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EDUCATIONAL AND RESEARCH ACTIVITIES

Progress Report

For the Period

July 1, 1976 to June 30, 1977

FORD NUCLEAR REACTOR

MICHIGAN MEMORIAL-PHOENIX PROJECT

THE UNIVERSITY OF MICHIGAN

Ann Arbor

July, 1977

Prepared For

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ABSTRACT

The Ford Nuclear Reactor continues to provide unique facilities for education and research by faculty, students, and researchers within the University of Michigan, from other universities and institutions, and from industrial research organizations.

During the academic year 1976-77, the reactor was maintained on a continuous operating schedule which made it available for use 63% of calendar time. Sixteen University of Michigan departments, 18 other universities and institutions, and 12 industrial research organizations utilized the reactor for a total of 30,521 experiment hours. As part of a public education program, 2,660 people participated in 110 tours.

Experimental utilization by University of Michigan departments included: neutron activation analysis of archeological, biological, botanical, environmental, and geological samples; age dating of mineral samples; measurement of radioactive isotope cross sections and decay schemes; materials damage studies; isotope production for research and for medical diagnosis and therapy; neutron radiography; materials studies through neutron spectroscopy; reactor laboratory courses; courses in neutron activation analysis techniques, analytical chemistry, and radiation protection, and; master's and doctorate degree projects. The following departments utilized the reactor: Anthropology, Atmospheric and Oceanic Science, Botany, Chemical Engineering, Chemistry, Geology and Mineralogy, Great Lakes Research, Institute of Environmental and Industrial Health, Materials and Metallurgical Engineering, Mechanical Engineering, Nuclear Engineering, Pharmacology and Medical Chemistry, Phoenix Memorial Laboratory, Physics, University Medical Center, and Zoology.

Utilization by other universities and institutions was primarily in the of neutron activation analysis, medical isotope production, reactor laboratory courses, and analytical chemistry courses. The reactor was used by Bowling Green State University, Cranbrook Institute, Eastern Michigan University, Detroit Institute of Art, Grand Rapids Junior College, Lafayette Clinic, Mayo Foundation, Michigan Technological University, Northwestern University, Ontario Ministry of the Environment, Rice University, Trinity Christian College, University of California Santa Barbara, University of Cincinnati, University of Massachusetts Boston, U. S. Department of Commerce, U. S. Department of the Interior, and Wayne State University.

Industrial research organization uses of the reactor included neutron activation analysis, production of radioactive tracers for industrial use, radiation damage studies, attenuation measurements of neutron shielding materials; semi-conductor doping by thermal neutron irradiation; production of radioactive sources for induced X-ray fluorescence, and training of electric utility personnel. Industrial users were Brand Industrial Services, Brooks and Perkins, Consumer's Power Company, Dow Corning, E. I. du Pont Experimental Research Laboratory, Eastman Kodak, Environmental Research Group, Ford Motor Company Scientific Laboratory, General Motors Research Laboratories, KMS Fusion, Meteorological Research, and Owens-Illinois.

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1. INTRODUCTION

The Ford Nuclear Reactor is operated by the Michigan Memorial - Phoenix Project of The University of Michigan. The Project, established in 1948 as a memorial to students and alumni of the University who died in World War II, encourages and supports research on the peaceful uses of nuclear energy and its social implications. In addition to the Ford Nuclear Reactor (FNR), the Project operates the Phoenix Memorial Laboratory (PML). These laboratories, together with a faculty research grant program, are the means by which the Project carries out its purposes.

During 1976-77, as in previous years, the operation of the Ford Nuclear Reactor has provided major assistance to a wide variety of research and educational programs. The FNR provides neutron irradiation services and neutron beam port experimental facilities for use by faculty, students, and researchers from The University of Michigan, other universities and institutions, and industrial research organizations. FNR staff members teach classes related to nuclear reactors, provide reactor training for electric utilities and other universities, and assist in reactor-related laboratories.

Tours are provided for school children, university students, and the public as part of a public education program. During 1976-77, approximately 2,660 people participated in 110 tours.

The continuous operating schedule of the reactor enables a sustained high level of participation by research groups. Continued support by the Energy Research and Development Administration through the University Research Reactor Assistance Program (Contract No. AT(11-1)-385) and the Reactor Facility Cost Sharing Program (Contract No. AT(11-1)-2117) has been essential to maintaining continuous operation of the reactor facility.

2. FACILITY OPERATION

2.1 Operations Summary

In January, 1966, a continuous operating cycle was adopted for the FNR at its licensed power level of two megawatts (MW). The cycle consisted of approximately 25 days at full power followed by three days of shutdown maintenance. In June, 1975, a reduced continuous operating cycle was adopted consisting of 10 days at full power followed by four days of shutdown maintenance. A typical week consisted of 120 full-power operating hours. In April, 1977, the sole commercial source of reactor fuel ceased production. The reactor cycle was reduced to 96 hours per week to conserve fuel until an alternative supplier is assured. The reactor presently operates from noon on Monday through noon on Friday each week. During the period of July 1, 1976 to June 30, 1977, the FNR was available for use approximately 63% of calendar time.

Experimental utilization of the reactor can be divided into three categories:

1) Short-term, sample irradiations for a period of less than one cycle to be used in a variety of applications.
2) Long-term, small target irradiation for many cycles for use as gamma sources in spectrographic studies.
3) Continuous reactor beam port use primarily in neutron spectroscopy. Five of the eight available ports are used.

Long-term irradiations and beam port use make the experiment-hour alone unsuitable as a measure of reactor utilization. Therefore, the utilization data in the table that follows is broken down into the three categories listed above.

	1976-77
Operating Hours	5,509
Operating Hours at 2 MW	5,051
Accumulated Megawatt Hours	10,102
Experimental Utilization Hours	
Short-term Experiments	5,202
Long-term Irradiations	12,122
Long-term Beam Port Use	13,197
Total	30,521
Reactor Availability	
Percent of Calendar Year	63%

2.2 Reactor and Core

The reactor operates at a maximum power level of 2 MW which produces a peak flux of 5×10^{13} n/cm^2/sec. A typical core configuration consists of 35-40, 93% enrichment, plate-type fuel elements. Standard elements contain 140 grams of U-235 in 18 aluminum-clad fuel plates. Control elements, which have control rod guide channels, have nine plates and contain 70 grams of U-235. Overall fuel element dimensions are approximately 3" X3" X 26".

