EDUCATIONAL AND RESEARCH ACTIVITIES

For the Period

July 1, 1977 to June 30, 1978

PHOENIX MEMORIAL LABORATORY

FORD NUCLEAR REACTOR

MICHIGAN MEMORIAL - PHOENIX PROJECT

THE UNIVERSITY OF MICHIGAN

Ann Arbor

July, 1978

Prepared For

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ABSTRACT

The Ford Nuclear Reactor (FNR) and the Phoenix Memorial Laboratory (PML) continue to provide unique facilities for use in programs of education and research by faculty, students, and researchers within the University of Michigan, and from other universities and institutions, and for use in research activities of industrial research organizations.

During the academic year 1977-1978, the reactor had a continuous operating schedule which made it available for use 64% of calendar time. Eight University of Michigan departments, five other universities and institutions, and 11 industrial research organizations used the reactor for a total of 28,007 experiment hours. In addition, reactor services were provided by the Phoenix Memorial Laboratory to 16 University of Michigan departments, 79 other universities and institutions, and 14 industrial research organizations for a total of 2,870 experiment hours. As part of a public education program, 2,390 people participated in 125 tours.

Use of the reactor by University of Michigan departments included neutron activation analysis of archaeological, biological, botanical, environmental, and geological samples; age-dating of mineral samples; measurement of radioactive isotope cross-section 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 undergraduate, master's, and doctoral degree projects. The following departments used the reactor: Atmospheric and Oceanic Science, Chemical Engineering, Chemistry, Geology and Mineralogy, Environmental and Industrial Health, Materials and Metallurgical Engineering, Mechanical Engineering, and Nuclear Engineering.

Use by other universities and institutions was primarily for neutron activation analysis, medical isotope production, reactor laboratory courses, and analytical chemistry courses. The reactor was used by Eastern Michigan University, Michigan Technological University, Oberlin College, Ohio State University, and Wayne State University.

Use of the reactor by industrial research organizations and utilities included neutron activation analysis, production of radioactive tracers for industrial use, radiation damage studies, attenuation measurements of neutron shielding materials, semiconductor

doping by thermal neutron irradiation, production of radioactive sources for induced X-ray fluorescence, neutron radiography, and training of electric utility personnel. Industrial users were Battelle Memorial Institute, Brand Industrial Services, Brooks and Perkins, Chrysler Corporation, Consumers Power Company, Detroit Edison, Dow Corning, E Systems, Environmental Research Group, Ford Motor Company Scientific Laboratory, and General Motors Research Laboratories.

Services by the Phoenix Memorial Laboratory which included reactor use were provided in the areas of radiochemical production, neutron activation analysis, gamma ray irradiations, and neutron radiography. University of Michigan departments serviced by the Phoenix Memorial Laboratory included Medical Chemistry and Pharmacology, Nuclear Pharmacy, Physiology, Atmospheric and Oceanic Sciences, Geology and Mineralogy, Great Lakes Research, Botany, Chemical Engineering, Anthropology, Chemistry, Environmental and Industrial Health, Materials and Metallurgical Science, Microbiology, Nuclear Engineering, Space Physics, and the Kelsey Museum of Anthropology. Services were provided to the following other universities and institutions: University of Cincinnati, Edsel B. Ford Institute for Medical Research, Ohio State University Toxicology Department, University of Arizona, Cranbrook Institute of Detroit, Detroit Institute of Art, the University of Hawaii, Henry Ford Community College, Hunter College, Michigan Technological University, Toledo Art Institute, Wayne State University, the University of Iowa, three Ann Arbor high schools, and 63 hospitals located in the United States, Puerto Rico, Canada, Finland, France, Denmark, and Scotland. Industrial research organizations which were provided services by the Phoenix Memorial Laboratory include Ford Motor Company Scientific Laboratory, General Motors Research Laboratory, John Deere Tractor Works, Ramsey Corporation, Anatec Services, E. I. du Pont Research Laboratories, KMS Fusion, Metal Improvement Company, Meteorological Research, U. S. Fish and Wildlife Service, Haig Jewelry Company, Amer Company, Naval Regional Medical Center, San Diego, 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 1977-78, 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 and radiography 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 1977-78, approximately 2,390 people participated in 125 tours.

The operating schedule of the reactor enables a sustained high level of participation by research groups. Continued support by the Department of Energy through the University Research Reactor Assistance Program (Contract No. EY-76-C-02-0385) and the Reactor Facility Cost Sharing Program (Contract No. EY-76-C-02-2117) has been essential to maintaining 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. 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 was assured. In September, 1977, the reactor returned to the 120 operating hours per week schedule. During the period of July 1, 1977 to June 30, 1978, the FNR was available for use approximately 64% of calendar time.

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

1) Short-term, sample irradiations for a period of less than one cycle to be used in a variety of applications.
2) Continuous reactor beam port use primarily in neutron spectroscopy. Five of the eight available ports are used.

