RESEARCH ACTIVITIES AND CAPABILITIES OF THE OAK RIDGE NATIONAL LABORATORY

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INTRODUCTION

The President's energy message as released on June 29, 1973 calls for the creation of a new Energy Research and Development Agency which would be responsible for energy related research now being conducted by four agencies (78% AEC, 16% DOI, 5% EPA, 1% NSF). In addition to the consolidation of current energy research, the new agency would undertake research and development into new energy fields. The new agency would be constituted primarily from the present AEC organization. The AEC's current research capability resides in large part in the facilities and staffs of its federal laboratories. It is the intent of this report to describe the facilities and capabilities of the Oak Ridge National Laboratory for contributing to the AEC's changing role toward broad development of energy related technology.

OVERVIEW OF ORNL

Oak Ridge National Laboratory (ORNL) is located near the town of Oak Ridge (population 28,000) in eastern Tennessee. Knoxville (population 175,000), thirty miles distant, contains the main campus for the University of Tennessee and the central administrative offices for the Tennessee Valley Authority. ORNL is one of the three plants operated by Union Carbide Corporation for the AEC sited on the 32,000 acre federal reservation at Oak Ridge; the others are the Oak Ridge Y-12 Plant, a developmental engineering and fabrication organization engaged primarily in defense applications of nuclear energy, and the Oak Ridge Gaseous Diffusion Plant, one of three U.S. plants for separating uranium isotopes.

The ORNL research and development staff includes about 640 with Ph.D. degrees, 350 with M.S. degrees and 500 with B.S. degrees employed in the following occupations: 525 in engineering; 115 in mathematics and computer sciences; 325 in life sciences, including over 50 ecologists; and 525 in physical sciences. Technicians total 600 and other staff 2010 for a total employment at the start of FY 74 of about 4100, down from a level of about 5000 in FY 69. The 800 member design and general engineering staff for the three AEC plants at Oak Ridge is centrally managed and available to the separate plants as needed.

In FY 73, ORNL's operating budget was about $100 million of which 80% was for AEC work and the remainder was work primarily for other federal agencies. AEC funds in FY 73 included $27 million for reactor development, $32 million for physical research, $14 million for biology and medicine and $4 million to support AEC's directorate of regulation. Other federal agency funding in FY 73 included $5.2 million from NIH, of which almost half was from the National Cancer Institute; $4.8 million from the National Science Foundation primarily for environmental research and studies related to the use and conservation of energy; $4.2 million total from Department of Defense agencies and the National Aeronautics and Space Administration, largely for radiation and nuclear shielding research, chemical analysis and computer

services; $1.3 million from the Department of the Interior for its desalting program at ORNL; and $0.7 million from Housing and Urban Development for studies of integrated utility systems and urban growth patterns.

The investment in physical facilities at ORNL exceeds $350 million. Special facilities include: an assortment of nuclear reactors ranging from the HFIR, which produces the world's highest neutron flux, to the Tower Shielding Facility, a reactor that can be suspended in the air for shielding studies; several particle accelerators, including ORELA, an advanced electron linear accelerator, and the ORIC, which has special capability for accelerating heavy ions; a variety of chemical processing development facilities, including the Transuranium Processing Plant for separating californium and other heavy elements and the Thorium-Uranium Recycle Facility for shielded remote fabrication of fuel elements for any reactor; capacity for housing 330,000 small animals in support of several controlled small animal facilities with capabilities for studying genetic and somatic impacts of radiation and ambient chemicals; the Thermal Effect Laboratory for studying the effect of water temperature on fish and other aquatic life; extensive materials development facilities, including capabilities for purifying, casting, forming, and testing both metals and ceramics; extensive and varied chemical laboratories and chemical analysis facilities; a large diversified fabrication and shop capability for the three-plant complex including equipment for highly specialized operations such as ultrasonic machining for highly irregular shapes, virtual electrode drilling for holes as small as 0.001 inch, and liquid and gas honing and electropolishing; and an extensive three-plant computer facility.

EXAMPLES OF BROAD ENERGY SYSTEM ACTIVITIES AT ORNL

While most of the research programs at the Laboratory are in support of the AEC's primary objective of development of peaceful uses for atomic energy, a fraction of the total research program, supported both by the AEC and other federal agencies, has broad application to the U.S. energy system. These activities are listed below, organized in accordance with the general category of energy research involved and are subsequently briefly described.

R & D CATEGORY	ACTIVITY TITLE
SYSTEM ASSESSMENT, PLANNING & POLICY (Energy supply and demand studies, economic studies, information handling, system analyses of alternative energy development strategies, etc.)	A. ECONOMETRIC ANALYSES B. WORLD ENERGY RESOURCE SURVEY C. DIRECTORY OF ENERGY RESEARCH D. AGRO-INDUSTRIAL STUDIES E. POWER PARK STUDY F. URBAN GROWTH PATTERNS
RAW MATERIALS SUPPLY (oil and gas stimulation, mining, exploration, geothermal energy extraction)	G. COAL MINING STUDIES H. HYDRAULIC DRILLING
ENERGY & FUEL PRODUCTION & CONVERSION (Production technologies for fossil, nuclear, solar and geothermal energy sources, coal, oil and oil shale processes for sulfur removal and production of usable forms of oil and gas, thermo-electric processes - MHD, potassium topping, etc.)	I. POTASSIUM TOPPING CYCLES J. OHIO VALLEY ELECTRIC CORP. STUDY K. COLD FLUID TECHNOLOGY L. ENHANCED HEAT EXCHANGER DESIGN
ENERGY STORAGE & TRANSPORT (Superconducting power transmission, coal slurry piping, batteries, intermetallic compounds for hydrogen storage, etc.)	M. CRYOGENIC POWER TRANSMISSION N. COMPRESSED AIR POWER LEVELING
EFFICIENCY OF ENERGY USE (Air conditioner and heat pump efficiency, stirling engine development, energy efficiency recycling waste products, efficiency of electrolytic processes, etc.)	O. RESIDENTIAL SPACE HEATING & COOLING P. TRANSPORTATION Q. MODULAR INTEGRATED UTILITY SYSTEMS
ENVIRONMENTAL EFFECTS (Waste management, effects and control of airborne pollutants from exhausts, smoke stacks and cooling towers, waste heat recovery and disposal, etc.)	R. TRACE CONTAMINANTS S. GENERIC EIS STUDIES T. WASTE HEAT UTILIZATION U. INTERNATIONAL BIOLOGICAL PROGRAM V. COOLING TOWER EFFECTS

A. Econometric Analyses

The Laboratory has prepared an econometric analysis, with the assistance and partial support of Cornell University, of the electricity demand in the United States. The analysis consists of the selection of the best of several alternate statistical models describing the demand for electricity for various relevant consumer classes based on data for the 25-year period ending in 1970. The model has been used to extrapolate past trends of consumption to the future when generally higher electricity prices are projected. The model has also been applied to several specific tasks, including the prediction of the effect of a sulfur emission tax on electric power demand and the prediction of future water demand (carried out for the FPC).

