pumps and piping, small-diameter drills, well packers, perforators and depth samplers are available for conducting tests in the cased wells or other facilities.

The laboratory uses a high performance exploration seismograph, twelve-channel system with flexible control modes and with frequency response to allow either reflection or refraction investigations. The system consists of twelve amplifiers with associated input, output, control, filter and test elements, a 27-channel recording oscillograph, geophones or seismometer detectors and the necessary power supplies and auxiliary equipment. Recording is currently done in the analog mode, but provision for digital recording is incorporated in the system with addition of tape transport, analog to digital converter, and multiplexer. The system can easily be expanded to twenty-four channels by adding amplifiers. Programmed signal-gain control may also be incorporated for recovery of true amplitude ground motion information (Figure 6).

Neg 32867-1

FIGURE 6. *Explosion on the Desert in a Seismic Measurement for the Determination of Geologic Structures*

Exploration seismic techniques are used in geo-hydrological and rock structure investigations to determine depth, structure and extent of various subsurface features such as the water table, bedrock and other stratigraphic zones of interest. Seismic methods are also used in evaluating foundation conditions for building and dam construction, earth material ripability, and quarrying and highway construction.

Field research will continue to define the overall geology of the Hanford Project and the surrounding Pasco Basin. Additional work is planned on the earthquake response of Hanford basalt, the local sediments and the overall structures.

The geochemical-geophysical research group is engaged in a diversity of research in hydrologic and related fields. Studies are conducted in the development and application of new, more accurate methods for analyzing large, complex ground water flow systems. Specifically, digital computer programs have been developed for evaluating the changes in a heterogeneous, three-dimensional flow system due to outside influences. These and related mathematical models also have the flexibility to provide rapid analysis of essentially any ground water system for which input field data are available. Accurate flow paths and travel times from one point to another are obtained. Thus, the methods are particularly adaptable to the analysis of the movement of pollutants in ground water systems.

An outstanding feature of these mathematical models is their ability to analyze steady state partially-saturated flow in the zone of aeration which is frequently disregarded or erroneously simplified in waste transport and water supply analysis. Also, consideration is given to minimizing the amount of field data required in the analysis, since frequently the cost of obtaining such information far overshadows the cost of its evaluation. Minimization of field data requirements has been accomplished by model development on an energy dissipation basis and by the determination of unique relationships between the independent and dependent variables of space, permeability, time, and ground water potentials.

In addition to their importance in waste transport, these programs have direct application and utility in solving problems related to ground water supply and artificial recharge, seepage from irrigation canals and

surface ponds, and petroleum reservoir analysis. Other conventional flow system evaluation techniques, such as the use of electrical analogs, are available.

The increasing emphasis on complete and accurate analysis of ground water flow systems and the basin-wide approach requires large amounts of accurate field input data. It is desirable, of course, that as many input data as possible be deduced from few but accurate field observations. Use of the streak function, in which variations of ground water potential are measured against time, holds promise for making a significant contribution toward minimizing the number of field observations needed. Completion of the uniqueness proof and the development and testing of the needed equations and programs are on-going activities. Geophysical methods for determining aquifer characteristics by seismic techniques are also studied but the field is new and progress to date is minimal.

The problems in this area of three-dimensional, transient partially-saturated flow in heterogeneous soils are difficult to solve but are yielding to concentrated effort. The nuclear application is in evaluating disposal facility drainage and underground waste tank and pipeline leaks. The evident applications in nonnuclear fields are concerned with waste solution movement, irrigation, the redistribution of soil moisture following rainfall, and perhaps most important, the ground water distribution in a river basin.

Specialized laboratory equipment, much of which was developed at Hanford, is used for conducting soil moisture and hydraulic research. A soil column packer is used in conjunction with gamma-ray counting and capillary pressure measuring equipment to evaluate unsaturated flow parameters. A large electrolytic tank is used to analyze well hydraulics. Readout is by a versatile digital voltmeter which provides digital display, print-out and punched tape records of voltage, voltage ratio or resistance at a rate of three nodes per second. Sand box models are used for conducting scaled experiments when such are needed.

Much of the research has required the development of specialized instruments, due to the radioactive nature of the wastes and the precision desired in field and laboratory measurements. A vehicle-mounted well logger and recorder is used interchangeably with a sensitive temperature probe, vertical flow meter, neutron moisture probe and gamma scintillation

probe to make field measurements. A submersible television camera is used for well casing examination and for special work where visual contact is required (Figure 7).

Waste Treatment and Water Quality

Large volumes of water containing radioisotopes--the low and intermediate level radioactive wastes--have been discharged to the ground from the chemical processing plants at Hanford. The minimal environmental contamination which has been realized from these disposals has resulted from two kinds of action. In the first place, much chemical and engineering research and development and continued improvement effort has been expended on the plant processes. This and continual operating attention in-plant has directed more and more of the fission products into wastes to be stored rather than into those to be disposed to the ground. In the second place, earth sciences research was brought heavily to bear upon all natural mechanisms which delay the movement of a contaminant through a soil system. In particular, the delay of radioactive ions in travel with the ground water and the holdup by exchange on the soil particles became recognized and understood. It was demonstrated that sufficient decay time was thus provided to ensure that radiological safety standards would be met at the points of nearest public contact.

Among the process changes which have brought about a decrease in environmental contamination has been the replacement of contact condensers with surface condensers, thus greatly decreasing the volume of a ground disposed waste and aiding in the soil retention of its contained radioisotopes. Rerouting and reuse of certain process streams has brought about an overall decrease in radioisotopes requiring ground disposal. As a third example, chemical research showed how ruthenium compounds could be retained in the residue during a distillation process rather than entering the distillate and causing a ground disposal problem later.

Several major chemical engineering programs in progress are also directly involved in various aspects of pollution control or resources management. A prime illustration is the Laboratory's current role as the national demonstration facility for radioactive waste solidification processes. In this program, processes developed at Hanford and at other AEC sites are being engineered for remote operation, designed, built, and tested for incorporation into a hot cell for demonstration with actual high level radioactive wastes. This prototype facility, with capacity for processing

Neg 17731-4

FIGURE 7. Television Camera Goes Down a Well for Casing Examination

radioactive waste equivalent to that from a ton of irradiated uranium per day, is solving important problems in essentially every aspect of chemical engineering from design to demonstration. The program involves the handling and control of highly radioactive liquid, solid, and gaseous waste streams and again is increasing the experience and abilities of scientists and engineers for application to related problems.

Another major continuing program concerns methods for reducing the amount of radioisotopes discharged via reactor cooling water to the Columbia River. This has included considerable research into the chemistry of water treatment methods. These studies have provided optimization of process variables to achieve maximum removal of specified ionic impurities from Columbia River water, and have encompassed several different concepts of water treatment. Maximum removal of ions and colloidal material of either charge has been accomplished by adjustment of the electrokinetic potential of the flocculum by manipulation of the addition rate of the flocculating agent or by the application of poly-electrolytes. Although the results of these studies have been applied only to the high throughput water treatment facilities, they are also germane to the treatment of certain industrial waste streams prior to their discharge to the environment.