2.3 Fuel Cycle

Standard fuel elements are retired after burnup levels of approximately 17% are reached. Control elements are retired after burnup levels of approximately 35%. This replacement schedule resulted in the use of three control and 19 standard fuel elements during 1976-77.

Fuel burnup rate is approximately 2.46 gm/day at 2 MW. Under the normal 2 MW operating schedule, 22 fuel elements will be required for one year of operation.

Spent fuel is shipped annually via NL Industries shipping cask to the du Pont Company in Savannah River, South Carolina for reprocessing.

2.4 Heavy Water Cycle

During 1976-77, the use of the Heavy Water Reflector Tank on one face

of the FNR core required a throughput of 204 pounds of heavy water. Fresh heavy water was used to replace heavy water in the tank as the tritium level reached the limit imposed by the reactor operating license.

2.5 Reactor Utilization Summary

During 1976-77, approximately 94% of the utilization of the reactor was by students, faculty and staff from The University of Michigan. Experimental work that was done for other universities by PML personnel is grouped with all other "Phoenix Memorial Laboratory" experiment hours.

	1976-77
University of Michigan	
Atmospheric and Oceanic Science	14
Chemistry Department	29
Geology and Mineralogy Department	7
Great Lakes Research	1
Department of Environmental and Industrial Health	3
Materials and Metallurgical Engineering Department	317
Mechanical Engineering Department	3
Nuclear Engineering Department	13,950
Phoenix Memorial Laboratory	2,278
Physics Department	12,122
Zoology Department	1
	28,725
Albion College	0
Eastern Michigan University	29
Grand Rapids Junior College	1
Michigan Technological University	28
Northwestern University	16
Toledo University	-
Wayne State University	-
U. S. Public Health Service	-
Industrial Research	
Brand Industrial Service	94
Brooks and Perkins	29
Consumer's Power Company	36
Environmental Research Group	54
Ford Motor Company Scientific Laboratory	30
General Motors Research Laboratory	0
KMS Fusion	2
Dow Corning	1,477
Total Experimental Utilization	30,521

3. FACILITY UTILIZATION BY THE UNIVERSITY OF MICHIGAN

3.1 Anthropology Department

Prehistoric human bone samples were analyzed by neutron activation analysis to determine strontium content. The project is attempting to determine diet differences between early man and modern man. Sixty-five samples were analyzed.

3.2 Atmospheric and Oceanic Science Department

Loss of Halogens from Aerosol Samples

Laboratory generated NaCl aerosols were collected on filter paper and exposed to varying concentrations of H_2SO_4. The expected reaction is H_2SO_4 aerosol $+2$ NaCl $\longrightarrow$ Na_2SO_4 $+2$ HCl gas. Collection filters were analyzed by neutron activation analysis to determine the Cl loss caused by conversion to HCl gas.

Trace Metals in Sediment

Neutron activation analysis was performed for trace metals in the organic fractions of 174 samples.

3.3 Botany Department

Determination of Silicon in Sugar Cane

Silicon is utilized in sugar cane nutrition. It deposits in the epidermal or outer layer of cells adding structural rigidity. This project involved correlation of silicon content in developing leaves and internodes of 3 cultivated varieties of sugar cane and their resistance to lodging or being toppled over by wind and rain. Twelve samples have been analyzed by neutron activation analysis to this point.

3.4 Chemical Engineering Department

Trace Metal Analysis of Liquified Coal Fractions and Pulverized Coal

The nature and distribution of corrosion and ash-fouling elements in liquified coal fractions and pulverized coal can be determined by a complete metal analysis of samples of these materials. The analysis is to be carried out under the ERDA sponsored project "Physical and Chemical Behavior of Liquified Coal in Solid Separation." The project involves neutron activation analysis of two sets of samples. The first set are different fractions of liquified coal. It is of interest to determine trace metals in different molecular weight fractions of liquified coal in order to better understand the nature and behavior of these fractions. The second set of samples are pulverized coal which are utilized as power industry boiler feed and which have been separated into specific gravity ranges. A complete metal analysis of these samples assists in determining the nature and distribution of corrosion and ash-fouling elements.

Catalytic Material Analysis

Eleven catalytic material samples were analyzed for palladium, platinum, and gold.

Oxygen Analysis In Liquified Coal

Forty liquified coal samples were analyzed for oxygen content.

3.5 Chemistry Department

Decay Schemes of Reactor Produced Nuclides

Samples of thallium (Tl) -205 were irradiated to produce Tl-206 in order to search for a 362 Kev gamma decay scheme for Tl-206. The project was ERDA sponsored.

In the decay of Tl-206, the predominant gamma rays are emitted at 1165 Kev and 803 Kev. The sought after 362 Kev gamma decay is a weak transistion between the 1165 Kev state and the 803 Kev state of Tl-206.

Samples of lead (Pb) -204 were irradiated with fast neutrons to produce metastable Pb-204. The decay scheme of metastable Pb-204 was examined.

Samples of neodymium (Nd) -150 were irradiated to produce Nd-151. Nd-151 decays by beta emission to promethium (Pm) -151. The decay scheme of Pm-151 was examined.

Small Fission Cross Section Measurements

Samples of thorium (Th)-227 for measurement of capture cross section and radium (Rd)-223 and Th-228 for measurement of fission cross section are being prepared. Measurements are to be based on etched tracks in plastic films.

Chemistry 995: Doctoral Thesis

Two Ph.D. candidates utilized the reactor for thesis work.

3.6 Geology and Mineralogy Department

Fission Track Dating of Volcanic Ashes on the Snake River Plain

The Ford Nuclear Reactor has been utilized in fission track dating of volcanic ashes. Irradiation of ash samples and subsequent counting of fission tracks in plastic films provide a measure of uranium concentration in the sample. Fission track data aid in correlating ashes from different localities and in establishing a time framework for the deposition of sediments. This new information permits refinement of the stratigraphy of the Snake River Plain, and contributes to the evolutionary history of the fossil fauna there. Since volcanic ashes in sediments are common in this region and since other dating techniques are more expensive, more time-consuming and less definitive, fission track dating is the best method for obtaining absolute ages of rock layers in the Snake River Plain. Some K-Ar dates are available from Snake River Plain lavas for cross-checking the validity of dates.

Trace Elements in Magnetites

The purpose of the project is to evaluate whether a knowledge of the trace element composition of magnetite, a common mineral in alkalic and gabbroic rocks, distinguishes different modes of origin of these rocks. Of particular interest are the Gem Park and McClure mountain complexes of south-central Colorado.