B. World Energy Resource Survey

Laboratory staff are assisting the AEC in preparing a survey of world energy resources in time for the 1974 World Power Conference in Detroit. Resources of coal, lignite, oil, gas, uranium and thorium as well as undeveloped hydro-power are included in the country-by-country survey. The information will be computerized for easy retrieval.

C. Directory of Energy Research

With support from the NSF, information specialists at ORNL have compiled an inventory of abstracts of current energy research. The inventory is intended to include research in both public and private sectors for all energy categories. The abstracts are stored by computer for easy information retrieval.

D. Agro-Industrial Studies

ORNL studies have demonstrated that in regions where arid but otherwise fertile lands lie near a seacoast, it may be economically attractive and technically feasible to construct an agro-industrial complex - a regional development consisting basically of a large steam supply, an electric power generation plant and a seawater distillation plant, all surrounded by irrigated agricultural land and

electric power intensive industries. The studies have not only included investigations of the types of industries and crops most suitable for exploitation in given regions, but they have considered the economic, political and social impacts to be encountered in implementing such a complex.

E. Power Park Study

Studies of alternative policies for power station siting encompass the full range of considerations affecting the electric utility industry - fuel supply, transmission network, system demand, waste heat disposal. Laboratory engineers are assisting the AEC central planning staff to evaluate the "power park" concept wherein many power reactors are jointly sited on a federal reservation. The concept may be attractive from the standpoint of managing nuclear materials since fuel could be reprocessed on site and emissions and effluents monitored and controlled.

F. Urban Growth Patterns

Quantitative research is conducted for HUD on national urban growth patterns, the principal factors affecting such patterns, and alternate policies that might be employed to modify or direct future population distribution. The socioeconomic data base used in these studies includes the 1960 and 1970 Census data, the Census County Business Patterns data, the Internal Revenue Service data, and the Social Security Continuous Work History Sample data.

G. Coal Mining Studies

Systematic studies of the technology of coal extraction at ORNL are aimed at identifying areas where improved techniques will reduce costs, conserve resources, or minimize ecological damage. The studies have included an analysis of the social costs of surface (strip) mining, including in the latter case techniques for land restoration, and a review of the literature dealing with ecological damage from present coal extraction methods. Personnel involved in the coal mining studies have worked closely with both local and federal agencies.

H. Hydraulic Drilling

Improved (high speed, low cost) methods for the excavation of underground cavities underlie the economical development of several technologies for energy production, storage or transport, such as enhanced deep mine coal production, extraction of geothermal energy, in situ coal gasification, rejuvenation of oil wells and underground cavities for compressed air energy storage. Experiments at ORNL have demonstrated that hydraulic drilling using high pressure water jets can deliver more usable horsepower to the drilling face, drill through various rock formations at higher speeds, and require less frequent drill replacement than conventional drill bit techniques.

I. Potassium Topping Cycles

Studies and experiments at ORNL have demonstrated the thermodynamic advantages and the technical feasibility of turbine power cycles using liquid potassium as a working fluid. Combined (binary) power cycles involving a potassium topping turbine would provide for the recovery of 25% more electric energy (with a corresponding reduction in release of waste heat) from fossil fired plants beyond that possible using modern steam power cycles.

J. Ohio Valley Electric Corporation (OVEC) Study

Laboratory chemical engineers are preparing a comprehensive technical analysis to assist the AEC in evaluating alternative methods of meeting emission limitations proposed by regulatory agencies for OVEC's Clifty Creek station near Madison, Indiana. The Clifty Creek station is fueled with coal typically high (3.5%) in sulfur content, and supplies a large portion of the electricity used at the AEC's uranium enrichment facility at Portsmouth, Ohio. Alternative methods to be evaluated include: purchase of low-sulfur fuels, flue gas treatment, gasification of high-sulfur coal, solvent refining of coal, pyritic sulfur removal from coal, and hydroliquefaction of coal.

K. Cold Fluid Technology

Significant quantities of useful electric energy can be generated from a variety of low temperature heat sources, provided suitable

cold working fluids are used and economic power generation and heat transfer equipment are available. A program aimed at demonstrating various aspects of cold fluid technology and determining its economic potential for several applications, including bottoming cycles used in conjunction with conventional steam turbines and power cycles for recovering geothermal energy, is under way at ORNL. Work so far has included development of computer programs for the prediction of thermodynamic and transport properties of ammonia and other cold fluids, and the modification of existing steam power thermodynamic and cost estimating programs to accommodate the bottoming cycle analysis.

L. Enhanced Heat Exchanger Design

As part of a cooperative effort with the U.S. Dept. of Interior Office of Saline Water, an experimental program at ORNL has led to the development and performance testing of evaporators and condensers with heat transfer performance far exceeding that of conventional smooth tubes. The improvements include the use of economical enhanced heat transfer tubing and the design of tube bundles to facilitate the continual removal of non-condensable gases. These developments have broad potential applications to energy technology such as power station condensers and feedwater heaters, industrial requirements for heat exchange for waste heat recovery, or more efficient automobile radiators.

M. Cryogenic Power Transmission

Significant increase in the power capacity of underground electrical transmission can be accomplished using cryogenic superconducting cables operating at temperatures from 4 to 90°K. Basic research is underway at ORNL on the preparation and properties of materials for use as conductors and dielectrics at cryogenic temperatures. It is conducted by specialists from the thermonuclear program already familiar with the state-of-the-art technology of cryogenic dielectrics and superconductors and by metallurgists familiar with preparation of high conductivity substrates for use as the superconductor.

N. Compressed Air Power Leveling

An analysis was prepared by ORNL of the technical feasibility and economic feasibility and economic potential of using excavated underground caverns as a means of leveling out the electric energy demand of utility systems. The caverns would store compressed air which would be used subsequently to operate gas turbine electric generators. The analysis compared compressed air storage to the alternate, pumped water storage, from the standpoints of costs, geographic and geologic limitations, and efficiency.

O. Residential Space Heating and Cooling

Analytical work at ORNL has led to far-reaching studies of many factors which could contribute to more efficient use of electric energy. For example, the efficiencies of air conditioners and residential heat pumps have been analyzed for various climatic conditions and energy costs, as has the value of increased insulation in reducing energy losses due to heat leakage.