The extensive efforts which have been conducted in the fields of radiochemical waste management and process chemistry have led to experience and capability in the following additional areas pertinent to pollution control:

- Engineering scale pilot plant evaporation and deentrainment by conventional methods, submerged combustion, hot gas sparging, electrical heating and wiped film methods,
- Engineering scale distillation and fractionation of inorganic acids, principally nitric, sulfuric and phosphoric,
- Engineering scale pilot plant calcination by agitated trough calciner, fluidized bed calciner and spray calciner,
- Engineering scale methods of solids separation from solutions and gases including filters, centrifuges and cyclones,
- Conversion of inorganic waste material into forms suitable for handling or storage, including powders, solidified salt cakes, ceramics, and glasses,

- Engineering scale pilot plant operation of solvent extraction processes and associated evaporation and filtration requirements, and
- Engineering scale ion exchange process and contactor development for separation and recovery of inorganic chemicals.

Waste water research has involved basic studies of ion removal from aqueous systems by ion exchange, chemical and electrochemical reactions, waste treatment preceding environmental disposal, and soil-waste interactions after disposal. Particular capabilities exist in geochemistry with emphasis on soils and environmental chemistry; in the former are included such specific interests and abilities as mineralogy and crystallography while in the latter are the chemical and biological interrelationships in the earth's crust and its waters.

Applications which have resulted from many years of research in this area include removal of trace radioions from solutions containing macro-concentrations of nonradioactive species by ion exchange on both natural and synthetic zeolites, determination of migration rates of ions in soil and in ground water, prediction of exchange behavior of a given ion in multi-ion systems, and development of electrochemical techniques for treatment of wastes. Some of the highlights of these activities are of particular interest.

Studies of ion exchange materials have included basic investigations into ion selectivity, ion capacity and the determination of binary and ternary isotherms and thermodynamics for several ion systems with natural and synthetic aluminosilicate zeolites, inorganic ferrocyanides and organic resin exchangers. An initial study of the ion exchange characteristics of several natural zeolites of various compositions showed a correlation between the cation selectivity of the mineral and its silicon-to-aluminum ratio. On the basis of the correlation, several commercially available synthetic zeolites were selected for desirable cation selectivities, and several were synthesized with desired selectivities for specific applications. The ion loading kinetics of zeolites and exchange resins also were studied to establish their optimum characteristics for use in columns.

Electrodialysis was studied as a method for the removal of ions from waste waters, especially those waters not suited to ion exchange treatment.

Several chemical reactions were studied as methods alternate to ion exchange and electrodialysis. Replacement reactions were found to be highly specific for the removal of certain ions from aqueous solutions and these hold considerable promise for special application.

The knowledge derived from such basic studies was applied to ion removal from several specific waste water systems. The ion exchange method applied to several problem wastes showed the value of highly ion-specific zeolites for decontamination before disposal. The use and effectiveness of manganese dioxide scavenging for water decontamination was investigated in detail.

A large part of the water research effort has been in the area of waste-soil-radioisotope interactions that are of concern after the disposal of the waste water and its various contaminants to the environment. The ion exchange character, ion capacity, ion diffusion and dispersion, and distribution of radioisotopes between soil and waste water have been intensively studied. Specific mineral exchange reactions have been isolated and separately studied. The effects of various dissolved organics and detergents in waste water have been investigated for such systems. It has been shown that a statistical model of radioisotope distributions between soil and waste water is valid when the range of major chemical constituents in the waste water is known.

Major study areas continue to be concentrated on waste water decontamination before disposal and on soil-waste water relationships after disposal to the environment. Studies include the determination of zeolite cation selectivities at high temperatures and pressures with possible application to recycled reactor cooling water decontamination, water filtration studies, the treatment and disposal of contaminated organic wastes, the decontamination by ion exchange of condensate waste from the glass-forming waste treatment. Predictive regression equations based on the statistical treatment of radioisotope distribution data are part of the soil studies. Improved characterization of the soils through the use of X-ray diffraction, X-ray fluorescence and differential thermal analysis techniques are used to clarify the effects of soils on distributions in the system.

Methods and techniques that have proven successful in water treatment and the study of radioactive waste waters are often directly adaptable to use in the treatment and disposal systems for nonradioactive waste waters. Typical processes which are applicable to the treatment of waste waters include ion exchange; manganese oxide coagulation; activated carbon adsorption and filtration; steam stripping; lime, alum and iron hydroxide scavenging; fractional distillation; and electrodialysis and deionization.

Research capabilities in support of water resources research, pollution control and general environmental sciences may be summarized:

- Effects of pollutants in soil systems,
- Advanced waste water treatment systems,
- Biological and biochemical treatment processes,
- Water resources management as influenced by water quality and waste water treatment, and
- Support of optimized waste management systems including solid, water and air pollutants.

These research groups are well equipped with modern instrumentation: elaborate counting equipment, multi-channel analyzer, gamma spectromemeter, spectrophotometers, flame spectrophotometer, and miscellaneous precision instruments; laboratory-designed equipment such as the hydrothermal high pressure reactor for use in inorganic synthesis also adds to the overall capabilities. Facilities for the study of environmental control are available and include soil-waste incubation cells and various aerobic and anaerobic systems used in the study of the degradation of organic compounds.

A final group of studies concerns a different aspect of the water problem.

The reactor operations at Hanford have a close association with the quality of water in the Columbia River. A part of this association is the need for high quality water for cooling the reactors and thus involves conditions upstream while a second part involves the actual or potential impact of the reactors on water quality downstream. One of the parameters that has received special emphasis is water temperature because the economics

of reactor cooling is involved on the one hand and the potential interaction of the added heat load with downstream water use must be considered on the other.

For several summers, efforts have been made to reduce peak river temperatures at Hanford by manipulation of discharges from Grand Coulee Dam. In support of this program, sophisticated studies were made of the temperature regime of the river and this has led to the development of computerized water quality simulation models. These consider the natural hydraulic flow paths of the stream, the thermodynamic inputs from such sources as plant effluents, thermal radiation, surface winds, evaporation and conduction, and special considerations brought about by upstream impoundments. These last include submerged streams or current jets which form as a result of stratification and whose shape is governed by complex hydrodynamic forces still under research.

As a result of five years of study specifically directed to this simulation effort and twenty years of general supporting effort in river research, expert knowledge of the Columbia River has been developed. For example, in routine operations analysis supporting the seasonal river cooling program, the computer program can predict downstream temperatures to within ± 0.25 °C of a daily average over an annual period when flows expand and contract over 300% and involve a complete seasonal weather cycle.

The basic tools of this work are the computer programs that have been prepared and that can be run on short notice on the Univac 1107 digital computer. Appropriate input data are, of course, required to tailor the model to the specific programs at hand. When historic data on a river flow, temperatures, stratification, advected heat, meteorologic conditions, etc. are not available or are inadequate, portable instruments are on hand to make such measurements. These include recording thermographs accurate to ± 0.1 °C, a resistance thermometer designed for use from a boat and which furnishes a continuous signal accurate to ± 0.1 °C, a portable meteorological station with recorders for temperature, wind speed and direction, net thermal radiation, and humidity. Where unusual flow patterns, such as density currents, may exist, dye tracer techniques and equipment are available for use (Figure 8).