Most of the work in 1977 dealt with the development of procedures to assure reliability of analysis, to avoid interferences, and to achieve sufficient sensitivities. Having achieved these goals, completion of the initial project will involve a complete anaylsis of 30 to 50 samples.

Determination of Uranium and Thorium in Rocks

The purpose of the project is to confirm, by neutron activation analysis, radiometric determinations of uranium and thorium in rocks. The analyses assume a radioactive equilibrium of these elements. An accurate result is crucial to heat flow estimations, temperature estimates, and global tectonic problems in the earth.

A sensitive analysis method has been developed utilizing fusion of the irradiated rock in lithium barite, dissolution in dilute nitric acid, and ion exchange resin collection of the released radioisotopes. To date, uranium and thorium have not been observed in the rock samples analyzed, probably because these elements were at levels below the detection limits of the neutron activation analysis technique.

Potassium - Argon Age Determinations

Techniques are being developed to provide a simple, rapid method of ascertaining the ages of rocks by determining the argon (Ar) -40 and potassium (K) -40 contents. The method will be helpful as a survey technique in geological mapping.

Rare Earth Determination In Minerals

Mineral samples from a region in Texas known to be rich in rare earth elements were analyzed by neutron activation analysis. The analyses were part of a project studying the geology, mineralogy, and geochemistry of the region. Twenty-nine samples were analyzed.

Uranium Analysis in the Ocean Bottom

Neutron activation analysis was utilized to measure the uranium content of six ocean bottom samples as part of a study to determine the thermal activity of the earth's crust and upper mantle.

Geology and Mineralogy 455: Determinative Methodology in Mineralogical and Inorganic Materials

Eighteen students utilized the reactor and neutron activation analysis techniques in analysis of mineralogical and inorganic materials.

Geology and Mineralogy 995: Doctoral Thesis

One Ph.D. candidate utilized the reactor for thesis work.

3.7 Great Lakes Research

Great Lakes Sediment Compositions

Neutron activation analysis is used to determine the composition of modern and presettlement sediments in the Great Lakes. Changes in the concentrations of certain elements with sediment depths are thought to reflect the recent history of changes in the composition of overlying water. In combination with sedimentation rates, determined radiometrically, concentration profiles provide a means of estimating accumulation rates and reconstructing the minor element geochemical history of the Great Lakes. One study of Lake Michigan is funded as a subcontract from Argonne National Laboratory. A second study of Lake Huron is funded by the Environmental Protection Agency.

Contour maps showing the concentration of major and many minor elements in recent sediments for southern Lakes Michigan and Huron have been prepared. In addition, maps showing the gross and net rate of accumulation of elements have been completed.

Publications

1. Edington, D. N., Wahlgren, M. A., and Robbins, J. A. "Transport and Fate of Heavy Metals in Lacustrine Sediments", Tenth Great Lakes Regional Meeting of the American Chemical Society Abstracts, p. 206, Northwestern University, Evanston, Illinois, June, 1976.

2. Fingleton, D. J. and Robbins, J. A., "Trace Elements in Air Over Lake Michigan Near Chicago", Twentieth Annual Conference on Great Lakes Research of the International Association for Great Lakes Research, Ann Arbor, Michigan, May, 1977.

3. Robbins, J. A. and Edington, D. N. "Major and Minor Elements in Sediments of Southern Lake Michigan", Twentieth Annual Conference on Great Lakes Research of the Internation Association for Great Lakes Research, Ann Arbor, Michigan, May, 1977.

4. Ullman, W. and Robbins, J. A., "Major and Minor Elements in Sediments of Southern Lake Huron and Saginaw Bay: Patterns of Deposition, Historical Records, and Interelement Associations", Fortieth Annual Meeting of the American Society of Limnology and Oceanography, Lansing, Michigan, June, 1977.

5. Edington, D. N. and Robbins, J. A., "Radioactive Geochronology and Pollution History Recorded in Lake Sediments", American Nuclear Society Winter Meeting, San Francisco, December, 1977.

6. Robbins, J. A. and Hess, L. W., "Concentration Profiles of Heavy Metals in Recent Sediments of Saginaw Bay, Lake Huron", Annual Meeting of the Ecological Society of America, Michigan State University, East Lansing, Michigan, August, 1977.

Atmospheric Phosphorous Inputs to Southern Lake Huron

Neutron activation analysis was utilized to analyze air grab samples taken over southern Lake Huron.

The input of phosphorous was demonstrated to be seasonally dependent. Of the total input approximately half is potentially available, and one fourth is immediately available. Inputs due to wet and dry deposition were roughly equal in magnitude. The major source appears to be agriculture with at least 10% from combustion sources.

Publications

1. Delumyea, R. G. and Petel, R. L., "Atmospheric Inputs of Phosphorous To Southern Lake Huron, April - October 1975", EPA-600/3-77-038, U. S. Environmental Protection Agency, Duluth, Minnesota, April, 1977.

3.8 Department of Environmental and Industrial Health

Bromine Organics in Water Treatment

Six samples were analyzed by neutron activation analysis to determine bromine content in water as an indication of the importance of brominated organics in the water treatment process.

EIH 508: Radiation in the Environment

Ten students were given an introduction to the magnitudes and to the processing of airborne, liquid, and solid wastes at the Ford Nuclear Reactor.

Short Course on Radiation Protection Surveys

Health physics technicians from commercial nuclear power plants were given an introduction to survey techniques at the Ford Nuclear Reactor.

3.9 Materials and Metallurgical Engineering Department

Irradiation of Polyethylene for Materials Experiment

Amorphous polyethylene was irradiated to a cumulative dose of approximately 5×10^{17} neutrons per square centimeter in order to destroy the crystallinity of the branched polyethylene. The amorphous polyethylene specimens became dark brown and glass-like under irradiation.

Experimental results showed that the crystallinity of polyethylene specimens decreases as neutron dose increases. These results were judged from wide angle X-ray scattering studies.

Publications

1. Gupta, M. R. and Yeh, G. S. Y., "Application of Paracrystalline Lattice Theory to the DRDF of Amorphous Irradiated Polyethylene," Presented paper, American Physical Society Meeting, San Diego, 1977.

3.10 Mechanical Engineering Department

ME 537: Power Generation Systems

Theory and principles of operation of the Ford Nuclear Reactor were presented to a class of 18 students.