P. Transportation

Patterns of energy consumption in the United States for all transportation modes were examined both for urban and inter-city traffic. Differences in energy efficiency among the various modes and historic and projective trends were developed and analyzed. As part of this program, an estimate was prepared of the total energy required to operate the automobile industry, including that needed to manufacture, distribute, operate, and maintain the vehicles as well as to produce and distribute the fuel and build and maintain roads.

Q. Modular Integrated Utility Systems

Studies at ORNL for HUD have attempted to determine the economic and resource conservation potentials associated with central total energy systems for residential complexes. These systems generate and distribute hot and/or chilled water for space heating and cooling as well as supply the electric power needs of the complex. Incineration of combustible solid waste along with the primary fuel, using novel furnace designs, has also been studied as an economical way both of disposing of the wastes and recovering their energy potential.

R. Trace Contaminants

The disposition of toxic elements present in trace quantities in coal and other fossil fuels and released during combustion in large power plants is being studied experimentally using test information from a TVA steam plant. One phase of the study consists of taking enough test samples of coal and air entering the plant and of the effluent gases and slag to determine material balances around the plant for each of a wide variety of trace elements. A second phase involves identifying those components of the environment that accumulate the trace elements, thus evaluating the impact of a fossil fired plant on its surroundings.

S. Generic EIS Studies for AEC

The Laboratory is preparing a series of generic Environmental Impact Statements (EIS) covering energy sources and conversion systems considered as possible alternates to specific nuclear fueled steam power plants. The generic statements (to be prepared for such energy sources as solar, geothermal, windpower, etc.) will then be available to the AEC regulatory staff to be incorporated or referenced as needed in the preparation of specific EIS for proposed new power reactors. ORNL staff members assisting in the preparation of the generic EIS will also be available to assist in their use.

T. Waste Heat Utilization

The utilization of waste heat from large steam power plants (fossil or nuclear) to enhance the growth rate of various commercial foodstuffs (plants, animals and fish) has been under investigation by ORNL. A pilot plant greenhouse, designed and built as a joint venture between the Laboratory and TVA, is currently undergoing tests at Muscle Shoals, Alabama. Based on test performance, a demonstration unit will be built and operated in conjunction with the TVA Browns Ferry Power Plant.

U. International Biological Program

Headquarters for the Eastern Deciduous Biome of the IBP, a NSF activity, is in the Environmental Sciences Division and includes a

significant local research effort. The long-term goal of this program is to evaluate man's impact on a region in order to reach a scientific basis for resource management and utilization of land and water.

V. Cooling Tower Effects

The waste heat load of new steam power plants is frequently dissipated by wet cooling towers. The air circulated through them carries, in addition to the evaporated water, suspended particles of water treatment chemicals which are in turn deposited on the landscape. The long-term environmental consequences of these potentially harmful substances are being investigated by the Environmental Sciences Division using the cooling towers located at the Oak Ridge Gaseous Diffusion Plant.

ORNL CAPABILITIES AND ERDA

Energy R & D activities suitable for application in the near-term will emphasize coal and oil shale technology and the breeder reactor. For longer range application, technologies such as superconducting power transmission, solar-electric energy, fusion power, and hydrogen or hydrogen derived synthetic fuels may be important.

Technology Development

Successful development of each energy technology will require, in most cases, capability in chemical technology, project engineering, and materials science. ORNL has strong capabilities in each of these areas:

Chemical technology - The Laboratory has developed nine radiochemical processes over a 25-year period (see Table 1). Technology developed at ORNL is now being used in almost every ore recovery and reactor fuel reprocessing facility in the world. In fuel development as well, the Laboratory has made major contributions. Early ORNL work on aluminum-uranium alloy and cermet fuels provides the basis for all research reactor fuels, including the HFIR fuel element. Contributions have also been significant to power reactor fuels; one development, done cooperatively with Gulf General Atomic, is now in use in the HTGR.

Current timely projects in applied technology are the Laboratory's programs in high- and intermediate-level radioactive waste disposal. In a 14-year study, the value of bedded underground salt deposits as repositories for long-term disposal of high-level radioactive wastes was determined to the universal satisfaction and approval of the scientific community by a team of ORNL health physicists and geologists. This activity has now moved to the stage where specific sites in Kansas and New Mexico are being investigated as potential federal reservations for waste storage, and detailed engineering designs for the storage facilities are being prepared. Complementary to this

effort was the development of a method for reducing high-level liquid wastes to a solid and fixing them in a glassy matrix for safe and stabilized storage.

The oil-field technique of hydraulic fracturing of bedded underground strata has been refined and adapted for disposal of intermediate-level wastes by ORNL. In this process, the liquid wastes are mixed with a suitable concrete grout and injected underground, at appropriate depths, into carefully mapped shale formations. At the chosen level the intruding slurry extends a horizontal fissure created initially by a slotting and water pressure procedure. The slurry spreads into a thin lamina that hardens into an insoluble rock-like deposit.

Table 1. Chemical Technology Missions at ORNL

Radiochemical Processes	Years	ORNL Cost
Purex - Pu, U, Reduction Extraction	1948-54	$ 2,500,000
Thorex - Th Extraction	1952-56	3,000,000
Idaho Chemical Plant	1949-53	32,000,000
TRU - Transuranium Process Plant	1962-68	17,500,000
Redox Pilot Plant - Reductive Extraction of U and Pu	1948-50	2,000,000
Metal Recovery	1948-54	1,500,000
Fused Salt Volatility	1948-62	2,500,000
Chop Leach Head-End	1958-62	2,000,000
Sol-Gel Fuel Preparing	1958-72	3,500,000

Project engineering - In 25 years of reactor development, ORNL has completed 10 reactor projects (see Table 2): seven for research and three power reactor experiments, one of them military. Research reactor projects culminated in the completion of the High Flux Isotope Reactor (HFIR), a research tool unsurpassed in power density and neutron flux. It was conceived, designed, and built to provide a neutron flux greater than 3 x 10^{15} n/cm^2/sec for the production of transuranium isotopes and for neutron beam research. These objectives were met within the budget and on schedule. Power reactor development at ORNL reached an accomplishment peak with the successful construction and operation of the Molten Salt Reactor Experiment, representing the collaborative R & D efforts of seven Laboratory divisions and demonstrating the power of the combined research and technical skills of the Laboratory.

ORNL staff has undertaken the conception, design, and construction of a number of landmark research facilities, among them the Oak Ridge Isochronous Cyclotron and the Oak Ridge Electron Linear Accelerator. This last facility was designed and built to obtain fast neutron cross sections, primarily for the LMFBR program but also to play an important research role in basic physics. The approved budget of $4.8 million was underrun by $200,000, permitting the construction of a 200-meter flight station to give a final underrun of $3000. The operational performance and reliability of ORELA has been outstanding. It is a machine that is developing the state of the art as it operates, producing ten times as many neutrons for short pulse operation than any other linear accelerator.