Neg 30437-4

FIGURE 8. *Equipment Used for Measuring the Temperature of the River*

The general format requirements of these models are such as to make them immediately applicable to any stream, large or small, for which a history of flow and weather data is available. The simulation model has been used to predict river temperatures under improbable conditions, such as combinations of very hot weather and very low-flow. It has also been used to predict temperatures that might exist in various parts of the Columbia River system following installation of thermal power generating stations.

These modeling capabilities can be used in a variety of studies involving the impact of industry, or of society at large, on stream water quality. Such uses might include analysis of the effects of simple impoundments in order to determine in advance the degree of stratification and the relation of density currents on downstream quality parameters involved with upstream emissions. Additionally, this problem could be combined with one or more pumped storage systems and many thermal plant inputs all combining to induce complex water quality changes affecting downstream users.

Using this simulation system, it is possible to evaluate the economic loss resulting from successive installations in a stream reach or, knowing safe limits, to predict the extent to which industrial development might be permitted. The accuracy of the system also permits back calculation of thermal inputs into a stream reach knowing upstream and downstream temperatures at rather remote distances from the source of effluent. Finally, this system permits modeling of an entire river basin in order to determine future effects of today's decisions.

Environmental Chemistry

Several large analytical chemistry laboratories are available to carry out the routine sample analysis and the complex specialized analyses necessary in any research and development and environmental studies.

- A water quality laboratory routinely determines concentrations of natural and introduced impurities in water from the Columbia River and from water treatment plants. The major equipment items used routinely include modern spectrophotometers, flame spectrophotometers, and emission spectrographs; atomic absorption equipment is available for use as needed.

- Very sensitive isotopic analyses of the heavier metals can be made using the standard types of mass spectrometers; instrument research and development keeps the methods up to date.
- The gas mass spectrometer and gas chromatograph are used for gas analysis. The former may be connected directly to the effluent of the latter, giving a powerful tool in identifying individual gases or vapors in air or in complex mixtures.
- Special laboratories serve the usual emission and absorption spectroscopy, X-ray emission spectroscopy, and X-ray structural determinations. Others use electron-spin-resonance and nuclear-spin-resonance spectrometers, electronic particle sizers, infrared spectrophotometers, CHN analyzer, instruments for measuring molecular weight and electrophoretic mobilities of substances, 1800 curie ^{60}Co source, 2 MeV Van de Graaff electron accelerator and a positive-ion accelerator.
- The counting rooms are important in the atomic industry and the Laboratory has several such installations containing the most modern equipment for all kinds of alpha, beta, gamma and neutron counting. Particular strength in radiochemical analysis resulted in these laboratories being called in to help with identification and analysis of fallout materials in several of the major U. S. tests such as Buster-Jangle, Red Wing and Bravo.
- New facilities include an ultra low-level analysis building with its clean rooms, laminar flow ventilation, particle separating equipment, optical microscopes and electron probe analyzer.
- Mobile continuous analyzers for the measurement in the parts per million range of significant pollutants in ambient air are in hand for sulfur dioxide, nitrogen dioxide, nitric oxide, total oxidants, and aldehydes. Similar instrumentation for carbon monoxide and total hydrocarbons, as well as portable sequential samplers for use in assessment of air quality are nearing readiness.

In addition to the broad competence in process and environmental analytical chemistry already referred to, groups of research personnel have breadth and depth in the fields of environmental chemistry and instrumental analysis; these are highly suited for studies of pollution control and resources management (Figure 9).

A prime example of such a specific capability is that for analyzing radioactive materials at very low concentrations by activation analysis. The method uses two dimensional gamma ray spectrometry and gives selectivity and sensitivity many orders of magnitude better than the more usual sensitive methods using single crystal gamma-ray spectrometry, itself quite new in most laboratories.

One group has pioneered the development of such equipment for the measurement of radionuclide mixtures in environmental samples and in man. Leadership in development and application of these instruments is well established. The group has eight of these spectrometers, an investment of over one-half million dollars, and thus has the capacity for carrying out large scale programs on the physical, chemical, and biological behavior of complex mixtures at levels well below the natural radioactive background.

Studies of the physical and chemical behavior of the artificial and natural radionuclides in the environment are some of the most comprehensive which have been made. These include the atmospheric distribution and behavior of airborne radionuclides, movement through the Alaskan food chain to man; the natural uptake and distribution of radionuclide tracers in the aquatic organisms of the Columbia River; the behavior and seasonal variation of reactor effluent water on transport by the River into the ocean; the behavior of the tracer materials in the open ocean and their uptake by marine organisms; the behavior of contaminants released to a reactor containment vessel following a fuel rod failure; the measurement of the natural concentration of radionuclides in farm produce; the simultaneous behavior of multi-tracers in diffusion, transport, nucleation and washout processes in the atmosphere; and the discovery of the cosmic-ray produced Cl^{38} in the air (Figures 10, 11 and 12).

Neg 0670059-223

FIGURE 9. A Corner of the Low-Level Counting Laboratory Showing a Lithium-Drifted Silicon Detector for X-Ray Analysis of Environmental Materials

Neg 0671477-2

FIGURE 10. A Stack of Membrane Filters With Resin Beds for the Selective Removal of Particulates by Size and the Separate Collection of Anions and Cations from Deep Ocean Waters.

Neg 0671477-1

FIGURE 11. One Mile of Plastic Hose for Ocean Water Sampling at Depth

Neg 0671477-3

FIGURE 12. *In the Rain Forest Along the Upper Hoh River, Olympic Peninsula (The mosses are the major collectors of fallout in this ecosystem).*

In another chemical research group the work is aimed at the establishment of the chemical forms and reaction mechanisms of potentially toxic substances generated by ionizing radiation, by the industrial production of radioisotopes, or by the use of commercial herbicides. Free radicals have been investigated most intensively and the program has been directed toward establishing the chemical structure of these transient species, evaluating their rates of reaction with other chemicals in living forms, and assessing their contribution to radiobiological damage. Chemical protective agents have been developed which reduce considerably the amount of radiation damage.

Much more physical than chemical, a research and development analytical program has been conducted for many years aimed at contributing to radiation protection in the atomic energy program. The main work has been in whole body counting and radiation dosimetry. Some applications of the developments have been related to the diets of Alaskan Eskimos and local populations; these are referred to elsewhere.

A significant group of problems has centered around the chemical and physical form of the radionuclides originating in reactor effluent water and entering the Columbia River from that source. The ions may carry either a positive or a negative charge and may change in character as they proceed downstream. Additionally, they may be found either in true solution, as a colloid, or in the precipitated sediments. Seasonal variations exist in the deposition. The program has more than academic importance. The chemical and physical form of the isotopes have important influences on their presence or absence in the water at any point in the river and thus upon their availability to the species there, or to the plants irrigated with the water withdrawn there; this is the ecological aspect of the work. The material balance consideration is also significant from the river engineering viewpoint and it is desirable always to know the inventory of radioisotopes on the sediments. Finally, there is much knowledge to be gained from this work on the behavior of river currents, sedimentology, and fresh water bodies in general; this is expected to have relevance to such possible large future projects as river impoundment and canal building.