3.11 Nuclear Engineering Department

Triple Axis Crystal Spectrometer

The triple axis crystal spectrometer is set up to study small angle neutron scattering from polymeric systems. The performance of the spectrometer is checked by two known systems: 1) Gaussian Random Coil: polystyrene in cyclohexane (C_6D_{12}) at 41°C, and; 2) Spherical particles of polystyrene with diameters from 0.085 micrometers to 1.091 micrometers.

The corrected scattering curve of the polystyrene in cyclohexane experiment shows the nature of the Gaussian Random Coil. The standard deviation in concentration fluctuation of polystyrene particles can be measured for powder samples by comparing the scattered intensities of neutrons at very low angles with powder in two different nonsolvent liquids.

Further studies will be directed to the determination of the standard deviation in concentration fluctuation in mixtures of protonated and deuterated polymers.

Photoneutron Sources for Cross Section Measurements

Three different spherical cores used as gamma ray sources for generating photoneutrons were activated in the reactor. The spherical cores consisted of sodium fluoride (NaF), lanthanum oxide (La_2O_3), and gallium oxide (Ga_2O_3) surrounded by welded aluminum shells. The activated cores are fitted with hemispherical shells of either beryllium or deuterated polyethylene in which the photoneutrons are generated by high energy gamma rays emitted by the activated core. Using various combinations of cores and shells, nearly monoenergetic neutron sources covering the range of 24 to 964 Kev can be provided.

These sources were used in a continuing program for the measurement of absolute fission and capture cross sections in the photoneutron laboratory. Over the past year cross section measurements have been made of uranium (U) -235 and plutonium (Pu) -239, as well as preliminary cross section measurements on lithium (Li) -6.

The photoneutron cross section project is entering its ninth consecutive year of ERDA sponsorship. The data provided have played a significant role in the establishment of neutron cross section standards in the Kev region. The facilities for activation, rapid transfer, and experimental use of photoneutron sources have been extensively developed and are unmatched anywhere in the world.

Photoneutron Source Manganese Bath

In order to study the dynamics of the manganese bath neutron calibrator associated with photoneutron cross section measurements, a small sample of manganese sulfate solution was activated in the reactor. Samples of the activated solution were injected at various radii in the spherical bath to determine the delay and mixing time involved in counting that activity in the associated detector. These studies were important to complete a thorough analysis of the bath dynamics in order to improve the precision to which short lived neutron sources are able to be calibrated.

Profiling Depth and Diffusion of Implanted Helium (He) -3 in Metals

The project currently involves the profiling of implanted He-3 distributions in the first micrometer of metal surfaces. This is done by measuring the energy spectrum of protons created in the reaction He-3 (n,p) H-3 escaping from the metal. The proton release reaction is produced by a thermal neutron beam from the reactor.

Observation of the profile at various stages of annealing yields information about the trapping and diffusion of helium in the metal. In the future this technique will be extended to studying the behavior of other impurities such as lithium and boron in a variety of host materials.

The profiling technique has been proven by obtaining several good profiles of He-3 in niobium foil. The resolution is as predicted, several hundred angstroms, but the sensitivity is not yet as expected. Sensitivity should be improved as the annealing experiments proceed.

Tritium Production from Lithium Carbonate (Li_2CO_3) Irradiation

Flat samples of stainless steel were coated on one side with lithium carbonate. Irradiation in the reactor implanted tritium into the surface by the reaction Li-6 (n, α) H-3. The depth distribution after implantation was determined by measuring the tritium activity of electrolytically removed layers of the stainless steel samples.

The results obtained were unexpected. Instead of an approximately linear drop of activity as a function of depth, to a maximum range of about 19 micrometers, as is expected theoretically and as was observed from cylindrical samples, the tritium activity was distributed almost uniformly through the first 40 micrometers. No explanation has been provided for this unexpected behavior. Possibly there could be grain boundary diffusion, the avoidance of which was hoped for by annealing samples before irradiation. Another possibility is that the electrolysis used for taking thin layers of material off the sample may have driven the tritium into the sample.

Student Thermal Neutron Spectrometer

The student spectrometer was used to conduct two experiments in neutron diffraction for NE 445 - Nuclear Reactor Laboratory, to conduct a similar experiment for a Northwestern University reactor laboratory, and as a monoenergetic neutron source for neutron transmission measurements through neutron shielding materials.

NE 315: Nuclear Instrumentation Laboratory, and NE 515: Nuclear Measurements Laboratory

These courses provide an introduction to the devices and techniques most common in nuclear instruments and measurements. The reactor is used as a source of short-lived radioactive sources. Samples of indium (In) were activated to provide rapidly decaying sources for an experiment in which dead time of a detector was measured. Standard mineral samples were irradiated as part of an activation analysis experiment. Samples of reactor pool water provided a source of several rapidly decaying gamma emitters for an experiment on gamma ray spectroscopy.

NE 445: Nuclear Reactor Laboratory

In this course, experiments are carried out to measure core power densities and fluxes, shim safety rod calibrations are performed, temperature and void coefficients are measured, critical experiments are performed, shutdown power is measured, xenon-samarium transients are observed, and other reactor operating parameters are investigated. Experiments are performed using the general purpose crystal spectrometer, a proton recoil counter, and the reactor pneumatic tube facilities.

The Nuclear Reactor Laboratory was conducted in the fall, winter, and spring terms in 1976-77 for a total of approximately 50 students.

NE 490: Nuclear Power Plant Systems

This course is intended to provide an introduction to electric utility planning, logistics, power production, and power distribution; power station arrangements, systems, components, and operation; and nuclear generating stations. Fifteen students participated.

NE 599: Master's Project; NE 799: Special Project, and NE 995: Doctoral Thesis

Approximately 10 M.S. candidates and 10 Ph.D. candidates utilized the reactor for thesis work.

3.12 Pharmacology and Medical Chemistry Department

Fluorine (F)-18

Fluorine-18 was provided to the Pharmacology and Medical Chemistry Department for studies in labeling organic compounds useful in nuclear medicine applications. Four samples totaling 3.98 millicuries were provided for this work.

Bromine(Br)-80, 82

Bromine-80 and bromine-82 are being produced in small quantities to test the feasibility of the Szilard-Chalmers process for increasing specific activity of these isotopes for labeling organic compounds. This work is presently in progress.

3.13 Phoenix Memorial Laboratory

Bromine(Br)-82 Labeled Motor Oil

There are currently two industrial research users of Bromine-82 labeled motor oil for the determination of oil consumption in newly designed internal combustion engines. This radiometric method of providing rapid and precise oil consumption data was developed about nine years ago by the General Motors Research Laboratories. Since that time the Phoenix Memorial Laboratory has made the radio-labeled oil available to licensed institutions desiring to perform these tests.