	1977-78
Operating Hours	5,585
Operating Hours at 1 and 2 Megawatts	5,131
Accumulated Megawatt Hours	5,656
Experimental Utilization Hours	
Short-term Experiments	16,702
Beam Port Use	14,175
Total	30,877
Reactor Availability	
Percent of Calendar Year	64%

2.2 Reactor and Core

The reactor operates at a maximum power level of two megawatts 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" X 3" 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 11 standard fuel elements during 1977-78.

Fuel burnup rate is approximately 2.46 gm/day at two megawatts. Under a two megawatt operating schedule, 22 fuel elements are required for one year of operation.

Spent fuel is shipped periodically to the E. I. du Pont Company (Savannah River), Aiken, South Carolina for reprocessing. One shipment of 24 fuel elements was made in 1977-78.

2.4 Heavy Water Cycle

During 1977-78, the use of the Heavy Water Reflector Tank on one face of the FNR core required a throughput of approximately 100 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 1977-78 most 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.

	Experiment Hours 1977-78
University of Michigan	
Atmospheric and Oceanic Sciences	1
Chemistry Department	8
Geology and Mineralogy Department	91
Great Lakes Research	1
Environmental and Industrial Health Department	3
Materials and Metallurgical Engineering Department	29
Mechanical Engineering Department	3
Nuclear Engineering Department	14,959
Phoenix Memorial Laboratory	2,870
	17,965
Ambulance Service	2
Ann Arbor Fire Department	2
Burn's Security	8
Eastern Michigan University	67
Michigan Technological University	24
Oberlin College	1
Ohio State University	70
Wayne State University	1,019
Industrial Research	
Battelle	9
Brooks and Perkins	217
Consumers Power Company	80
Detroit Edison	160
Dow Corning	10,946
E Systems	180
Environmental Research Group	102
Ford Motor Company Scientific Laboratory	18
General Motors Research Laboratories	7
Total Experimental Utilization	30,877

3. FACILITY UTILIZATION BY THE UNIVERSITY OF MICHIGAN

3.1 Atmospheric and Oceanic Science Department

Little Traverse Bay Sediment Trace Metal Analyses

During the past year, the facilities of the Ford Nuclear Reactor and Phoenix Memorial Laboratory were utilized to perform neutron activation analyses of sediment samples from Little Traverse Bay, Lake Michigan. The study attempts to use the elemental concentrations of heavy metals and rare earth elements as geochemical tracers in order to establish the link between sediment dispersal processes and sediment composition in a near shore lacustrine environment.

Publications

1. J. E. Mackin and R. M. Owen, "Geochemistry of Bottom Sediments, Little Traverse Bay, Lake Michigan", 21st Great Lakes Research Conference, p. 92, Ann Arbor, Michigan.

Master's Thesis

1. J. E. Mackin, "Geochemistry of Bottom Sediments, Little Traverse Bay, Lake Michigan", University of Michigan, 1978.

3.2 Chemical Engineering Department

Oxygen and Trace Metals in Liquefied Coal Fractions

The object of the program is to measure the oxygen and trace metal contents of liquefied coal samples. The results are used to understand the physical behavior of liquefied coal. Neutron activation analysis procedures were developed by John Jones, Phoenix Memorial Radiation Laboratory Manager, and Utpal Sen Gupta for determination of oxygen in liquefied coal fractions. Oxygen as phenolic oxygen plays an important role in the solution behavior of liquefied coal because of hydrogen bonding. The procedure developed by Jones and Gupta has been used successfully

and is currently being used by Karen Steinke to analyse coal liquefaction samples for a Department of Energy (DOE) contract, "Physical and Chemical Behavior of Liquefied Coal in Solids Separation." Samples are also analysed for trace metals to determine the fate of such metals in solids separation processes. Some of the results on trace element analysis were used to interpret electrophoresis experiments with liquefied coal.

Publications

1. D. Briggs, "Physical and Chemical Behavior of Liquefied Coal in Solids Separation," Annual Report for October 1, 1977 to September 30, 1978, Department of Energy Report FE-2550-4.

Master's Thesis

1. R. Topliff and S. Proval, "Transport of Metals in Liquefied Coal When in an Electric Field," University of Michigan, 1978.

Undergraduate Project

1. K. Steinke, "Oxygen and Metals in Liquefied Coal," University of Michigan, 1978.

3.3 Chemistry Department

Isomeric Transitions in Lead (Pb)-204

Although extensive studies of the gamma rays, conversion electrons, and coincidence relations for transitions in Pb-204 following the decay of Bismuth (Bi)-204 have been reported and compiled, these data have not been sufficient to identify the mechanism of the substantial feeding of the well-known 67 minute isomer in Pb-204. The decay of Bi-204 (6^+, 11.3 hours) is found to populate a delayed 7^- state (0.45 μsec, E = 2264 keV) in Pb-204. A transition from this state accounts for 60% of the feeding of the well-known 9^- isomer at 2185 keV.