It can be seen that these modern analytical methods open up a research methodology which is widely applicable to environmental work of all kinds.

The natural and introduced artificial radionuclides in the environment may be used as tracers in studying pollution, ecology, meteorology, oceanography and geophysical processes.

Environmental Health

The release of noxious materials to an environment can proceed safely only if it can be demonstrated that the resulting concentrations in the public domain will be lower than those that might compromise the health of people, biotic resources, or other uses of the environment. In many cases, the acceptability of environmental conditions can be predicted by the judicious use of suitable mathematical models on the basis of anticipated releases and specific knowledge of a region. Such computations are made routinely where planned releases are small and for postulated serious accidents where engineered safeguards may be required. In other cases, where significant amounts of material may be released routinely, calculations may not be sufficient to show that dilution by the atmosphere or surface waters will reduce concentrations to within acceptable standards of quality at all points of interest. This is especially true of some radioactive materials and organic compounds that may be reconcentrated by food chains. For such releases, there will always be a need for systematic sampling and analysis programs, accompanied by expert evaluation of the data.

The status of the environment in relation to the release of effluents at Hanford has received intensive study since the startup of the first reactors. This program has combined comprehensive surveillance with a variety of associated research studies. The result is an advanced capability for evaluating the significance of releases both to the atmosphere and to the Columbia River. It has involved investigation of physical dispersion of effluents in relation to agricultural areas, population centers, and various uses of the river; investigation of areas of accumulation that might conceivably develop into problems at some future time; and investigations of the pathways that particular contaminants follow through the environment from the points of release to places where they may interact with people or affect the economy.

The Columbia River has received a great deal of attention because most of the radioactive materials that are released by Hanford facilities are

discharged to it. The effluent plume from each of the reactor outfalls has been mapped in three dimensions at a variety of river flow rates with respect to radionuclides, stable elements and temperature. The time required for releases from each of the reactors to reach downstream points, and the spread of the release with distance has been determined.

Field measurements and the collection of field samples are basic parts of any environmental evaluations program and a great variety of equipment is in continual or frequent use in connection with studies of the Hanford effluents. For collection of samples of the atmosphere, an extensive network of fixed and portable stations is operated both within the reservation and offsite up to distances of more than 100 miles. A typical station contains equipment for drawing metered volumes of air through high efficiency filters, absorbers, and/or scrubbing solutions so that selected contaminants of interest are retained for subsequent analysis in the laboratory.

For the collection of water samples, key locations (such as municipal water supplies and dam sites) are equipped with automatic devices that composite samples over periods of hours or days, as desired. For comprehensive sampling throughout the width, depth, and length of a river, a variety of gear has been developed to operate from outboard powered boats. Water samples may be taken from any desired depth, intermittently as desired or continuously. Sediments may be drawn from the river bottom or taken as cores from deposits under still water or at impoundments.

Effluent dispersion and transport in a river are best determined by the use of dye tracer. The necessary equipment for mixing, storage, pumping and metering has been developed and is housed in a special trailer. Measurement of the dye may be accomplished in situ by a specially equipped spectrometer and recorded automatically on strip charts; special samples are taken to the laboratory (Figure 13).

Gamma-emitting radionuclides can be traced not only through the environment, but into people as well with whole-body counters that can discriminate between different kinds of nuclides as well as determine the body burdens. One such counter is of a shadow-shield type and is readily mobile (Figure 14).

Neg 39298-2-cn

FIGURE 13. *A Tracer Dye Rises With the Reactor Effluent Water From an Outfall on the Bottom of the Columbia River*

Neg 40382-43

FIGURE 14. *Elementary School Children May Provide a Seven-Day Diet Record and Be Measured in the Mobile Shadow-Shield Counter*

The evaluated results of the special studies and field surveys on the flux of contaminants through the environment provide a sound basis for the siting of facilities, engineered safeguards, and for the management of waste discharges. Facets of this evaluation include identification of:

- The kinds and magnitude of releases postulated for specific facilities,
- The probable environmental consequences of postulated accidents,
- The status of an environment following routine releases in respect to appropriate standards,
- The specific kinds of contaminants that warrant the greatest control, and
- The characteristics of release points that will favorably influence the movement of contaminants through the environment.

LIFE SCIENCES

Research in the life sciences centers in the Biology Department, but the total capability encompasses the potential for medical studies within the Biophysical Sciences Section and the Hanford Occupational Health Foundation, the population and environmental survey capabilities of the Environmental Health Department, and supporting abilities in statistics, physical dosimetry, instrumentation, radiation chemistry, meteorology, and geology. Activities may be grouped under four broad specialties.

- Molecular and cellular biology
- Animal physiology and toxicology
- Marine and freshwater biology
- Terrestrial ecology and agriculture.

Molecular and Cellular Level Biology

Much of the effort in fundamental cellular and biochemical fields is in support of more applied problems and wherever possible an effort is made

to understand the findings of applied research in terms of underlying mechanisms. Thus, comprehensive studies in the biochemistry of lung tissue have been developed in connection with the inhalation studies; animal experiments on gastrointestinal function are supported by basic studies of ion transport; pioneering studies of immunological reactions in fish are conducted in support of the broader ecology program. Electron microscope techniques are involved in many programs, but particularly in connection with the effect of radiation and bile in the gastrointestinal tract and with the effect of temperature adaptation on the ultrastructure of fish tissues.

A well-rounded pathology group provides clinical analyses, histologic preparations, autoradiographs, and interpretation of observed pathology and is intimately involved in the planning and conduct of animal toxicity studies. It conducts its own research programs in hematology, toxicology, cyto-histochemistry, and immunology.

A microbiology group carries out research in the broad area of cellular regulatory mechanism. Currently emphasized are studies of amino acid transport, revolving particularly around the "tryptophan cycle" in *Neurospora* and studies of factors controlling ribonucleic acid synthesis in *Escherichia coli*.

Animal Physiology and Toxicology

A notable feature of the Department capability is the variety and magnitude of animal experimentation. Facilities are available for several hundred dogs, miniature swine, sheep, and several thousand mice and rats under controlled conditions. A herd of miniature goats provides opportunity for studies in a conveniently handled lactating herbivore. Extensive aquarium and pond facilities are available for studies with aquatic organisms. Salmon and trout are used extensively.

Inhalation studies constitute a major activity and the highly specialized facilities available for such work are probably the equal of those found anywhere in the world. Beagle dogs, bred and raised in the laboratory kennels, are employed. Animals exposed to particles via inhalation may be retained for long periods while the inhaled material is followed by external measurement of radiation in a whole-body counter and by analysis of excreta;

the development of toxic symptoms is simultaneously followed by X-ray, hematological and other clinical procedures. Basic studies on the physiology and biochemistry of the lung form an important part of the program.

A major program of many years duration is concerned with the metabolism and toxicity of chronically ingested strontium-90 in miniature swine. A similar study, of over 15 years duration, on the toxicity of iodine-131 in sheep is nearing completion. The strontium study promises to yield significant data on the basic problem of leukemogenesis. Chronic exposure at high dosage levels has led to the development of leukemia and other hematopoietic lesions rather than to bone tumors, the more commonly observed consequence of acute exposure.