The users during 1976-77 were:

a) Ramsey Corporation, Division of TRW, Inc., St. Louis Missouri.

b) General Motors Technical Center, Warren, Michigan.

Seventy-three samples of bromine-82 labeled motor oil containing a total of 8.76 curies of bromine-82 were produced.

The Phoenix Memorial Laboratory is the sole supplier of bromine-82 labeled oil in the United States.

Fluorine (F)-18

During the year 1976-77, 520 millicuries of fluorine-18 and 26 samples were supplied to the Edsel Ford Institute at the Henry Ford Hospital in Detroit for an on-going research program. The early detection of aseptic necrosis of the femoral head which is known to be associated with a number of diseases including Cushing's disease, hemoglobino pathies disease, rheumatoid arthritis, and chronic alcoholism is an important part of this research effort.

Non-neoplastic lesions in patients who have undergone renal transplation are being studied using the short-lived fluorine-18 carrier free radionuclide as an indicator of the location and status of the lesions. These patients who have normally been on a high steroid treatment to prevent rejection are tested with fluorine-18, which tends to concentrate in any areas where lesions exist.

The Department of Medicine and the Department of Physics and Biophysics of the Edsel Ford Institute have used fluorine-18 successfully as an imaging material to detect necrosis before too much damage is done to the patient. This approach has proven to be particularly successful when patients have undergone steroid treatment.

Publications

1. Guise, E., Levine, N., Dumlar, F., and Vulpetti, N., "The Hot Hip of Osteonecrosis", Annual Meeting of the American College of Surgeons, Chicago, 1976.

Neutron Activation Analysis

Neutron activation analysis (NAA) services were utilized more heavily in 1976-77 than in any other year since first being offered as a routine service by the Phoenix Memorial Laboratory. Not only was there heavy usage by researchers from the University of Michigan, but many colleges and other nonprofit educational institutions found the sensitivity, variety of types of materials that could be analyzed, the large number of elements

that could be detected, accuracy, and the essentially nondestructive nature of the method to be an excellant analytical tool. All types of samples, from human blood to archeological specimens were analyzed using lithium drifted germanium detectors interfaced to a computerized analyzer system which provides unusual flexibility. An automatic sample changer and magnetic tape system provide a high degree of automation to the analytical process while still allowing the experimenter to exercise maximum control over the data acquisition and reduction process. Special abilities such as the automatic dispatch of samples in the pneumatic tube system under computer control provide both accuracy and a reduction in human error for the analysis of such short lived radioisotopes as nitrogen (N)-16 used to measure oxygen in liquified coal and fluorine (F)-20 used to measure the amount of fluorine in chloro-sulfonic acid.

The total number of samples analyzed for University of Michigan researchers, which include Phoenix Grant recipients, was 617. This included many samples which were both irradiated only a few minutes in the pneumatic tube system and then irradiated in the reactor core for as long as 40 hours. Counting time ranged from 40 seconds to 400 seconds depending upon the element being analyzed and the protocol of the experiment. With the invaluable assistance of the ERDA cost sharing program, the Phoenix Memorial Laboratory has made available its neutron activation analysis capabilities to educational institutions throughout the United States. A total of 540 analyses were performed for universities and education institutions other than the University of Michigan during 1976-77.

At the same time the laboratory was experiencing additional requests for neutron activation analysis services to the University of Michigan and to other educational institutions, additional requests were made for these services by industrial research interests. These ranged from measurements of various noble metals in catalytic materials used in modern automobile exhaust systems to the determination of multitrace elements in air samples collected as

parts of air sampling programs around coal burning power plants. These unique services provided to industrial scientific organizations have permitted data to be collected which could not be made available by any other technique. A total of 379 analyses were performed during the year.

Cobalt-60 Source

The Phoenix Memorial Laboratory provides a large cobalt (Co)-60 gamma ray irradiation facility for research activities. The facility was in use approximately 50% of calendar time during 1976-77.

Experimenter	Samples and Purpose	Megarad - Liter Irradiations
Eastern Michigan University Biology	Exposure of fungi and yeasts to intense gamma radiation to study the morphological effects and radiosensitivity of these organisms.	28
KMS	Radiation effects on gas mixtures.	253
University of Iowa Medical Center	Sterilization of human cartilage for plastic surgery.	153
University of Michigan Chemistry	Radiation effects on styrene monomers.	74
Chemistry	Radiation effects on polymers.	339
Chemical Engineering	Radiation damage studies on polyethylene and natural rubber.	
Great Lakes Research	Sterilizing dose to water samples.	57
Physics	Irradiation of sucrose, crystalline sugar, to study spin diffusion in the magnetic double resonance.	10
U. S. Department of Agriculture Poultry Research Laboratory	Role of cellular immunity in genetic resistance to Marek's disease in chicks.	1

Publications

1. Mar, J. E., Kato, M., and Ko, J., "Stress - Strain Isotherms for Noncrystallizable Networks at High Elongation", Journal of Polymer Science, Symposium No. 54, pp 217-225, 1976.

2. Yu, C. U. and Mark, J. E., "The Use of Compression Measurements to Study Stress - Strain Relationships and the Volume Dependence of the Elastic Free Energy of the Polymer Network", Polymer Journal, Japan Society of Polymer Science, Vol. 7, No. 1, 1975.

3. Yu, C. U. and Mark, J. E., "Thermoelastic Studies of Diene Polymers in Elongation and Compression", Polymer Journal, Japan Society of Polymer Science, Vol. 7, No. 2, 1975.

3.14 Physics Department

Uranium and Thorium Content of Oceanic Rock

Attempts are being made to measure the U and Th content of rocks which are thought to have originally solidified at considerable depths in conjunction with motion of the earth's plates away from the ocean ridges.

3.15 University of Michigan Medical Center

Surgery

Radioactivity of forty-five tracer samples was measured during 1976-77. The tracers were used in experiments to determine the uptake of cesium (Ce)-134, strontium (Sr)-89, and chromium (Cr)-51 in body organs.

Upjohn Center

Forty blood samples were analyzed for bromine content using neutron activation analysis.