Currently, the Laboratory is constructing a major test facility to study heat transfer during light water reactor blowdown for simulated conditions. Studies of comparable significance for breeder reactor loss-of-coolant-accident (LOCA) safety and structural design are conducted in the Thermal Transient Test Facility. Here the tendency of LMFBR piping to deform plastically under the influence of repeated temperature transients is studied by subjecting a representative LMFBR piping segment incorporated in a closed loop to successive abrupt temperature cycles. Temperature cycles are pro-

duced by passing through the loop a stream of molten sodium, having a pre-set thermal gradient, starting at 1100°F and cooling to 800°F within 10 seconds. Another test studies the effect of partial blocking of the coolant flow paths on LMFBR using electrically heated rods to simulate LMFBR fuel pins.

Table 2. Reactor Missions at ORNL Since 1947

Research Reactors	Years	ORNL Cost
Materials Test Reactor (MTR)	1948-51	$ 5,500,000
Light Water Test Reactor (LITR)	1948-51	1,300,000
Swimming Pool (BSF)	1950	300,000
Tower Facility (TSF)	1952-54	2,000,000[a]
Oak Ridge Research Reactor (ORR)	1952-58	5,000,000
High Flux Isotope Reactor (HFIR)	1960-65	22,000,000
Military Reactors		
Power Package	1955-67	4,500,000[b]
Aircraft Nuclear Propulsion (ANP)	1950-61	89,000,000
Civilian Reactors		
Aqueous Homogeneous (HRE, HRT)	1950-61	70,400,000
Molten Salt (MSRE)	1957-72	51,000,000[c]
Experimental Gas Cooled Reactor (EGCR)	1958-66	32,000,000 (ORNL ONLY)
Savannah	1958-63	4,500,000[d]

[a] Excludes subsequent reactors.

[b] APPR-1 cost was $1,300,000. Balance of cost primarily for development and testing of fuels for Army reactors.

[c] R & D on MSRE was ~$13,000,000.

[d] Includes $1,000,000 which would have been associated with operation and improvements and ~$1,500,000 for maritime loop and advanced fuels.

Materials science - The Metals and Ceramics Division at ORNL has had success in the development, fabrication, and characterization of both conventional and unusual materials. Within its experience are aluminum and its alloys, conventional and stainless steels, nickel- and cobalt-base alloys, refractory metals and their alloys, ceramics, cermets, and graphite. For characterization of the materials it handles, the division is equipped with a large x-ray laboratory, metallography expertise, electron microprobe and other sensitive surface analysis methods, electron microscopy including a 650-kV machine (now being upgraded to 1000 kV), a versatile nondestructive testing laboratory, and facilities for compatibility and corrosion testing in conventional and exotic media. The successful development of new fabrication and characterization techniques is documented in such achievements as the complex HFIR fuel element, the development of nondestructive eddy-current inspection techniques with optimum response and zero trial-and-error efforts, efficient fabrication of molybdenum and tungsten by extrusion, countering radiation damage in structural metals with alloy modifications, extension of electronic band theory calculations to mixtures and nonmetals, the success of its nickel-base alloys when used in molten fluorides and other demanding environments, the introduction of europium oxide as a reactor control material, and the fabrication of stainless steel cermet fuel elements for compact reactors.

Currently, ORNL pursues several general investigations in mechanical properties of piping and vessels, welding, and nondestructive testing methods. A major activity in progress involves definition of the properties of thick steel sections in order to predict the cracking and crack-arrest behavior of pressure vessel materials. Model pressure vessels of forged reactor-grade steel with 6-inch-thick walls are tested: first, artificial cracks of carefully chosen shape and depth are made in the walls at selected locations; the vessels are then heavily instrumented with stress- and dimension-measuring devices, and are hydraulically pressurized until rupture occurs. Typically, pressures in excess of 28,000 psi - about 3 times the rated vessel pressure - are required. Theoretically predicted failure pressures and cracking modes are then compared with observations to aid in developing better design methods for full-sized reactor pressure vessels.

Environmental Effects

In addition to energy technology development, there is the need to predict and monitor the environmental impact of a technology as it is applied. This requirement implies the ability: to analyze and characterize the chemical nature of pollutants; to trace and determine the effect of chemical effluents as they are ecologically assimilated; and to measure and understand the importance of low-level insults to public health. ORNL has unusual strengths in analytical chemistry, environmental science, health physics, and biology:

Analytical chemistry - ORNL's Analytical Chemistry Division has acquired expertise in many techniques and a massive array of specialized modern instrumentation. The radiochemical and activation analysis capabilities are most extensive, and include the High Flux Isotope Reactor; the Oak Ridge Electron Linear Accelerator, which makes possible high sentivity photon activation analysis; and electron spectroscopy facilities, a very new technique that is uniquely suited for determining oxidation stages of solid materials and adsorbed substances. Organic and biochemical determinations are made possible by the zonal centrifuge, high-pressure ion-exchange chromatography, optical and electron microscopy, and physical testing. A unique facility at ORNL performs chemical and physical analysis of cigarette smoke and cigarette smoke condensate, a process that requires a host of analytical techniques and has obvious application to public health problems.

Other analytical techniques include emission and spark-source mass spectrometry, flame photometry, photoelectron spectroscopy, and such bio-organic analysis methodology as ultra-violet, infrared, magnetic resonance, and mass spectrometry. Of particular utility are mass spectrometers and gas chromatographic-mass spectrometric systems used specifically with organic compounds. The division has designed and built a high resolution organic mass spectrometer for organic identification.

Environmental science - The Environmental Sciences Division of the Laboratory has more than 15 years of research experience in the behavior and consequences of radioactivity released to the environ-

ment. This group has established a national leadership and an international reputation in ecology and in the application of physics, chemistry, and mathematics to energy-related environmental problems. The division staff of about 125 people includes ecologists, limnologists, soil chemists, geochemists, engineers, botanists, mathematicians and information specialists.

The 32,000 acre government reservation near Oak Ridge provides undisturbed terrestrial and aquatic environments for research in a variety of ecological systems. The Walker Branch Watershed is a 250 acre portion of this area that has been developed into a highly sophisticated experimental study site with advanced instrumentation for remote monitoring and measurement of environmental parameters. It is used by ecologists to study the ecological cycle of nutrients, radionuclides, and trace elements (heavy elements) typically introduced into land-water systems by man -- some as a consequence of energy development and use.

The effect on the aquatic biota of thermal effluents from steam power plants is investigated by field studies and by controlled laboratory studies in a recently constructed Thermal Effects Laboratory. The impact of man's activities on regional complexes of ecosystems is under investigation at ORNL for the International Biological Program.