The miniature swine is, in many respects, an ideal stand-in for man in biological investigations. It would appear to be markedly superior to primates for simulation of effects in man of other than mechanical and psychological stress. The Laboratory's breadth of experience with the animal constitutes one of the more significant capabilities for future expanded application.

Another focus of animal experimentation has been the study of gastrointestinal function in both large and small animals, as influenced by radiation and other insults. Current interest centers upon the influence of the bile in controlling varied aspects of intestinal function.

In addition to the major programs mentioned, a wide variety of techniques has developed from emphasis on the metabolism of internally deposited radioelements. Comprehensive studies have been conducted on the interrelationships of similar ions, particularly strontium and calcium. These studies have extended to aquatic, as well as terrestrial organisms, and to soil-plant interrelationships. Continuing emphasis has been placed on the development of methods for accelerating the removal of radioelements deposited in or on the body.

The ability of fish to adapt to a wide range of environmental temperatures has been utilized to correlate changes in ultrastructure and function of

the liver. This is valuable not only for the light it may shed on the process of temperature acclimation in fish, but from the standpoint of liver function generally it permits the variation of a parameter not accessible in mammalian systems.

A smaller project of immediate practical importance concerns the response of insects to radiation. The work is designed to identify the factors causing one species to be more reproductively successful than others and to study radiation stress as compared with and as related to other environmental stresses--both natural and man-made. The work on combined stress of radiation and insecticides will be of real interest to agriculture. The work on flour beetles has attracted international attention.

Marine and Freshwater Biology

The widely varied nature of liquid wastes and the varied manner of their discharge necessitate the broadest possible ecological research effort. Reactor cooling water discharged to the Columbia River contained a wide variety of fission product and neutron-induced radioelements as well as corrosion retarding chemicals and heat. Chemical plant effluents were released to both the atmosphere and the soil. Both types of solutions and their effects were studied in detail.

Interest in the river program focussed on the commercially important salmon and other game fish and laboratory studies have determined the effect of temperature increments, various chemicals, and radiation on the salmon eggs and the salmon fry. The nesting of salmon in the Hanford stretch of the Columbia River has been surveyed annually. Advantage has been taken of the low levels of radionuclides incorporated in the resident Columbia River fish to study patterns of migration and movement. A general concern for the welfare of Columbia River fish has led to studies of disease problems as they may be influenced by thermal pollution and other factors associated with hydroelectric dams and industrial development. Capabilities are not limited to freshwater investigations; bottom-dwelling amphipods, intertidal shore crabs, a pelagic euphasiid, and oysters have been employed in comparative studies of marine and freshwater organisms.

The whole food web in the river was the subject of study. Many of the radionuclides released to the river find their way into fish and other higher organisms, primarily through the food web. Some of these, particularly those of biological importance, are concentrated many thousand-fold by microscopic organisms (Figure 15).

Cooperative studies with state and federal agencies on the resident and migratory waterfowl are segments of the work. As an example, population studies of the locally-nesting geese have been carried out for some years in part to detect any possible effect of their nesting locations on islands in near proximity to the Hanford reactors. In the same way, the local gull colonies have been followed in detail (Figure 16).

The importance of comprehensive ecological studies in the last remaining undammed stretch of this relatively unpolluted major river can hardly be overestimated.

Terrestrial Ecology and Agriculture

The large Hanford Reservation, ranging in elevation from about 350 feet to 3600 feet, has offered an opportunity for a coordinated study of ecology and some facets have been explored over the years. Studies have been made of grass productivity as influenced by rainfall, temperature and shading variations in the soil and of the influence of shrubs on the chemical composition of the soil. Jackrabbit thyroids were found to be an effective monitor of radioiodine release to the environment. In several instances experimental radioiodine releases were conducted to determine the transfer of iodine from the atmosphere, to vegetation, to grazing cattle, and via milk to man.

Field studies have been supported by laboratory investigations, particularly of the uptake of radionuclides by plants; controlled environment growth chambers have been available. The results have been of significance for the light which they have shed on basic processes of ion uptake by plants from soil and by foliar absorption of atmospherically dispersed pollutants (Figure 17).

An important extension of the terrestrial ecology program has been the series of cooperative investigations conducted over the past several years in Alaska where certain ethnic groups of Eskimos were found to

FIGURE 15. *Ecologists Collect Bottom Organisms From an Alaskan Stream*

Neg 8826-3

FIGURE 16. *Geese and Goslings From the Local Columbia River Nesting Are Banded in a Cooperative Study With Government Wildlife Personnel*

Neg 36419-40

FIGURE 17. *Looking Toward the North-East Slope of Rattlesnake Mountain (In the foreground a tunnel and tube leads a radioactive tracer to the sagebrush roots).*

contain an unusually high level of cesium-137. These Eskimos consume large quantities of caribou meat, the caribou subsist largely on lichens during the winter months, and lichens have an unusually high concentration of fallout cesium-137, due to their long-lived nature and habit of growth. The unravelling of this story provides an excellent example of the diversity of talents which can be brought to bear in the solution of a complex problem. Most critical was the synthesis of the data, guided by knowledge of the total environment, into a meaningful whole. The availability of such a diversity of skills represents a most significant and unusual capability of Battelle-Northwest.

The Rattlesnake Springs Radioecology Facility is an 800 acre reserve for the study of terrestrial and aquatic communities. A constant source of water is available from a permanent stream which arises and flows about 1 1/2 miles down the small valley before disappearing into the ground. Improvements are a dam and ponds of various sizes and depths and a building for field laboratory space and apparatus. Studies include the population dynamics of the established plants and animals, investigations of biogeochemical cycles and the effects of the severe environmental factors upon the ecological systems.

A most significant plan is for a widely cooperative study on a major scale of the ecology of the surrounding arid lands. This would consist of a large expansion of the Rattlesnake Springs station into some 120 square miles, now relatively undisturbed and representative of desert steppe terrain. One part of this Project of Arid Lands Ecology will consist of the controlled modification of selected peripheral regions of the principal area; this segment of the work should contribute significantly to arid lands agricultural, range management and water management; in other parts of the Project, concepts of longer term interest will be studies of natural pollutants and other variables in the atmosphere, the soil and the water. An experimental program of controlled modulation of parts of the area will aid in the interpretation of the slower natural changes and in the earlier recognition of trends. Finally, the comprehensive long-term ecological study of the reserved area itself, in combination with the peripheral studies, will be a project unduplicated in the Western Hemisphere and possibly in the world. It will be of inestimable national value as fundamental to the future use of such presently worthless lands by a rapidly growing population.

INSTRUMENTATION

Advanced and refined instruments are needed in research and engineering and in industrial measurement and control problems, as exemplified in the diverse radiation measurement and process control requirements of the atomic energy industry. The instrumentation groups of Battelle-Northwest have made significant contributions in these areas through the development of specific instruments and systems.