Radiopharmacy

The Phoenix Memorial Laboratory continued to provide radiation services to the radiopharmacy of the University of Michigan Medical Center. The

services primarily involved the routine production of an investigational new drug, I-131-6β -Iodomethylnorcholesterol used in the diagnosis of diseases of the adrenal glands. This cooperative effort between the laboratory and the medical center provided a total of 211 samples containing 3,245 millicuries of labeled material to 51 different hospitals and research institutions including hospitals in France, Northern Ireland, Norway, and Canada. This represents an increase in the production of this research material by 46.5% over last year's production.

3.16 Zoology Department

Activation of Geological Specimens

Neutron activation analysis was utilized in the multielement analysis of 64 ash samples from the Snake River Plain.

4. FACILITY UTILIZATION BY OTHER UNIVERSITIES AND INSTITUTIONS

During 1976-77, total services provided to other universities and colleges consisted of 422 sample-hours of reactor irradiations, 64 hours of exclusive use of the reactor, and 273 hours of technical and administrative assistance.

In addition to the services described below, which were provided directly, neutron activation analysis services were provided by the Phoenix Memorial Laboratory to other universities and colleges. Those services are described in Section 3.13.

4.1 Bowling Green State University

An instrument analysis course was conducted for chemistry students at the Ford Nuclear Reactor. Part of the course involved neutron activation analysis experiments conducted in part by Professor K. Rengan of Eastern Michigan University.

4.2 Cranbrook Institute, Detroit, Michigan

A pilot study was conducted to determine the feasibility of measuring trace elements in aquatic vascular plants which may serve as sinks for hazardous materials. Twelve samples were analyzed by neutron activation analysis. Additional work will be sponsored for 1977-78.

4.3 Eastern Michigan University

Arsenic Determination in Biological Samples

The purpose of this project was to develop a radiochemical separation procedure for arsenic determination in biological samples. A procedure for arsenic determination was developed using a tin dioxide inorganic exchanger. Total arsenic concentrations in a variety of Lake Michigan fish were determined using this method.

Production of Trace Quantities of Various Elements

Trace quantities of the following elements were produced in the Ford Nuclear Reactor: sodium (Na) -24, chromium (Cr) -51, zinc (Zn) -65,

potassium (K) -42, copper (Cu) -64, arsenic (As) -76, zirconium (Zr) -97, yttrium (Y) -90, lanthanum (La) -140, cadmium (Cd) -115, mercury (Hg) -197, and mercury (Hg) -203. These isotopes were utilized in research by undergraduate students, in Eastern Michigan University chemistry courses, and in an instrument analysis course conducted for Bowling Green State University.

Publications

1. Hartwig, M. and Rengan, K., "Use of Isooctylthioglycolate for the Separation of Tin and Antimony", accepted for publication in the Journal of Radioanalytical Chemistry.

2. Rengan, K., "An Elegant Neutron Activation Analysis Experiment for Undergraduate Curricula", accepted for publication in the Journal of Chemical Education.

Chemistry 481: Radioisotope Techniques, Chemistry 581: Advanced Analytical Chemistry

Students from Eastern Michigan University utilized the Ford Nuclear Reactor and analytical equipment for course work primarily in neutron activation analysis.

Master's Thesis

Two students completed master's degree theses in the area of arsenic determinations in biological samples.

4.4 Detroit Institute of Art

Neutron activation analysis was used to conduct elemental analyses of paint fragments from ancient Tibetan Thang-has paintings as a pilot study to determine the feasibility of expanded research utilizing this technique. The object of the program is to learn more about the types of pigments used in these works of art. Five samples were analyzed by neutron activation analysis. In addition, several paintings were examined by neutron radiograph techniques in order to gain information concerning the paint pigments utilized.

4.5 Grand Rapids Junior College

A class of 14 students participated in a two-day laboratory course in neutron activation analysis.

4.6 Lafayette Clinic, Detroit, Michigan

Neutron activation analysis was utilized to perform multielement analyses for polysaccarides on two samples.

4.7 Mayo Foundation

A special shipment of flucrine-18 was sent by charter aircraft to the Mayo Foundation in Rochester, Minnesota for research. One sample containing 20 millicuries of activity was shipped.

4.8 Michigan Technological University

Uranium and Thorium Analysis of Upper Michigan Rocks

Neutron activation analysis was utilized in uranium and thorium analyses for Michigan Technological University's Geology Department as part of a program to evaluate the uranium potential of Precambrian rocks from the Upper Michigan Peninsula. A total of 77 samples were analyzed.

Rare Earth Analysis of Tuffs and Lavas

Neutron activation analysis was utilized to conduct multielement analyses for rare earths in tuffs and lavas genetically associated with late Cenozoic base and precious metal mineralization. Ninety-nine samples were analyzed.

Reactor Laboratory

A two-day reactor laboratory was conducted for 20 students. Experiments were performed in subcritical multiplication, shim safety rod worth, reactor power level determination, power defect measurement, and xenon reactivity.

4.9 Northwestern University

Two days of intensive laboratory experiments including shim rod calibration, subcritical multiplication, temperature coefficient measurement, power level determination, xenon transient measurement, core flux measurement, and neutron spectrometer measurements were conducted for a group of 8 Northwestern University nuclear engineering students.

4.10 Ontario Ministry of the Environment

Neutron activation analysis was utilized for mercury analysis of river bottom sediments. Nine samples were analyzed.

4.11 Rice University

Artifact samples from Iran were compared by neutron activation analysis techniques with possible source materials in an attempt to identify the source of the samples being studied. This work was conducted in cooperation with the Anthropology Department. Twenty-one samples were analyzed.

4.12 Trinity Christian College

Neutron activation analysis was utilized in the determination of trace quantities of iodine in Echo Lake, Michigan water samples. Comparison was made to similar samples from Lake Michigan. Five samples were analyzed. Measurements were performed at the 1-3 nanogram per milliliter level.

4.13 University of California, Santa Barbara

Forty-two obsidian samples, collected in Southern Mexico, from a deposit dated about 3000 - 2100 B.C., were analyzed by neutron activation analysis. These samples represent one of the earliest obsidian assemblages presently available from a coastal low land site in Mesoamerica. An attempt to locate the source will be made utilizing the data collected from this project.

4.14 University of Cincinnati

Irradiated lithium carbonate (Li_2CO_3) containing unprocessed fluorine-18 was prepared for the Nuclear Medicine Department of the University of Cincinnati. Total fluorine-18 activity was approximately 20 millicuries.

4.15 University of Massachusetts, Boston

Neutron activation analysis was utilized in the analysis of felsite, rhyotite, and chert samples for trace elements to determine the source or archeological artifacts. Two hundred and fifty-nine samples were analyzed as part of a Harbor Island archeological salvage program.