Publications

1. L. G. Sobotka, H. C. Griffin, and E. C. Kao, "Isomeric Transitions in Lead (Pb)-204," Physical Review C, Volume 17, No. 2, p. 816, February, 1978.

Chemistry 399: Undergraduate Research

An undergraduate research project investigating isomeric transitions in Pb-204 was conducted.

Chemistry 995: Doctoral Thesis

1. E. C. Kao, "The Decay Schemes of Bismuth (Bi)-203 and Bismuth (Bi)-204," Doctoral Thesis, University of Michigan, 1977.
2. C. M. Wysocki, "Neutron Activation Spectrometry Using Fission Spectrum Neutrons and Gamma-Gamma Coincidence Techniques," Doctoral Thesis, University of Michigan, 1978.

3.4 Geology and Mineralogy Department

Study of Trace and Minor Element Contents of Magnetite Samples from the McClure Mountain Complex, Colorado

Work was completed on the study of trace and minor element contents of magnetite samples from the McClure Mountain Complex, Colorado. Magnetites were analysed for the trace elements platinum (Pt), palladium (Pd), gold (Au), and minor elements titanium (Ti), manganese (Mn), vanadium (V), and aluminum (Al). Titanium, manganese, and aluminum trace elements were also determined by use of an electron microprobe. The electron microprobe results were from two to ten times higher in trace element content than the results obtained by neutron activation analysis. This is interpreted to mean that submicroscopic inclusions containing high concentrations of these elements contributed to the analyses by microprobe, but, because the samples for activation analysis were taken into solution and at least some types of these inclusions would be nearly insoluble, did not add to the neutron activation analysis

determinations. Inclusions of these types are visible under the microscope; during the microprobe analyses the beam was carefully positioned so as to avoid them, as nearly as could be ascertained. Further work to pinpoint the cause of the discrepancy would be helpful.

Major Element Determinations in Common Rocks

An attempt was made to develop a useful method for determining the major elements in common rocks. Specifically, an attempt was made to circumvent the interferences of silicon (Si) with aluminum analyses and of aluminum with magnesium (Mg), by use of boron nitride encapsulation of samples. All three of these elements occur in major concentrations in most rocks. The techniques developed were only partially successful, but the results suggest modifications that have a fair chance of bypassing the difficulties.

Uranium (U) and Thorium (Th) Determination by Activation Analysis

Attempts were made to determine the uranium and thorium content of rocks by neutron activation analysis. Satisfactory results were not obtained and sufficient time was not available to identify the sources of the difficulty. Analyses of standard rocks gave results derived from irradiating the samples, fusing with $Li_2B_4O_7$, dissolving in dilute nitric acid, collecting the radionuclides in Dowex resin, and comparing against standard aqueous solutions which were not subjected to this set of treatments. In the end only about 10% of the quantity of material present was detected. Probably the error lies in losses of the radionuclides during one or more stages of the procedure used in the treatment of the rock samples.

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

A tour of the laboratory and reactor facilities was conducted for 14 students enrolled in the course. The normal procedure is to have the students prepare

samples and interpret the spectra, but due to problems with other exercises earlier in the term, the laboratory schedule for the course had to be shifted with the elimination of specific lab work at the reactor.

Geology and Mineralogy 995: Doctoral Thesis

1. P. Kimmel, "Stratigraphy and Paleoecology of Miocene-Pliocene Sedimentary Rocks of Southwest Idaho and Adjacent Oregon," Doctoral Thesis, University of Michigan, 1978.

3.5 Environmental and Industrial Health Department

Environmental and Industrial Health 508: Radiation in the Environment

Approximately 10 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 radiation survey techniques and reactor operations.

3.6 Materials and Metallurgical Engineering Department

Irradiation of Polyethylene for Materials Experiments

Amorphous polyethylene was irradiated to a cumulative dose of approximately 5×10^{17} neutrons/cm^2 in order to destroy the crystallinity of the branched polyethylene. The amorphous polyethylene specimens became dark brown and glasslike under irradiation. Experimental results showed that the crystallinity of polyethylene specimens decreases as the neutron dose increases. The results were judged from wide-angle X-ray scattering studies.

3.7 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.