Experience, formal training, and strong scientific and engineering talents embodied in the various instrumentation groups have contributed to the development of techniques utilized in radiological investigations, biological and medical studies, nuclear reactor operations, atmospheric physics measurements, radiation protection of personnel, dosimetry studies, geophysical investigations, and chemical process control. The research and development programs emphasize refined sensing methods, sophisticated electronic circuitry directed toward miniaturization and reliability, decreased power requirements, and improved signal conditioning and data handling characteristics.

The instrumentation groups have achieved significant progress also in the development of measurement techniques using microwave and infrared methods.

A research team exists to centralize instrumentation efforts in the area of pollution control. Electronics is expected to play an increasingly important role in instrumentation and data handling in this field. There is strong economic incentive to move toward automation and continuous processing techniques as well as remote automatic equipment, since pollution is affected by many variables thus necessitating measurement and control of many contributing parameters. The Battelle-Northwest capabilities extend, for applied research in this field, from the varied sensors required, through specialized interface instrumentation, to automatic data handling, retrieval, recording, and automated control.

The research and development has been largely pioneering in nature, requiring, in many cases, the development and application of instrumentation

and techniques to unique environments of greater severity than in any previously encountered. The following descriptions illustrate representative contributions.

- Instrumentation for measurement of the diffusion and transport of airborne particulates and for other atmospheric phenomena, automatic collection and telemetering of meteorological data,
- Instrumentation for study of raindrop charge and velocity of fall, determination of soil moisture content and similar environmental research,
- Instrumentation for measurement of radionuclides airborne and in liquid effluents,
- Integration of solar and sky radiation,
- Logging of radioactivity levels in deep wells,
- Radionuclide measurements in the Columbia River,
- Field instruments for alpha, beta, gamma, and neutron radiation measurements under adverse conditions.

Liquid effluents from the cooling system of an experimental plutonium-fueled reactor might contain minute quantities of radioactive material. To monitor this effluent, total activity of gamma emitters in the liquid was required to be measured in a most reliable instrument with a detection range of approximately 10^{-4} to 5 microcuries per milliliter. Suitable meter indication, chart recording, and selectable-level alarm signaling were to be included. A sensitive, reliable liquid effluent monitor for gamma-emitting radionuclides was developed for this use. The instrument uses a scintillation detector, solid state circuitry, a four-decade logarithmic response count-rate meter, and an additional direct metering circuit.

Field experiments on the diffusion and transport of particulates required instrumentation to record automatically the wind speed, wind direction, and temperature profile at six elevation levels on an 80 ft portable tower. In the instrument developed wind data from all levels are recorded during a 5-second interval and the temperatures are recorded during a 30-second interval. Data appear as printed and punched paper tape readouts to simplify immediate visual review and to provide for data reduction at the

computation facility. The system can be operated from either an electric utility line or a small portable generator or can be located in a mobile field laboratory mobile van.

Precautionary radiological analyses are performed continuously on Columbia River water at several points and several types of specific and general purpose radiological monitoring instruments are used.

The radiological monitoring system measures gamma dose rates from continuously-pumped samples of the river water. The system includes a scintillation detector, stable and reliable circuitry, recording instrumentation, and both on-station and remote alarm signaling circuitry. The alarm circuitry provides local and remote, visual and aural signaling. Off-standard conditions or power failure will cause a system alarm. The emergency water sampling equipment will obtain a sample for laboratory analysis whenever above-normal dose rates occur.

The dissipation of heat from underground tanks retaining radioactive wastes is an important consideration. Determination of the thermal conductivity of the soil, used to evaluate the heat dissipation, can be aided by a measurement of subsurface moisture. A soil moisture monitor was developed for such studies. Other geologic and hydrologic applications of the monitor include study of moisture in the zone above the water table; determination of porosity in the saturated zone to aid in measurement of ground water flow rates; and study of stratigraphic discontinuities associated with changes in the particle size of sedimentary earth materials. The instrument is a neutron soil moisture monitor, developed also as a geophysical well-logging tool to measure directly the moisture content of the sediments adjacent to test wells; the system includes: a probe with a fast neutron source, slow neutron detectors and solid state circuitry, five BF_3 counter tubes, an amplifier, a high voltage supply, and a one curie Pu-Be neutron source. A pulse height discriminator, power supply and record charts are located at ground level.

Beryllium is a modern, versatile element, but one which is highly toxic. There was need for an instrument system to determine the beryllium content of the atmosphere. The beryllium from a known volume of air can be trapped and concentrated on a filter; the element emits neutrons when

bombarded with alpha particles and this reaction provides a technique for the determination of the beryllium content on such filters. Three curies of Po-210 on a sealed disc serves as the alpha source. Ten to 20 micrograms of beryllium can be detected.

It will be desirable frequently in the future to monitor for possible radioactive contamination in sanitary drinking water supplies. Electronic instrumentation has been developed for such purposes. The complete monitor consists of a multiplier phototube, special scintillator, discriminator, clock timer, and printing register. The circuitry is all solid state for reliability, stability and ease of maintenance.

Both aerial and ground-level environmental radiation surveys are conducted routinely at Hanford. To provide for these surveys two special-purpose gamma monitors were developed; one is an aerial monitor for an airplane operated approximately 500 ft above the ground at 140 miles per hour; the second instrument is for a ground vehicle operated over difficult terrain.

In order to provide data on wind speed, wind direction, and radiation level from various locations on the reservation, a telemeter network was developed to use up to 20 remotely-located stations. The stations are called to report at preset times by a master recording station and provide the data via FM radio link.

An integrator was required for averaging the output of a pyrliometer used for measuring the intensity of solar and sky radiation. On cloudy days the recorded output is erratic while on clear days the trace approximates half of a sine wave. It was desired to measure the average radiant energy per day. The instrument as finally developed utilizes a smoothing network which automatically calculates and records periodically the weighted average of the solar radiation of the previous period; its results compare favorably with those obtained by tedious manual graphical analyses.

An instrument was developed capable of monitoring and recording air concentrations of a phosphorescing zinc sulfide tracer on a real time scale. In operation, the air containing the pigment enters a chamber where it is exposed to ultraviolet radiation, then passes to the viewing chamber where

its phosphorescence is observed by a phototube. Both the instantaneous and the integrated anode currents are presented on a dual pen strip chart recorder.

Technology has been developed applying automatic techniques of process control to chemical plants. Most of these were required because of the enforced remote maintenance of the equipment due to the radiation fields around it. The use of automation in plants handling radioactive materials takes on an added importance since here a major human error resulting in release of radioactivity could seriously contaminate a process building or a large surrounding area.

Some general examples of this kind of work will demonstrate the breadth of experience in this significant field:

- Determination and continuous monitoring of process variables, including the chemical variables of pH, electrical conductivity, solute concentration, and off-gas composition; physical parameters such as flow, pressure, temperature, density, and viscosity
- Solvent extraction column instrumentation--interface control, pulse frequency and amplitude, flow ratio control, measurement of dispersed phase hold-up
- Ion exchange column instrumentation--resin level detection, precision flow controls, control of continuous exchangers
- Programmed start-up and temperature control of furnaces and calciners
- Controls and concentration sensors for electrochemical systems
- Process control applications of devices which use fluids instead of electricity and which replace conventional electronic components tending to fail in hostile environments
- Strain gage applications for fluid flow, pressure, and jet impact measurements
- Development of statistically reliable techniques for sampling, sensor calibration and treatment of experimental data
- On-line computer control, data acquisition and data handling for chemical process systems.