Representatives of some fourteen Laboratory divisions are contributing to the preparation of Environmental Impact Statements for nuclear power plants. Over thirty statements have been produced in the past eighteen months; they provide not only a detailed description of the plants but also an independent assessment of the potential impact of their construction and operation on the community and the environment.

The zonal centrifuge, developed initially to separate components of biological systems, is now being used to separate the organic and inorganic components of soils and river sediments in suspended solids in order to determine the precise location of bound toxic materials. Both the GeMSAEC fast analyzer and the high resolution chromatography system developed for clinical use are now being used to measure trace contaminants in surface waters.

Health physics - The field of health physics originated at ORNL. For 30 years, the health physics staff has been concerned with controlling and minimizing the deleterious effects of ionizing radiation on man and his environment. Health physics research at ORNL involves studies of the interaction of radiation with matter at all levels and the development of appropriate measurement capabilities, the determination of dose to man and to other living things that may be exposed to internal or external sources of radiation, the defense of civil populations in the nuclear age, and the trends and growth of urban populations.

The staff of the Health Physics Division, currently about 200 people, includes applied health physicists, physicists, chemists, electrical and nuclear engineers, mathematicians, and demographers. Members of the division serve on all of the important international committees and commissions dealing with radiation safety and standards.

Information accumulated by health physicists for the "reference man report" for the International Commission on Radiological Protection provides considerable data on the metabolism of elements in man and has relevance to questions of toxicity of various materials inhaled or ingested by man. Fundamental studies of radiation interaction with matter enhance development of dosimetry techniques. A large fraction of the world's instrumentation and techniques for the measurement and control of radiation was developed at ORNL; this development has resulted in an extensive range of instrumentation and techniques for diverse other fields including sensitive pollutant detectors and archaeological dating techniques.

Biology - Biological research at the Laboratory has historically been directed toward understanding the impact of man-made materials on the normal functioning of living things. Most studies are focused on radiation effects, but other agents such as artificial smog and sulfur dioxide have been included in recent years. Primary inquiry is into the ability of these agents to induce cancer and mutations.

A 25-year study by ORNL biologists on the genetic effects of radiation on mice, spanning several scores of generations and involving some 6 million animals, has furnished the principal avail-

able data for setting national and international standards of radiation safety. Likewise, to study the somatic effects of small amounts of radiation during the lifetime of individual animals, very large-scale experiments involving statistically significant numbers of disease-free mice are in progress in ultra-clean animal housing, kept free of outside contamination for eight- to ten-year periods of time. Thus, ORNL has highly specialized and unique facilities, particularly for small animals. At any given time there is an animal population of approximately 330,000. On the basis of the facilities and experience gained from research on radiation insults to mammals, in the last decade ORNL biologists have also studied genetic and somatic effects of drugs, gasoline smog, and other toxic materials released to the environment by man.

The Molecular Anatomy Program is concerned with the development of systems, reagents, and techniques which directly affect human health and patient care. Instruments such as the ultracentrifuge and the fast clinical analyzer are used to separate materials at the cellular and molecular levels, to provide materials for research and reagents for diagnosis, and to perform automatic analyses for molecular constituents in body fluids and other materials.

Physical Research and Research Support

Backing up applied programs in technology development and environmental effects, the Laboratory maintains strong competence in the basic physical sciences as represented by separate line organization divisions in chemistry, physics, neutron physics, and solid state. Research support is provided through the Laboratory's computer facilities and services and information science activities.

Physical research - ORNL has many years of experience and a high level of capability in carrying on basic research in the physical sciences. It performs research at the frontiers of solid state and plasma physics, in chemistry and in mathematics. Modern accelerators provide tools for intensive studies in the fields of nuclear structure, scattering, cross sections, and energy levels. Chemistry research includes investigations into the properties of actinide elements, solid state, and solution chemistry at high temperature and pressure. ORNL's unique high flux reactor provides one of the best tools for neutron diffraction and materials science research into the properties of crystals and study of processes of crystal imperfection. The field of plasma physics has evolved in support of demonstrating controlled thermonuclear power.

The basic work at ORNL has fed new ideas and techniques into applied areas. To cite a few: the techniques of nuclear chemistry and physics led to the development of neutron and charged particle activation analysis as a highly sensitive analytical tool; investigation of the chemical selectivity of certain inorganic membranes led to the discovery of hyper-filtration and cross-flow filtration techniques that promise to be inexpensive methods of water purification; basic research on radiation induced defects in solids has made possible studies that address themselves directly to structural materials behavior in reactor systems.

Information - The Central Research Library subscribes to over 5000 periodicals and, with its three branches, offers access to over 125,000 volumes and 300,000 technical reports. Also offered are reference services, translation, microfilm technology, and an exchange agreement with area libraries at the University of Tennessee, Oak

Ridge Associated Universities, and TVA, as well as technical libraries across the nation.

The Laboratory is the locale for ten information centers: the Nuclear Data Project remains abreast of all nuclear structure information; the Information Center for Internal Exposure supplies interpretations and recommendations to the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurement; information centers on radiation shielding, nuclear safety, research materials, and a worldwide accelerator directory furnish select bibliographies as needed; the Environmental Information System comprises four environmental information centers (the Toxic Materials Information Center, the Toxicology Information Response Center, the Environmental Mutagen Information Center, the Ecological Sciences Information Center) and data bases related to other appropriate fields such as energy, social science, regional modeling, and solid waste management.

Computer facilities - Computer facilities and services are centrally managed for the three plant AEC installation at Oak Ridge. The Laboratory's computing center includes an IBM 360/91 system, an IBM 360/75 system, and a coupled PDP-10 and PDP-15 system. These computers carry on the computational work load and utility and support functions in conjunction with peripheral equipment such as paper tape to magnetic tape conversion, tape to printer operations, magnetic tape scanning and copying, listing or reproducing punch card decks, plotting, data and terminal adaptors, etc. A multiplicity of services is available to all divisions in the Laboratory and can be brought to bear on the solution of many problems the subject discipline, the supporting mathematical discipline, and the knowledge of high speed computing.

The Computer Technology Center at the gaseous diffusion plant is a consulting and problem-solving activity that provides service to the research development and production functions. Computer systems used in support of the Center include an IBM 360/65 intercoupled with a 360/50 and seven other computers.

TABULAR DISPLAYS

Selected Technical Facilities at ORNL*

ORNL Research Organization

Manpower at ORNL

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*For completeness, much of the material describing technical facilities is deliberately duplicative of information in the main body of the report.