3.8 Nuclear Engineering Department

Triple Axis Spectrometer

The University of Michigan triple axis spectrometer at the Ford Nuclear Reactor "A" beam port has been modified to study small angle elastic neutron scattering from polymeric systems. The arrangement uses three silicon crystals in the parallel condition with a sample interposed between the first and second crystals. The technique attempts to exploit the Bonse-Hart multi-crystal system which has been successful for X-rays (SAXS). Extremely small angle scattering, actually through zero degrees, is possible by small rotations of the second and third crystals. Angle resolution is also very good, of order 1/2 minutes of arc. Calibration measurements on polystyrene latex spheres of known diameters in emulsion have been made satisfactorily. Polystyrene polymer chains in cyclohexane have been measured to be compared with published experiments done elsewhere. Computer techniques for correcting slit geometry effects have been developed. Some data on polyethylene solid mixtures, 95% pronated-5% deuterated, have been gathered.

The results of the above measurements have shown the following:

a) The Bonse-Hart technique can be applied to neutron small angle measurements using silicon crystals as the best choice of a monochronometer, as for X-rays.

b) The Bonse-Hart technique is limited to three silicon reflections because the beam intensity loss per reflection is close to 65%. This means direct beam wings are not completely suppressed. As a consequence, only scattering targets of large cross-sections are practical. The application to polymer systems is, therefore, limited to relatively high concentration tagging (e.g. 5% deuterated polyethylene in 95% protonated bulk polyethylene).

c) The lower limits in observable momentum transfer, q, defined by

$$q = 2\pi/\lambda \beta\theta_{scatter}$$

are excellent; less than 10^{-3} per angstrom. Typical no-target beam intensity is 2×10^4 counts/cm^2/sec.

Lithium (Li)-6 Target Mass Determination

Lithium fluoride targets were placed in the reactor's vertical beam tube and the reaction products were detected by a surface barrier detector. A gold foil was simultaneously irradiated as a relative flux monitor. The number of lithium target nuclei can be inferred from the ratio of the gold activity to lithium reactions through their respective thermal cross-sections and the mass of the gold.

In a separate experiment the number of lithium target nuclei was determined by comparing the reaction rate of a lithium target in a thermal beam with the reaction rate of a U-235 target of known composition.

Nuclear Engineering 315: Nuclear Instrumentation Laboratory

This course provides 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 isotopes. 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. Samples of semiconductors were irradiated to measure radiation damage effects on semiconductor materials as part of a student project.

Nuclear Engineering 425: Applied Nuclear Radiation

This course applies nuclear methods for materials analyses, including

activation analysis, neutron diffraction, neutron radiography, tracer methods, ion beam analysis, and Mössbauer spectroscopy. With the exception of the experiment in Mössbauer spectroscopy, all experiments made use of the Ford Nuclear Reactor.

The applied nuclear radiation course was conducted in the Fall Term of 1977 for approximately 11 students.

Nuclear Engineering 445: Nuclear Reactor Laboratory

In this course, experiments are carried out to measure reactor 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 transients are observed, and other reactor operating parameters are investigated. Experiments are also 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 Winter and Spring Terms in 1977-78 for a total of approximately 30 students.

Nuclear Engineering 599: Master's Thesis

1. H. Fields, "Modelling of the Ford Nuclear Reactor Core Using Computer Codes LEOPARD and 2DB," Master's Thesis, University of Michigan, 1977.
2. C. Goddard, "A Digital Data Acquisition System for the Ford Nuclear Reactor," Master's Thesis, University of Michigan, 1978.
3. M. Liebman, "Ford Nuclear Reactor Flux Determinations," Master's Thesis, University of Michigan, 1977.

Nuclear Engineering 995: Doctoral Thesis

1. W. H. Teng, "Small Angle Measurements on Polymers Using Multiple Crystal Reflections," Doctoral Thesis, University of Michigan, 1978.

PETMS Program

During the summer of 1977, one senior level student conducted measurements of the reactor pool volume using activation and tracer techniques as part of the PETMS Program.

3.9 Phoenix Memorial Laboratory

Radiochemical Production

Eight radioisotopes and radiolabelled chemicals were produced by the Phoenix Memorial Laboratory during 1977-78. They were bromine (Br)-82 labelled motor oil, elemental bromine-80 and bromine-82 for pharmacological research, NP-59 (iodine-131-6β-iodomethyl-19-norcholesterol), fluorine (F)-18, sodium (Na)-24, cesium (Cs)-134m, and chlorine (Cl)-36 labelled $KClO_3$. The laboratory also dispensed iodine-125 to qualified users in small quantities from stock supplied by the University of Michigan's nuclear pharmacy.

1. Bromine-82 Labelled Motor Oil

   Eighty-one samples (10,125 millicuries) of bromine-82 labelled motor oil were provided to the Ramsey Corporation, General Motors Research Laboratories, and John Deere Tractor Works. The motor oil is used in research programs at these three organizations to help improve engine oil economy by testing engines under a variety of conditions.

2. Elemental Bromine-80 and Bromine-82

   Six samples of bromine-82 in activated charcoal matrix were provided to the University of Michigan's Department of Medical Chemistry and Pharmacology for studies in the synthesis of radiobrominated androgens. Two compounds which have been shown to possess high binding affinity for androgen receptors and thus are potentially

excellent imaging agents for the prostate were radiolabelled with bromine-82. One of the compounds was found to be stable and may be produced in the future labelled with bromine-77.