4.16 U. S. Department of Commerce

Twenty-five shark samples were analyzed for the Division of Natural Marine Fisheries. Neutron activation analysis was utilized to determine mercury content.

4.17 U. S. Department of the Interior

Neutron activation analysis was utilized to determine trace elements in fish scales. Thirteen samples were analyzed as part of a program to measure lake and river pollution conditions.

4.18 Wayne State University

Neutron activation analysis was utilized to analyze Italian neolithic ceramic materials for trace and major element profiles as an aid in correlating the various ceramic types which have been defined on the bases of simple visual inspection and traditional archeological classification procedures. Twenty samples have been analyzed.

5. FACILITY UTILIZATION FOR INDUSTRIAL RESEARCH

5.1 Brand Industrial Services (BISCO)

Radiation Damage Studies

A neutron and gamma irradiation test program was conducted on samples of boron carbide - silicon neutron shielding material. The material is flexible, can be poured in liquid form and allowed to "harden" in place, and can be cut easily.

Short-term irradiations up to total fluences of 1×10^{16} neutrons per square centimeter and absorbed doses of 1×10^{8} Rad gamma were run. Sample dimensions remained unchanged. Hardness increased, though some flexibility was retained. Weight decreased measurably. Gases were evolved, were analyzed, and were found to be hydrogen and methane.

Longer-term irradiations up to 9×10^{17} neutrons per square centimeter and 7×10^{9} Rad gamma caused significant dimensional changes and weight decreases, greatly increased hardness and loss of flexibility, and continued hydrogen and methane evolution.

Neutron Attenuation Measurements

The reactor's "I" beam port spectrometer was used to measure the neutron transmission characteristics of boron carbide - silicon neutron shielding material in samples of varying thicknesses and boron carbide concentrations.

5.2 Brooks and Perkins

BORAL Transmission Characteristics

The reactor's "I" beam port spectrometer was used to measure the neutron transmission characteristics of BORAL (boron carbide impregnated in aluminum) neutron absorbing material in plates of varying thicknesses and boron carbide concentrations.

A research project is underway to correlate experimental transmission results with theoretical calculations.

BORAL Performance Under Simulated Spent Fuel Storage Pool Conditions

Experimental observations were made of BORAL plates encased in stainless steel jackets similar to those proposed for storage racks in spent fuel storage pools. Sample plates were placed in fluences that approximated PWR and BWR storage pool fluences. Samples were tested dry and with 25 ml distilled water, 70 ml 2000 ppm boron solution, and 20 ml 2000 ppm boron solution injected within the stainless jacket. The liquid injections were to simulate development of a leak in the jacket in a storage pool.

In a gamma flux, the BORAL samples exhibited no detectable gas evolution, pressure buildup, or damage due to temperature or other effects.

In the presence of a neutron flux, hydrogen and oxygen gases were evolved from samples injected with 2000 ppm boron solution.

Radiolysis of Trace Quantities of Moisture in BORAL

BORAL plates have been known to swell in the presence of neutron radiation. Presumably, the swelling is caused by radiolysis, the dissociation into hydrogen and oxygen gases of trace quantities of water absorbed by boron carbide.

This project is an attempt to quantify and correlate gas evolution, moisture quantities, and neutron dose.

BORAL Radiographs

Numerous radiographs have been taken of BORAL samples in order to identify manufacturing process flaws.

5.3 Consumer's Power Company

Self-Powered Rhodium Detector

Tests were run to verify proper operation of a rhodium neutron detector previously used in the Palisades Nuclear Power Plant. The power plant had witnessed unexpecte

flux shifts within the reactor core. Attempts were made to determine whether the flux shifts were real or whether the detector was giving erroneous readings.

It was concluded that the detector was giving erroneous readings and that the errors were associated with rhodium burnup in the detector.

Reactor Instrument Technician Training Program

An intensive one week instrument technician training program was conducted for seven Consumer's Power Company Instrument Technicians in June, 1977. The program was a combination of classroom lectures, reactor experiments, and practical instrument training. Reactor experiments conducted included reactor startup and shutdown, subcritical multiplication, reactor power level determination, negative temperature coefficient measurement, control rod calibration, and the measurement of the reactor flux profile utilizing a self-powered rhodium detector. Practical training involved calibration and alignment of nuclear instruments and nuclear instrument channels, calibration of the reactor protection system, calibration of the reactor automatic control system, calibration of the reactor flow system, and alignment and calibration of various radioactivity measurement systems. Each Instrument Technician was allowed to make two reactor startups.

5.4 Dow Corning

Neutron-bombarded Float-zone Silicon for High Power Devices

The reactor has continued its efforts with Dow Corning to improve the technique for producing neutron-bombarded, float-zone, single crystal silicon for use in high current semiconductor devices such as 4000 volt thyristors.

Semiconductors doped by neutron transmutation exhibit radial sensitivity which is more nearly uniform than silicon that is doped by other methods.

The uniform resistivity eliminates hot spots and permits higher power capabilities along with improved reliability. Neutron transmutation converts a controlled number of silicon atoms to phosphorous atoms in the crystal. The effect is to provide almost completely uniform distribution of phosphorous dopant atoms in the silicon crystal. The new material is used for rectifiers and thyristors that are, for example, part of the DC power transmission systems of electrical utilities.

Publications

1. Burn, R., Cook, G., Jones, J., and Baker, J., "Phosphorous Doping of Floatzone Silicon By Thermal Neutron Irradiation", Proceedings of the American Nuclear Society, Reactor Operations Division Meeting, Chatanooga, Tennessee, August, 1977.

5.5 E. I. du Pont Experimental Research Laboratory

Two samples were analyzed using neutron activation analysis to determine fluorine contamination in chlorsulfonic acid.

5.6 Eastman Kodak

Neutron activation analysis was utilized to measure the metal content of six gelatin samples "spiked" with metals. The gelatin is to be used as an analytical standard.

5.7 Environmental Research Group (ERG)

Neutron Activation Analysis of Biological and Environmental Materials

ERG has been actively involved in the analysis of various stable elements in environmental and biological samples. In the past year as many as 5,000 samples have been analyzed. The goal of the analysis was to quantitatively estimate several stable elements, some of these toxics such as arsenic and mercury, in water sediments, fly ash, lignite, urine, clams, fruits, vegetables, and grass to detect any significant variation and buildup of some of these elements.