SELECTED TECHNICAL FACILITIES AT ORNL

Thermal Effects Laboratory. This facility comprises a 50' x 100' main building, a service annex that contains the flow and temperature controls, and six 1/4-acre outdoor ponds. Mixing valves, computer-controlled, provide required temperature fluctuations in the facility's 60 individually controlled 200-gal tanks. Growth rates, survival and predation habits of many species of fish undergoing temperature elevations; the effect of cooling system entrainment on fish eggs and larvae of invertebrates; and thermal effects on snails and clams are a few of the studies now under way.

Controlled Environment Chambers. ORNL has some 15 to 20 controlled environment chambers in which ecologists have performed uptake studies. Conditions of light, temperature, and humidity can be controlled, and studies have been made on animals as well as plant life. Metabolic measurements, i.e., O and CO_2 production, for instance, were taken on one colony of cotton rats, a species indigenous to the local area.

Precipitation Simulator. A mechanism for simulating rainfall, with controlled drop size as well as intensity, is available for small-scale studies of pollutant washout in the atmosphere. It affects an area of about 900 square feet, dropping rain from a height of about 30'.

Walker Branch Watershed. An instrumented watershed of approx 250 acres of relatively undisturbed deciduous forest, equipped with calibrated systems for input-output measurements, both terrestrial and aquatic. Movement of water and of chemical elements is under close observation throughout the watershed area. Within the system are several field plot areas on which controlled fallout and toxic effects studies have been performed.

Shale Fracture Waste Disposal Plant. Developed at ORNL was a method for disposing of intermediate-level liquid waste by depositing it in shale rock. After the waste is mixed with cement, fly ash and clays, it is injected into shale formations 900 ft below ground under enough pressure to create horizontal fractures of large area-to-thickness ratio. In this method over 300,000 gallons of waste, containing 110,000 curies of activity, have been permanently disposed of at ORNL.

Small Mammals Facilities. Genetic records spanning several hundred generations of house mice and involving over six million animals have been taken in the ORNL program studying the genetics effects of radiation. In another study, to determine the long-term effects of very small doses of radiation, very large-scale experiments involving statistically significant numbers of germfree mice are in progress in ultraclean animal housing, kept free of outside contamination for periods of eight to ten years. These two experiments account for a total of approximately 330,000 mice at any given time. In addition, a colony of golden hamsters are employed in a number of inhalation studies, and the small mammals laboratory in the Environmental Sciences Division includes several hundred gerbils as well as indigenous animals.

Inhalation Laboratories. A program of collaborative research between the Biology and Analytical Chemistry Divisions that includes several controlled-temperature and -humidity rooms in which machines smoke cigarettes, small mammals are cannulated for localized smoke and smog deposition, and the smoke and tissues are subjected to the extensive analytical methodology available at ORNL. Approximately 10 staff members participate in this program from each division.

Frozen Embryos Laboratory. A facility for controlled freezing and storage of a variety of biological materials in the viable state, including mouse embryos, mammalian tissue culture cells, and microorganisms of various sorts. The Laboratory is engaged in an investigation into methods of low-temperature storage and live retrieval of complex organisms as well as developing existing technology toward advancing methods of food production. It is staffed by two senior biologists and two research assistants.

Macromolecular Separations Facilities. This consists of five laboratories and two cold rooms, staffed by senior researchers in chemistry, chemical engineering, and biochemistry. The facilities were established for a program to develop methods for the preparation of highly purified biological samples. Techniques employed include reversed-phase chromotography, affinity chromotography, precipitation, centrifugation, and lyophilization (freeze-drying). Gram quantities of highly purified transfer ribonucleic acid have come from this program, as well as identification of specific nucleotides and nucleosides. Current work entails the purification of two hormones that are essential to the maturation process of bone marrow cells.

Bioanalytical Laboratory. Virtually all techniques of modern organic analytical chemistry are applied to the Cigarette Tobacco Smoke Characterization and Inhalation Methodology Projects. Approaches to identification of organic compounds include ultraviolet, infrared, magnetic resonance, gas chromotography, and mass spectrometry. Of particular utility is a high resolution (30,000 at mass 500) mass spectrometer designed and built at ORNL specifically for identifying organic compounds.

Whole Body Counter. A room, 10' x 10' x 10', constructed of 14-in. steel armor plate and lined with 1/8 in. lead, containing a steel cot with a basic detector suspended overhead consisting of a sodium iodide crystal 8 in. diameter by 4 in. thick. It can perform *in vivo* gamma ray spectrometry either with collimaters for selected areas of body or uncollimated for a complete, whole-body scan. It can detect very small radioactive deposits within a person, and provides the least equivocal and in some cases the only means of estimating internal radioactivity.

Molecular Anatomy Laboratory. A multipurpose laboratory, staffed by chemists, biochemists, physicists, and chemical engineers, with an imposing list of analytical and diagnostic devices developed over the past few years: the zonal centrifuge, the GeMSAEC, the chromatographic and the UV analyzer for body fluids. A research program at the Rockville, Md. branch of the MAN Laboratory is conducted into the isolation of specific viruses and the development of clean vaccines, using the centrifuge technology developed in Oak Ridge.

Emission and Spark-Source Mass Spectrometry. A technique whereby up to 40 metallic elements can be surveyed semiquantitatively. Used routinely to assess mercury, cadmium and lead presence in ambient air and water, it is an essential tool for detecting environmental problems.

Scanning Electron Microscope with X-Ray Fluorescence Analyzer permits simultaneous determination of the morphology and the elemental composition of extremely small samples, e.g., particles of fly ash. By means of a highly focused electron beam, which causes the emission from the sample of low-energy electrons as well as x-rays, an image can be produced on a cathode ray tube with resolution of 200Å. Particles as small as 1/2 micron can be analyzed.

Adiabatic Reaction Calorimeter. Designed to study reactions in aqueous systems at temperatures up to 250°C. It can be used to measure heats of solution, dilution, wetting, and adsorption. For example, it is used to measure heats of wetting of thorium oxide in water and dilute electrolyte solutions.

Activation Analysis. Three high-flux neutron sources at ORNL make possible analysis of virtually any size or type of sample. The Bulk Shielding Reactor, the Oak Ridge Research Reactor, and the High Flux Isotope Reactor provide high and ultra high sensitivity for most of the elements in the periodic table. Most multiple-element determinations can be made nondestructively; single element determinations can be performed routinely with a precision and accuracy of ±3%. In addition, the electron linear accelerator makes possible photon activation analysis, providing access to the elements with low atomic numbers. With this technique, carbon, nitrogen, oxygen, fluorine, sulfur, and phosphorus can be determined in the 0.01 to 0.1 nanogram range, and cadmium can be detected at levels as low as 0.1 ng.