One sample of bromine-80, prepared in the same matrix as was used for the bromine-82 experiments, was supplied to the Medical Chemistry and Pharmacology Department to determine if it could be used as an imaging agent in nuclear medicine.

Publications

1. R. E. Counsell, W. H. Klansmeier, R. W. Scotskinner, R. V. Pozderac, and P. A. Weinhold, "Synthesis of Radio-Brominated Androgens," 2nd International Symposium on Radiopharmaceutical Chemistry, St. Catherine's College, Oxford, England, July, 1978.

3. NP-59

NP-59, a Food and Drug Administration (FDA) approved Investigational New Drug for use in diagnosis of diseases of the adrenal glands, was produced in larger quantities than in any previous year. Two hundred eighty shipments were made to 63 hospitals in the United States, Puerto Rico, Canada, Finland, France, Denmark, and Scotland. A total of 3,767 millicuries of NP-59 were distributed during the year. This work is being done in cooperation with the University of Michigan Medical Center, Nuclear Medicine Unit and Radiopharmacy.

4. Fluorine-18

Thirty-four samples totalling 899 millicuries of fluorine-18 were supplied to the Edsel B. Ford Institute for Medical Research in Detroit and to the University of Cincinnati Medical Center. Its use by the Edsel B. Ford Institute was in a continuing research program aimed at detecting aseptic necrosis of the femoral head

before extensive damage has occurred to the patient's hip joint. Necrosis of the femoral head is known to be associated with several diseases and to occur in patients who have undergone kidney transplants. The fluorine-18 tends to concentrate in any areas where lesions exist and provides a radioactive marker for the physician who may examine the area with a gamma ray camera.

Fluorine-18 was also supplied in lesser quantities to the University of Cincinnati for research in labelling organic compounds.

5. Sodium-24

Forty samples totalling 10 millicuries of sodium-24 in the compound $NaHCO_3$ were supplied to the University of Michigan's Physiology Department for studies on brain capillary permeability. The experiments involved the simultaneous intra-arterial injection of both sodium-24 and iodine-125-albumin into test animals. Rapid cerebral venous blood samples were taken and analysis of the ratio of the two isotopes in the blood samples to their ratio when injected was used to determine the extent of flux of sodium in the brain.

6. Cesium-134m

Four samples totalling 45.6 millicuries of cesium-134m were supplied to the University of Michigan's Nuclear Pharmacy for preliminary tests as a possible heart scanning radiochemical. Results indicating whether this relatively less expensive radionuclide can be used to replace the cyclotron-produced thalium (Tl)-201 presently in use were inconclusive. Additional tests may be scheduled in the near future.

7. Chlorine-36

At the request of the Ohio State University Toxicology Department, Chlorine-36 in the form of HCl was converted to the chemical form $KClO_3$ by an electrolysis technique for use in cell-labelling

experiments at Ohio State. Approximately 100 microcuries were successfully produced and provided as a pilot project. Recently, 600 microcuries were also produced for this work. The chemical purity of the $KClO_3$ produced was estimated to be approximately 98%.

Neutron Activation Analysis Program

Neutron activation Analysis (NAA) services were utilized to an even greater extent in 1977-78 than in previous years. Utilization was up almost 46% over the previous record year 1976-77 which in turn was 41% higher than the year before. A total of 2,181 individual analyses were performed. New equipment purchased during the year made data handling more efficient. A 28 k memory Heath H10 computer and CRT display unit were integrated into the existing ND4420 computer analysis system. Programs similar to the data reduction programs previously written for the nuclear data system, but now written in FOCAL language, were developed. Similar programs written in BASIC are presently being developed to provide even greater speed in data handling.

In addition to neutron activation analysis services, the laboratory provides time and assistance to graduate students and class participation by students from the University of Michigan and from other educational institutions.

In the following tables, short-lived (S-L) multielement analysis refers to the elements aluminum, magnesium, manganese, chlorine, vanadium, titanium, copper, calcium, potassium, and sulfur which can be quantified after a brief irradiation in the reactor. Long-lived multielement analysis refers to the elements samarium, lutetium, uranium, cadmium, gold, barium, neodymium, arsenic, bromine, scandium, sodium, lanthanum, cerium, selenium, mercury, chromium, hafnium, silver, cesium, nickel, terbium, rubidium, iron, zinc, cobalt, europium, and antimony which can be measured after an irradiation of several hours at high flux levels in the reactor.