The subject has more than peripheral interest in the present writing because it can fairly be said that the stringent controls facilitated by the automation described above contributed importantly to the outstanding safety record of the Hanford installations and to the rarity of incidents leading to environmental contamination. So in other industry, automation and improved instrumentation should contribute in a valuable way to the retention of pollutants within the confines of the plant.

Facilities used by the instrumentation groups have a value of approximately one-third of a million dollars capital value and include oscilloscopes, amplifiers, multichannel analyzers, solid state detector spectrometry system, environmental test chambers, recorders, analog-to-digital converters, digital voltmeters, counters, radiation detectors of many types, and auxiliary equipment. Other facilities and equipment available for direct use include Van de Graaff accelerators, gamma and neutron calibration sources, high level gamma exposure facilities, X-ray machines, pulsed and continuous neutron generators, and fully equipped analytical laboratories. In addition, the analog and digital computer facilities described before are available along with the optical, machining, model shop, and electronics fabrication facilities. Several test reactors and specific facilities of the production reactors may be used for tests and measurements. Particularly significant are the small airplanes which can be instrumented readily for special purpose, experimental or routine observations.

SYSTEMS ANALYSIS AND ECONOMICS

The mathematics groups of Battelle-Northwest provide statistical, mathematical and conceptual analysis and computer sciences service to the Laboratory. Special capabilities exist in mathematical model building--the abstract simulation of real-life phenomena by the use of scientific, economic, mathematical, and statistical principles. The model building capacity is supplemented by the use of computing as a powerful aid in analyses and evaluation. The mathematicians also provide computer systems analysis functions and software support to computer control studies.

In applied mathematics activities, physical processes can be simulated as the fundamental principles of algebra, calculus or functional structuring are applied to the problem. Then the interdependent relationships and behavior patterns of the parameters can be examined by analytical or numerical methods. Typical of such research is a unique model used to simulate ultrasonic wave transmission in a visco-elastic medium. This stems from a quality control application for the nondestructive testing of metals, but it has application in seismic research and geological exploration as well. For a second example, mathematicians are engaged in a project to define the flow patterns and temperature gradients of Columbia River reservoirs. In addition to these more specific applications, study is in progress on the fundamental processes of diffusion and transport in matter--a work of interest in astro and nuclear physics.

Many staff members have experience in industrial technologies and maintain that competence. As a result, the personnel stand athwart the time lag that normally separates pure mathematics from applied technology and they can communicate equally well with both scholars and industrialists.

While mathematicians deduce relationships from theory, statisticians apply inductive reasoning to infer relationships from experimental data. The statistician begins with an experimental design so that a minimum number of observations will yield a maximum amount of representative information. With the data from the experiment, the statistician builds and tests a quantitative model and the questions are answered as this simulator is manipulated to characterize the data more and more closely.

The statisticians are particularly adept in two pertinent areas. The area of experimental design has had special emphasis because of the cost and inherent difficulty of obtaining data in nuclear energy applications. This restriction has dictated the preparation of lucid research objectives, design of optimal experimental efforts, rigorous simulation of the problem, and knowledgeable data analysis and interpretation. Battelle-Northwest personnel are also proficient in the area of production control which brings to manufacturing operations such modern procedures as quality control analysis, procurement sampling, system and component reliability evaluation, and measurement accuracy determinations.

Conceptual analysis uses principles from engineering, physics, economics, and mathematics to simulate very involved business situations. The capability in conceptual analysis is built upon a continuing role as analyst on reactor fuel cycles to the nation-wide AEC complex. Related development studies include the plutonium fuel recycle program, fast breeder studies, metal conservation efforts, fuel value analysis, and power conversion schemes.

Conceptual analysis is particularly applicable to the large process industries which consume resources. The development of techno-economic simulators can bring to business management a firm grasp of the decision-influencing factors and it allows the optimization of dynamic business situations. Conceptual analysis provides a means of assessing the economic consequences of a contemplated strategy without the heavy financial risk of actually trying it. Hence, management can focus on those situations which can bring maximum profit.

Competence is maintained in three areas of applied computer sciences. The first, computing, is concerned with time-consuming and involved calculations. These are the product of a complex program logic which is driven by small amounts of input data and produces small volumes of output data. The simulation studies previously mentioned are illustrative of computing applications. A talented staff of numerical analysts and computer programmers supports the model building efforts of the mathematics, statisticians, and conceptual analysts to bring a vertically integrated approach to the studies.

Information processing is the second general area of computer sciences concern. It is characterized as a system of computer programs which captures, converts, edits, sorts, and stores massive amounts of data. In addition, the system will retrieve, sequence, and format the filed information and report in any of several output media. Automated information processing has potential application in any of the life or physical sciences situations which produce data to be stored, analyzed, and/or compiled.

Information processing systems are developed and installed through a function customarily termed "systems analysis." Systems analysis which results in the installation of an automated information processing application is characterized by the following steps:

- Application Feasibility
- System Design
- Computer Programming and Testing
- Conversion and Installation
- Postinstallation Evaluation.

It is apparent that computer systems analysis for scientific applications is highly specialized work. The Mathematics Department provides such service with competence because of the personnel and corporate background in this field.

Many Battelle-Northwest systems analysts have grown professionally to senior positions serving as functional or supervisory leaders or consultants in the development or operation of a wide variety of information processing systems covering the gamut of scientific application.

Many of the Battelle-Northwest computer scientists have had educational or working experience in additional fields and find the laboratory's interdisciplinary operation conducive to maintaining a working acquaintance with new developments in these fields.

The Department has had extensive experience in the development of highly complex scientific information processing systems, several systems costing upwards of \$1,000,000 and many smaller ones. Some examples are cited to indicate problems encountered and their solutions.

A mammoth system for computing reactor burnup information was originally designed and programmed "piecemeal" by several contractors. When it became obvious that a single group was necessary to weld the various parts into an integrated system, the Department was selected. Not only were the various segments successfully molded into a powerful entity, but the system was expanded to become an even more useful tool.

Another system which handles vast amounts of radiochemical analysis data has automatic file unit accounting and flexible report generation features which can be adapted for use in any storage and retrieval system without regard to the type of information processed. A system should produce reports which are articulate to the user regardless of his degree of computer orientation. To this end, Battelle-Northwest system analysts employ reporting techniques which foster that degree of detail which fits his needs. Graphical techniques can be extensively used for the rapid quantitative analysis of massed results.

A third area of applied computer sciences, computer control studies, has been established in the group and the Department has developed to provide software support. A process control computer is capable of triple purpose use controlling a pilot plant chemical process, providing on-line mass and energy balance calculations for a waste solidification experiment, and data logging for ultrasonic studies.

As a further example, a computer-based reactor control system has been proven which will provide direct digital control of a Test Reactor; this is believed to be one of the most advanced reactor control systems in the western world.