Magnet Laboratory. Contains a number of magnet coils: The B_1 coil produces up to 64 kilogauss when energized with one generator rated at 3 MW continuous power. Its inner diameter is 6-1/2 in. A two-coil arrangement of the same type produces a field of up to 83 kG. The coil has an inner diameter of 13 in., and produces an extremely homogeneous field of 62 kG when energized with 6 MW. The D coil pair is capable of either mirror or cusp connection. With a 12-in. inside diameter, it can produce 63 kG in mirror connection with 6 MW. There are also several superconducting magnet coils in the laboratory. One is a 50-kG Magnion coil with 10 in. inside diameter; another is a coil for 30 kG with 4-in. inside diameter. The Magnet Laboratory has been used for: plasma physics research; development of high-powered, water-cooled magnet systems; development of superconducting coils; testing of superconducting materials; and calibration of magnetic instruments.

Metallurgy Laboratory. A facility for the preparation and fabrication of a wide variety of metallic, ceramic, and cermet materials. It contains induction, arc, and electron-beam equipment for melting alloys from nearly all metals, including refractory metals. A vacuum arc melting furnace can handle

50- to 400-lb heats of high-temperature alloys and refractory metals. Small (2-lb) arc and electron-beam furnaces are equipped to drop-cast alloys for better uniformity and fabricability. One arc furnace is contained in a hood for melting toxic materials. Fabrication capabilities include equipment for producing tubing, sheet, rod, and wire. A 1250-ton, 10-in/sec horizontal extrusion press can handle most alloys in billets of 3 and 4 in., and was used to develop extrusion techniques for refractory metals up to 2200°C. Seven rolling mills can handle hot and cold slabs up to 2.5 in. thick and 24 in. wide, reducible down to 0.001-in. foil. Recently installed are two high-temperature high-pressure autoclaves. One, at 1500°C and up to 20,000 psi, is for processing ceramics and graphite as well as metals; the other will maintain a pressure up to 200,000 psi, for use in determining the diffusivity of elements in alloys.

High Voltage Electron Microscope, at present operating at 650,000 volts, is scheduled to be upgraded to 1,000,000 volts within the year. With this instrument, microstructural examinations of welds and other bulk materials are possible, and in biological material the entire cell can be visualized.

Hybrid computer combines the capability for parallel operations and on-line interaction characteristic of the analog computer with the accuracy, memory and preprogramming capabilities of a digital computer. It is an effective tool for studying the dynamic behavior of complex processes and systems.

Thermal Cycle Facility. Consists of a package Besler boiler that can provide saturated steam at pressures of from 150 to 2000 psi, two water pumps that provide water at pressures up to 2000 psi, a high-pressure trapping station and a feedwater deaerator. It can provide steam at rates up to 5000 lb/hr, or mixtures of high-pressure steam and water. It is used to test components of high-pressure aqueous systems.

Nondestructive Testing Laboratories. A pioneer in NDT, the Oak Ridge National Laboratory has an extensive variety of methods for nondestructive testing of materials: penetrating radiation, both x-rays and neutrons; ultrasonics, including the schlieren technique; phase-sensitive eddy currents for identifying metals and inspecting small-diameter tubing; and liquid dye-bearing penetrants for detecting surface flaws. Instruments for nondestructive testing developed at ORNL have now been adopted by industry and are commercially available.

Advanced Filtration Equipment. The Water Research Program deploys test loops for studies of separations (desalination, pollution abatement, etc.) ranging from low-pressure cross-flow filtration of particulates to high-pressure hyperfiltration (reverse osmosis) removal of dissolved species. Included are five laboratory units with high-pressure (1,000 psig) capability equipped with circulation pumps of 50 gpm or greater; two laboratory cross-flow loops; one mobile hyperfiltration and one mobile cross-flow system, both mounted in trailers; and a movable hyperfiltration pilot plant (nominal 1,000 gpd). In addition, there is a 10,000 gpd cross-flow filtration pilot plant at the ORNL sewage plant, which was constructed by the Operations and Chemical Technology Divisions and is to be used in tests by them.

Heat Transfer Facilities. Single tube and multitube heat transfer test loops have been used to develop and characterize a variety of enhanced heat transfer tubing for use in steam condensers and evaporators. Loops are available for testing tube lengths to 20 feet and diameters to 3 inches in both vertical or horizontal orientations. A unique tube bundle model test facility has demonstrated its ability to predict the steam flow characteristics of large surface condensers and thus prevent the accumulation of non-condensable gases with subsequent wasteful loss of heat transfer performance.

Experimental Stress Laboratories. The Experimental Stress Laboratories have capabilities for performing structural tests of important primary system components used in nuclear and conventional electric power plants and other high performance industrial processes. Tests can be run on pipes, fittings, valves and pressure vessels up to several feet in diameter at hydraulic pressures to 50,000 psi. Strain gaging using resistance, capacitance, interferometer, and other methods can be performed from cryogenic temperatures to 1200°F.

Reactors

Bulk Shielding Reactor: Pool-type, water cooled & moderated. Can operate continuously at 2 MW. Equipped with 300-kV accelerator with beams of over 200 microamperes.

Health Physics Research Reactor: Fast-burst, unshielded & unmoderated. Two operating modes: steady-state at 10 KW and burst at 100,000 MW.

Oak Ridge Research Reactor. Pool-type, water cooled & moderated. Average neutron flux of arount 10^{14}. Four working levels, including neutron camera at the core.

High Flux Isotope Reactor. Pool-type, water cooled and moderated. Built to bombard plutonium targets with neutrons to make transplutonium isotopes. Highest neutron flux known: 5×10^{15}. Beam access holes for research.

Tower Shielding Facility. Two hairpin towers capable of elevating a bare reactor as high as 185 ft to test shielding technology. Operated remotely. Has two reactors for experiments: a light-water cooled and moderated reactor and a beryllium-reflected, NaK cooled SNAP reactor.

Accelerators

High Voltage Accelerator Laboratory uses a number of accelerators ranging in energies from a few thousand electron volts to greater than 100 meV.

Cockcroft-Walton, about 200 kV
3mV Van de Graaf
5.5 mV Van de Graaf
7.5 mV Tandem Van de Graaf

The Laboratory also has capabilities for performing accelerator and electronics maintenance, target preparation, off-line experimental setup, and other operations associated with accelerator experiments.

Oak Ridge Electron Linear Accelerator provides high-intensity, short-burst linear particle acceleration for neutron spectroscopy research, making possible neutron cross section measurements in the energy range of 1-300 keV. It offers improved intensity, resolution and reliability over existing electron linear accelerators.