Neutron Activation Analysis Using Natural Uranium Standards

Analysis of water, rock, and ore samples for uranium was conducted. In water samples, the level of uranium was about 0.5 parts per billion. In rock and ore samples, uranium concentrations varied from trace to minor levels.

5.8 Ford Motor Company Scientific Laboratory

Determination of Zirconium, Copper, and Chromium in Aluminum Alloys

Neutron activation analysis was utilized to analyze aluminum alloys for specific metals. The purpose of the analysis was to determine if neutron activation analysis could be used as an improvement over X-ray emission spectroscopy. No improvement over X-ray emission spectroscopy was detected.

Filter Analysis for $Fe(OH)_3$ and $Al(OH)_3$

Analyses were performed to identify iron and aluminum which was precipitated onto filter paper in the form of $Fe(OH)_3$ and $Al(OH)_3$. This project was part of work concerned with developing a sodium polysulfide storage battery.

Irradiation of Refined Oil Samples

This project, still in development, will utilize neutron activation analysis of refined oil samples to aid in the determination of the oil origin in oil spill occurrences.

Strontium Hexaferrite Analysis

The Ford Motor Company has a strontium hexaferrite ($SrFe_{12}O_{19}$) magnet manufacturing program. A study of the effect of impurities on magnetic properties is being conducted by the Scientific Laboratory. Magnet powder is prepared at the steel division of the Ford Motor Company from waste by-products. Iron hydroxide is precipitated from the waste by-products by sodium hydroxide and then is washed to remove impurities. Thereafter,

an analysis of the resultant powder is conducted for sodium, silicon, chlorine, and other impurities. Most expected impurities were able to be detected by neutron activation analysis with the exception of silicon.

Pr_2NiO_4 Analysis

The Ford Motor Company is investigating a promethium oxide (PrO) - nickel oxide (NiO) thermistor device to be used as an automotive exhaust temperature sensor. During the development of this device, a new phase compound was formed under ambient pressure with gases other than air. The analysis involved determining the chemical composition of this new phase which was postulated as Pr_2NiO_5. Considering the atomic weights of Pr, Ni, and O, it was assumed that neutron activation analysis would be the best way to determine the phase composition. The technique is to analyze the new phase for Pr and Ni and estimate the oxygen content by weight balance. The project is still in progress.

Arsenic in Polyethylene Foam

The purpose of this project was to analyze for arsenic content in polyethylene foam. The foam will be used for making gas tanks in automobiles. Arsenic is added to inhibit microorganism growth.

X-ray Fluorescence

The reactor was used to produce a gadolinium oxide (GdO_2) gamma ray source for new applications of radioisotope-induced X-ray fluorescence. Work is being completed on analysis of catalysts for platinum, lead, cerium, and palladium. Analysis of selenium in glass and air particulates will be investigated shortly.

Publication:

1. Elgart, M. F. "Analysis of Platinum and Palladium on Monolithic Catalysts", Conference on Applied Spectroscopy, Pittsburg, 1977.

Analysis of Chlorine in Polymeric Materials

Chlorine is an undesired contaminant in certain polymerizations. Analysis of chlorine is difficult and time consuming by wet chemical techniques. A neutron activation analysis method which provides high sensitivity and accuracy has been developed for the detection of this element. The method has been used on a routine basis for the analysis of chlorine in polymeric materials.

Toxic Elements in Waste Water

Neutron activation analysis was used to analyze for toxic elements, particularly selenium and mercury, in waste effluents from various manufacturing installations to verify compliance with state and federal regulations.

Autoradiography of Beta Alumina

The purpose of this project was to develop a technique to examine sodium distribution in beta alumina. Results have shown that the distribution of sodium in unacceptable beta alumina is inhomogenous.

Analysis of Platinum and Palladium on Quartz Surfaces

A neutron activation analysis technique was developed for the analysis of thin films of platinum and palladium sputtered onto quartz surfaces from a molten 1:1 mixture. The results showed that thin films produced by sputtering did not have the same chemical distribution as the starting molten material.

Radiograph of Turbine Blades

The purpose of this project was to develop techniques for radiographing ceramic turbine blade parts produced by the Ford Motor Company. Preliminary work involved establishing a large radiograph facility and producing test radiographs of ceramic turbine blades in order to identify cracks and failure points.

The scope of this work will be greatly expanded in the coming year. A project is being initiated to make a detailed study of all film radiography techniques and to examine, by these techniques, various manufactured parts.

Aluminum in Si_3N_4 Material

Neutron activation analysis was used to determine the aluminum contamination in 21 samples of Si_3N_4 material.

Sodium and Aluminum in Solid State Materials

Neutron activation analysis was used to measure sodium and aluminum contamination in two solid state semiconductor material samples.

Sodium in Beta Alumina

Thirty-eight beta alumina samples were analyzed by neutron activation analysis for sodium content.

Pennsylvania Tuscurora Tunnel Pollution

Neutron activation analysis was used to perform multielement analyses of 55 aerosol samples taken during a pollution study of the Pennsylvania Tuscurora Tunnel.

5.9 General Motors Research Laboratories, Analytical Chemistry Department

Bentonite Iron Casting

A project is commencing which involves analyzing casting molds for trace elements.

Radiometric Tool Wear Program

The object of the program was to improve machining techniques and reduce tooling costs. The radiometric tool wear method utilizes neutron activation of tools to evaluate various tool materials, workpiece materials, cutting fluids, and machining parameters.

The radiometric tool wear method is a unique approach that requires capabilities not available elsewhere. Work being pursued includes evaluation of fine grain tool materials, evaluation of coated tools, and evaluation of powdered metal components.

Catalytic Material Analysis

Neutron activation analysis was performed to determine platinum and rhodium content of materials used in automobile exhaust systems. Thirty-four samples were analyzed.

Hafnium/Zirconium Ratio in Metals

Ten metal samples were analyzed by neutron activation analysis to determine the hafnium/zirconium ratio.

5.10 KMS Fusion

Irradiation Damage Studies

Samples of nickel and aluminum were irradiated in the reactor as part of a materials damage testing program and to measure fast neutron-induced reactions.

Radiation Chemistry Studies

Radiation chemistry studies were conducted on gaseous mixtures, aqueous solutions, solids, and solid-gas systems for possible applications to fusion reactors.

5.11 Meteorological Research

Neutron activation analysis was used to perform trace element analyses of air samples taken at coal burning power plants. The analysis of 165 samples was completed.

5.12 Owens - Illinois

Measurements were performed on 17 samples to determine natural radioactivity in materials used in glass manufacture.