Finally, based upon the nuclear technology available here, Battelle-Northwest has been selected to manage development of the Fast Flux Test Facility, a reactor to be driven by three computers in an extremely sophisticated interrelated system.

In the field of Economics, Battelle-Northwest has designed and carried out studies for such varied purposes as water resource utilization and

control, industrial development planning, economic growth programs, power load forecasts, marketing-economic feasibility assessments, land use planning and general regional analyses. Typically, such economic studies vary in their degree of specialization, the amount and kind of detail and its precision depending upon the uses to which the findings will be put. In some cases a working economic assessment involved a summary of present economic structure, resource base, review of growth trends, prospects for future expansion and finally a recommended program for achieving levels of economic activity on a diversified base. More detailed studies have required specific industry forecasts relating to employment, production and future levels of activity. In some instances these industry forecasts were very specifically related to estimates of personal income, tax revenues and population, others have required complicated input-output models and the subsequent determination of interindustry relationships. Regional share and factor analyses are other economic review techniques regularly utilized.

These detailed economic measurements and projected levels of activity are necessary to and provide supporting information for such diverse objectives as transportation and commodity movements, trade expansion and development, regional economic development and water resource planning. Among other things, they provide the means for relating the economic parameters to the full study needs and a determination of what must be provided for in the study plan. Most important perhaps, they generally establish the economic mechanism within which the particular program must function.

With the proper statistical handling, these economic measurements can be translated into such items as water, dollars, people, or prospects.

Because the economic structure of most regions is in constant change, one-time assessments are seldom satisfactory. Long-term forecasts are even more susceptible to new developments. Unless otherwise required, all Battelle-Northwest study plans are designed to facilitate up-dating and revisions without the need for duplicating the basic information originally assembled.

The personnel have had extensive experience in designing and conducting all types of economic studies and have been instrumental in the origination of many new techniques. Staff members have been participants in many task force study teams. Thus they have working familiarity with such projects as the economic base study and planning review programs sponsored by the Washington State Department of Commerce and Economic Development; the input-output and modeling program conducted by staff members of the University of Washington; the service and trade industry reviews prepared by the Bureau of Business Research, Washington State University; the Puget Sound Transportation Study; state development study programs in Washington, Oregon, Idaho and Montana; the economic base study for the Puget Sound and Adjacent Waters Task Force; the various river basin economic reviews under way in the area; the economic base study program of the Bonneville Power Administration; and currently the study plans of the Cascade North Pacific Task Force.

In addition to the economic capabilities themselves, the mathematical and statistical specialties to create economic model simulation of the highest possible degree have been mentioned in the preceding. Many types of economic models and forecasting techniques are in process of development and the mathematical capabilities are becoming still more effectively utilized for economic study purposes. The skill and talents acquired in years of simulating nuclear decision making are now being directed toward economic determinations.

Decision making on water management in the future will require attention to all of the interrelated factors--the type of water deterioration expected, the physical and biological quality aspects, the technological advances then available, the established governmental standards for the waters concerned and the extrapolated placement of all of these into the future economics. An integrated look at the variables provided by computer-simulated mathematical models is undoubtedly the only feasible way to do this.

The services of a modern digital computing center are available as a part of the diversified Atomic Energy Commission complex at Richland.

Battelle-Northwest research personnel generally use the UNIVAC 1004 satellite computer located in the laboratory area and connected to the computing facility via high speed communications hook-up.

The computer installation is equipped with two powerful, high speed computing arrays--a UNIVAC 1107 and IBM 7090--as well as the medium range GE225. The full range of input-output devices, including a digital plotter and paper tape reader-punch, is at hand. Installation of a UNIVAC 1108 or comparable third generation system is anticipated; full time-sharing capabilities will be at the disposal of Battelle-Northwest scientists.

THE TECHNICAL LIBRARY

The research and development groups have had the support of an excellent technical library which has grown with the needs from the beginning of the Project activities to the present day. It now has a complement of thirteen professional employees with either technical or library science degrees. The book collection has 51,000 volumes and is particularly strong in nuclear science, engineering, physics, chemistry, mathematics, metallurgy and radiological sciences. On the periodical shelves are 23,000 bound volumes and 3,000 current subscriptions; there are long runs of the most important technical journals and extensive coverage of the abstracting and indexing services. Over 200,000 research reports, from AEC, NASA and DOD and including all the Hanford technical reports are on file.

The library staff utilizes an array of modern equipment in carrying out its responsibilities for information services. It makes extensive use of the data processing facilities having set up a computer program for compiling and maintaining bibliographies which is an example of great utility to the scientists.

Full use is made of offsite information sources. These include mechanized searches. The information services of the American Society for Metals, The American Chemical Society and the National Library of Medicine. Frequent use is made of the search capabilities of the Library of Congress and of numerous specialized information centers throughout the country, including the Defense Metals Information Center, the Radiation Effects Information Center, and the National Referral Center at the Smithsonian Institute. In addition, the library has an extensive interlibrary loan activity, borrowing materials on occasion from all major U.S. scholarly libraries. The Library provides direct translating abilities in French and German, subscribes to most of the basic Russian journals in cover-to-cover translation, and utilizes existing accumulations of translations such as the one at the John Crerar Library in Chicago.

It is difficult to overemphasize the important part that this Library has played in the scientific and engineering work of the Laboratories.

APPENDIX A

PERSONNEL SUMMARY
BY DISCIPLINE

APPENDIX A

PERSONNEL SUMMARYStaff Distribution by Academic Discipline
and Highest Academic Degree

<u>Academic Discipline</u>	<u>PhD</u>	<u>MS</u>	<u>BS</u>	<u>Total</u>
Atmospheric Sciences	1	6	4	11
Architectural/Civil Engineering	3	1	7	11
Ceramics	8	1	2	11
Chemistry/Chemical Engineering	70	75	135	280
Earth Sciences	4	2	4	10
Electrical Engineering	1	21	37	59
Environmental/Sanitary Engineering	2	2	1	5
Library Science		3	6	9
Life Sciences	22	3	8	33
Mathematics/Statistics	6	9	12	27
Mechanical Engineering	7	28	47	82
Metallurgical Engineering	12	26	27	65
Nuclear Engineering	7	17	3	27
Physics/Electronics	30	32	43	105
Other Technical	2	3	13	18
Business Administration		11	27	38
Law			4	4
Other Nontechnical	<u>1</u>	<u>3</u>	<u>11</u>	<u>15</u>
Total	176	243	391	810

APPENDIX B

BATTELLE-NORTHWEST
ORGANIZATIONAL STRUCTURE

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 BATTELLE-NORTHWEST
 ORGANIZATIONAL STRUCTURE

In multidisciplinary research programs, coordination of the research staffs directly involved is achieved through an overlay program approach. This coordinating mechanism has been developed and used successfully to form teams of staff members from several departments. Under this system, team members are responsible to a single project leader (appointed by an overlay program coordinator with approval of line management) for work on a specific project. At the same time, they remain members of their own departments for administrative purposes. Thus, each member becomes a project representative and may call on the manpower and facilities of his department for project work.

APPENDIX C
SELECTED BIBLIOGRAPHIES

APPENDIX C

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