Neutron Activation Analysis Services

University of Michigan

Department	Material Analyzed	No. of Samples	Elements Measured
Anthropology	Prehistoric human bone to determine differences in diet of early man	27	Sn and Long-Lived (L-L) Multielement
Atmospheric and Oceanic Science	Organic fractions of lacustrine sediment	25	L-L Multielement
		25	L-L Multielement
		27	L-L Multielement
		39	Short-Lived (S-L) Multielement
Botany	Plant material (sugar cane, oats)	64	Si and S-L Multielement
		43	P with Chemical Separation
Chemical Engineering	Coal samples	9	Na
	Catalytic materials	6	Co, Fe
	Coal samples	17	S-L Multielement
		18	S-L Multielement
		24	L-L Multielement
Geology and Mineralogy	Minerals from Texas known to be rich in rare earths	43	L-L Multielement
	Porphyry copper minerals	135	L-L Multielement
		56	S-L Multielement
		18	L-L Multielement
	Volcanic ash (prehistoric)	105	L-L Multielement
Great Lakes Research	Modern and presettlement sediments of Great Lakes	27	
		11	
Physiology	Plasma and urine	11	L-L Multielement
	TOTAL	730	

Neutron Activation Analysis Services
Other Universities and Institutions

Institution	Material Analyzed	No. of Samples	Elements Measured
University of Arizona	Flint and chalcedony various quarries in North Dakota, Wyoming, New Mexico, and Texas	19	L-L Multielement
Cranbrook Institute	Vascular aquatic plants from Saginaw Bay, Michigan	105	As and L-L Multi-element
Detroit Institute of Art	Trace element analysis of ancient southeast Asian paper samples	9	L-L Multielement
	African "gold" jewelry trace element determinations	3	Au, Ag, Cu, L-L Multielement
University of Hawaii	Hawaiian volcanic glass commonly found as artifacts in Hawaiian sites. Study to determine the prehistoric trade networks	55	L-L Multielement
	Southwestern ceramic "poly-chrome" study to determine centers of clay sources and manufacturing		
Henry Ford Community College	Trace elements in Rouge River water samples	38	L-L Multielement
Hunter College	Archaeological specimen from excavation in southwestern Iran	8	L-L Multielement
Michigan Tech (Geology)	Gold-bearing minerals	23	Au
	Kimberlite samples (to study the vertical zonation)	23	L-L Multielement

Institution	Material Analyzed	No. of Samples	Elements Measured
	Rock samples	54	L-L Multielement
Ohio State University	$KClO_3$	2	O_2
Toledo Art Institute	Gold mask, determination of the amount of gold	1	Au
U. S. Fish and Wildlife Service	Arsenic in fresh water fish and water samples	41	As
	Multielement analysis of fish and fish scales to determine effect of pollution	34	L-L Multielement
	Sediments to determine multi-element pollution	10	L-L Multielement
	TOTAL	425	

Neutron Activation Analysis Services
Industrial Research Organizations

Organization	Material Analyzed	No. of Samples	Elements Measured
Anatec Services, Inc.	Gold alloy	2	Au, Cu, Ag
	Unknown alloy	2	Cu, Mg, Al
	Unknown alloy	2	Co, Ta, Ti, W
E. I. du Pont Experimental Research Laboratory	Organic material	6	S, Cl, Br
	To measure chromium contamination in plastic films	10	Cr
Edsel B. Ford Institute	Human bone, pilot study to determine feasibility of calcium and trace elements determinations	9	Ca, S-L and L-L Multielement
Ford Motor Company Scientific Laboratory	Beta Alumina	9	Na
	Catalytic materials to determine attrition of noble metals from exhaust systems	389	Pt, Pd, Ba
	Plastic gasoline tank material	95	F
	Trace elements in tin and lead shot	8	L-L Multielement
	Trace elements in aerosol samples taken during pollution study of Tuscarora Tunnel, Pennsylvania	41	S-L Multielement and L-L Multielement
	Nickel and molybdenum in air samples	7	Ni, Mo
General Motors Research Laboratories	Platinum and palladium determinations of solubility in various reagents	167	Pt, Pd
	Analysis of iridium in catalytic materials	4	
	Analysis of boron nitride for oxygen content	4	O_2

Organization	Material Analyzed	No. of Samples	Elements Measured
KMS Fusion, Inc.	Glass samples	44	S-L Multielement
Metal Improvement Co., Inc.	Dyscan fluids analysis	27	Cl, F, Br, S
Meteorological Research, Inc.	Air samples taken at a coal-burning power station	200	S-L and L-L Multi-element
	TOTAL	1,026	

Cobalt (Co)-60 Gamma Source Utilization

The Phoenix Memorial Laboratory provides a large cobalt-60 gamma ray irradiation facility for research activities. The facility was in use approximately 50% of calendar time during 1977-78.