250-kV Cockcroft-Walton Accelerator (for biological irradiation) is complete with 4-ft concrete shield and all dosimetric and flux measuring devices required for quantitative fast neutron radiobiology. It is used for genetic and cytogenetic studies on plants, insects and small mammals, and to study free radical production in biochemical systems.

86-in. Cyclotron consists of tank and dees, 400-ton magnet, and power supplies. The magnet is energized to produce an 8800-gauss field within a pole gap of 18 in. The machine's internal proton beam of up to 3000 microamperes at 20 MeV is used to produce radioisotopes for medical research and as a proton irradiation facility.

Oak Ridge Isochronous Cyclotron is designed to deliver beams of many species of ions of a wide range of energies to target stations in two shielded experiment rooms. The cyclotron is available for research to universities, other government laboratories, and groups doing studies for other government agencies.

RESEARCH ORGANIZATION OF THE OAK RIDGE NATIONAL LABORATORY

BASIC PHYSICAL SCIENCES

Divisions:
- Analytical Chemistry
- Physics
- Thermonuclear
- Chemistry
- Neutron Physics
- Solid State

BIOMEDICAL AND ENVIRONMENTAL SCIENCES

Divisions:
- Health Physics
- Biology
- Environmental Sciences

Applied Programs:
- Environmental Reports
- Environmental Information
- NSF Environmental Program
- Molecular Anatomy
- Macromolecular Separations
- Graduate School of Biomedical Sciences

REACTOR AND ENGINEERING SCIENCES

Divisions:
- Chemical Technology
- Reactor
- Metals and Ceramics
- Instrumentation and Controls

Applied Programs:
- Liquid Metal Fast Breeder
- Gas Cooled Reactors - Thorium Utilization
- Pressure Vessel Technology - Seismic
- High Temperature Structural Design
- Fuels and Materials
- Nuclear Desalting
- Studies and Evaluations
- Nuclear Safety

ORNL MANPOWER REPORT
(EMPLOYEES AND GUESTS)
EFFECTIVE: 6-30-73

DIVISION	REGULAR PAYROLL HR.	WK.	MO.	TOTAL	EDUCATION PH.D.	M.S.	B.S.	EQUIV.	TEMPORARY OVER 10 MOS.	UNDER 10 MOS.	PART-TIME	TOTAL EMPLOYMENT	GUESTS (NON-PAYROLL) CITIZEN	NON-CITIZEN	TOTAL GUESTS	GRAND TOTAL
RESEARCH																
ANALYTICAL CHEMISTRY	0	43	78	121	24	17	30	7	2	1	0	124	10	0	10	134
APPLIED HEALTH PHYSICS	0	31	53	84	1	2	43	7	1	0	0	85	0	0	0	85
BIOLOGY	95	72	189	356	82	42	52	13	10	0	10	376	125	20	145	521
CHEMICAL TECHNOLOGY	0	83	140	223	41	32	55	12	5	2	0	230	8	2	10	240
CHEMISTRY	1	13	58	72	44	7	7	0	1	0	0	73	16	5	21	94
DIRECTOR'S	0	26	29	55	12	4	13	0	0	0	0	55	5	0	5	60
ENVIRONMENTAL INFOR. SYSTEMS OFFICE	0	12	7	19	2	3	2	0	0	0	2	21	0	0	0	21
ENVIRONMENTAL SCIENCES	0	35	34	69	24	5	5	0	31	2	2	104	34	1	35	139
HEALTH PHYSICS	0	26	51	77	29	14	6	2	7	2	3	89	34	6	40	129
INSTRUMENTATION & CONTROLS	0	11	46	57	8	11	20	7	0	0	0	57	7	5	12	69
INSTR. & CONTROLS - SERVICES	79	38	80	197	0	19	43	18	0	0	0	197	0	0	0	197
MATHEMATICS	0	1	12	13	11	1	0	0	0	0	0	13	3	0	3	16
MATHEMATICS - SERVICES	0	64	99	163	23	31	36	9	5	2	3	173	0	0	0	173
METALS & CERAMICS	0	86	112	198	46	26	33	7	4	1	0	203	5	4	9	212
MOLECULAR ANATOMY PROGRAM	1	7	19	27	6	5	4	4	4	0	0	31	12	0	12	43
NEUTRON PHYSICS	0	20	40	60	21	5	12	2	2	0	3	65	9	6	15	80
ORNL-NSF ENVIRONMENTAL PROGRAM	0	7	11	18	9	1	1	0	4	0	0	22	7	0	7	29
PHYSICS	0	26	64	90	44	5	13	2	12	0	3	105	26	8	34	139
REACTOR	0	71	136	207	36	37	57	6	5	2	0	214	2	3	5	219
REACTOR CHEMISTRY	0	8	46	54	25	8	12	1	0	0	0	54	1	3	4	58
SOLID STATE	0	13	49	62	33	5	10	1	6	3	0	71	7	2	9	80
THERMONUCLEAR	0	26	55	81	26	8	16	5	6	2	1	90	6	7	13	103
TOTAL	176	719	1408	2303	547	288	470	103	105	17	27	2452	317	72	389	2841
OPERATING																
BUDGET & PROGRAM PLANNING	0	10	16	26	0	0	10	6	0	0	0	26	0	0	0	26
GENERAL ENGINEERING	0	60	75	135	1	17	43	14	0	2	0	137	1	0	1	138
HEALTH	2	18	7	27	4	2	1	0	0	0	0	27	0	0	0	27
INFORMATION	0	92	35	127	4	12	13	6	1	0	0	128	0	0	0	128
INSPECTION ENGINEERING	0	23	12	35	0	1	3	8	0	0	0	35	0	0	0	35
ISOTOPES R&D	0	16	36	52	5	6	19	6	0	0	0	52	0	0	0	52
LABORATORY PROTECTION	51	14	9	74	0	0	1	8	0	0	0	74	0	0	0	74
OPERATIONS- RESEARCH	11	3	10	24	0	0	10	0	0	0	0	24	0	1	1	25
OPERATIONS- SERVICES	114	5	39	158	1	2	14	22	0	0	0	158	0	0	0	158
PERSONNEL	12	38	21	71	0	5	9	7	0	14	1	86	0	0	0	86
PLANT & EQUIPMENT	589	72	125	777	0	3	41	81	0	12	0	789	0	0	0	789
RADIOISOTOPES - PRODUCTION	20	17	18	55	0	1	8	9	0	0	0	55	0	0	0	55
STABLE ISOTOPES - PRODUCTION	0	6	32	38	1	0	27	4	0	0	0	38	0	0	0	38
TOTAL	790	374	435	1599	16	49	199	171	1	28	1	1629	1	1	2	1631
GRAND TOTAL	966	1093	1843	3902	563	337	669	274	106	45	28	4081	318	73	391	4472

PERSONNEL RECORDS