Department/ Institution/ Organization	Sample	Number of Irradiations	Irradiation Hours
University of Michigan			
Chemistry	Polymer	1	81.0
Chemical Engineering	Polymer	2	331.1
	Salts	2	162.6
	Liquid/ Polyethylene	2	8.2
	Aluminum/ Plastic	12	1,883.6
	Sapphires/ Opals	4	29.4
Environmental and Industrial Health	Gerbils	12	1.1
	"Ferris Wheel"	1	23.4
	Liquid Dosimeter	2	1.8
	Fricke Solution	3	1.7
	Cells/ Culture Media	4	0.7
	Cells	1	0.2
University Hospital	Cartilage	3	106.3
Materials and Metallurgical Science	PE	14	3,182.9
	PMMA	1	3.0
Microbiology	Mouse Chow	1	21.9
	Cells	5	1.0
	Mice	2	0.2
	Mice	1	0.1
Nuclear Engineering	BeO Film	4	330.3
Space Physics	Polyethylene	2	0.2
Other Universities and Institutions			
Ann Arbor High Schools			
Pioneer	Avocados	1	0.1
Greenhills	Seeds	4	1.2
Huron	Carrots/ Cells	2	18.0
	Seeds	1	210.9

Department/ Institution/ Organization	Sample	Number of Irradiations	Irradiation Hours
Eastern Michigan University	Fungi	2	24.7
	Enzymes	6	0.6
University of Iowa	Cartilage	9	225.9
Wayne State University	Beef/ Chicken Meat	1	24.0
Naval Regional Medical Center, San Diego	Cartilage	1	44.6
Industrial Research Organizations			
Haig Jewelry Company	Topaz	1	4.8
KMS Fusion	CO_2	7	15.0
	HCl	7	6.0
	H_2S	7	195.0
	HBr	7	9.8
	Polymer Film	7	409.0
	CO_2 + S	7	53.0
	Fricke Dosimeter	7	0.7
Owens-Illinois	RIA Culture + KNO_3	5	241.9

Neutron Radiography Services

The facility operates two neutron radiography facilities. A three inch diameter facility with a length/diameter ratio of 300 can provide extremely fine resolution of small objects. A larger facility associated with "F" beam port can produce full eight inch by ten inch radiographs with excellent resolution. The facility has an L/D of approximately 50 and neutron intensity variations of not more than ± 5% from average over the exposed film.

The neutron radiography program meets ASTM standards E94-68, 142-77, and E545-75. Neutron radiographs are qualified under ASNT SNT-TC-IA(1975).

1. Kelsey Museum of Anthropology

Neutron radiographs were taken of a Roman statue dated 500-600 A. D. The statue was of a boy and an eagle. For restoration purposes it was desired to locate iron support pegs which had been placed between various parts of the statue. Neutron radiography provided a significant improvement over standard X-ray techniques for locating these pegs in the marble statue.

2. Ford Motor Company Scientific Laboratory

Neutron radiography services were provided for numerous items from the Ford Motor Company Scientific Laboratory including a steel cam, sodium batteries, stressed steel bar, aluminum gears, steel valve stems, polyethylene discs, and ceramic turbine rotors.

Nuclear Engineering 425: Applied Nuclear Radiation

Two one-hour sessions were conducted by the Phoenix Memorial Laboratory for this course. One session involved the energy dispersion analysis of X-rays and the second session involved the analysis of reactor pool water by gamma ray spectroscopy.

Nuclear Engineering 445: Nuclear Reactor Laboratory

Three four-hour sessions were conducted wherein gamma ray spectroscopy was used to do neutron flux mapping of the Ford Nuclear Reactor core.

Nuclear Engineering 515: Nuclear Measurements Laboratory

Three four-hour sessions were conducted in neutron activation analysis techniques.

Bowling Green State University Chemistry

A four-hour session in neutron activation analysis was conducted for approximately 10 Bowling Green State University students.

Eastern Michigan University Chemistry 485

A four-hour session in neutron activation analysis techniques was conducted for approximately 10 Eastern Michigan University students.

Grand Rapids Junior College

A class of 15 students participated in a one-day laboratory and lecture session on neutron activation analysis.

Michigan Technological University Physics

Two days of lectures and laboratories in neutron activation analysis were conducted for students from Michigan Technological University. This program is part of an annual physics course conducted for Michigan Tech at the reactor and laboratory facility.

Publications

1. J. D. Jones, P. B. Kaufman, and W. L. Rigot, "Method for Determination of Silicon in Plant Materials by Neutron Activation Analysis," American Society of Plant Physiologists Meeting, Blacksburg, Virginia, June, 1978 and Fifth Symposium of Recent Developments in Activation Analysis, St. Catherine's College, Oxford, England, July, 1978.

4. FACILITY UTILIZATION BY OTHER UNIVERSITIES AND INSTITUTIONS

During 1977-78, services provided to other universities and colleges consisted of 1,157 sample-hours of reactor irradiations and 24 hours of exclusive use of the reactor.

In addition to the services described below, additional services provided by the Phoenix Memorial Laboratory to other universities and colleges are described in Section 3.9.

4.1 Eastern Michigan University

Radiochemical Separation Procedures

The purpose of this project is to develop radiochemical separation procedures for trace element determinations in biological samples. A procedure for arsenic determination has been developed and used for the determination of arsenic in Lake Michigan fish. Currently, a procedure is being developed for mercury determination in biological samples using a chelating resin.

Publications

1. K. Rengan, "Adsorption of Hg (II) by a Chelating Resin," American Chemical Society Regional Meeting, Butler University, Indianapolis, May, 1978.

Metallic Trace Element Production

Trace quantities of the following elements were produced in the Ford Nuclear Reactor: sodium-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-203. These nuclides were utilized in research and in undergraduate and graduate courses at Eastern Michigan University and in an instrument analysis course at Bowling Green State University.

Publications

1. M. Hartwig and K. Rengan, "Use of Isooctylthioglycolate for the Separation of Tin and Antimony," Journal of Radioanalytical Chemistry, 42, p. 105, 1978.
2. K. Rengan, "An Elegant Neutron Activation Analysis Experiment for Undergraduate Curricula," Journal of Chemistry Education, 55, p. 203, 1978.

Neutron Activation Analysis of Various Materials

The purpose of this project was to determine low concentrations of a variety of elements, nondestructively, in a number of samples. At present the concentrations of gold (Au), selenium (Se), and arsenic in ancient Roman coins are being determined.

Chemistry 481: Radioisotope Techniques in Chemistry and Biology

Twenty-two Eastern Michigan University students participated in this course which teaches the basics of radioactive tracer techniques to biology and chemistry students.

Chemistry 594: Neutron Activation Analysis

Six Eastern Michigan University students participated in this course which provides the fundamentals of neutron activation analysis in a lecture and laboratory format.

Undergraduate Project

1. K. Mittelstrass, "Separation of Cr (III) and Cr (VI)".

Master's Thesis

1. M. Kimiatek, "Studies of Ancient Roman Coins by X-ray Fluorescence, Metallography, and Neutron Activation Analysis," Master's Thesis, Eastern Michigan University, 1978.
2. A. Vijanpour, "Hg (II) Adsorption by Chelex 100," Master's

Thesis, Eastern Michigan University, 1978.

3. M. Kaserouni, "Ag (I) Adsorption by Chelex 100," Master's Thesis, Eastern Michigan University, 1978.

4.2 Michigan Technological University

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.

4.3 Oberlin College

Sodium Half-Life Measurements

Approximately 0.249 grams of sodium carbonate sealed in a welded aluminum capsule were irradiated for use in sodium half-life experimental measurements.

4.4 Ohio State University

Neutron Activation Analysis of Sediment Samples

In the early 1960's, Spring Valley Lake, Ohio was treated with sodium arsenite to curb the growth of certain plant specimens. The purpose of this study is to use neutron activation analysis to determine the extent of the accumulation of arsenic in the bottom sediments after the initial desired effects had been obtained. Samples were taken from depths down to 20 cm in the sediment and were irradiated at the Ford Nuclear Reactor. Gamma photon spectra were measured with a standard spectroscopy system utilizing a germanium detector. Arsenic concentrations of each sediment layer sample were obtained. Several other trace elements were also identified. A qualitative model describing the depth distribution of arsenic in the sediment as a function of time has been developed.

Pharmacokinetics of cis-Platinum (II) Diamminedichloride

Neutron activation analysis is used for the measurement of drug and metabolite levels in biological specimens as a function of time following the administration of cis-Platinum (II) Diamminedichloride to patients with non-hematologic malignant disease. A pharmocokinetic model system is used in the computer fitting of the plasma concentration-time data, thereby providing hybrid microscopic rate constants, volumes of distribution, half-lives, and total body clearance values for each patient. The effects of dioresis and the concomitant administration of other anti-neoplastic agents on the pharmacokinetics of the drug are being investigated.

Neutron Activation Analysis of Silicate Rocks and Minerals

Nondestructive
precise technique for the determination of cobalt, chromium, iron (Fe), hafnium (Hf), sodium, nickel (Ni), scandium (Sc), tantalum (Ta), and thorium (Th) and the rare earth elements lanthanum (La), cerium (Ce), neodymium (Nd), samarium (Sm), europium (Eu), turbium (Tb), ytterbium (Yb), and lutetium (Lu) in silicate rocks and minerals. The technique has received wide use since the cooperative analysis of lunar samples indicated that neutron activation analysis is comparable to or better than many existing techniques.

Present studies at the Ohio State University nuclear reactor laboratory are aimed at establishing routine neutron activation analysis procedures for rock analysis, with particular emphasis on the analysis of rare earth elements. Preliminary studies indicate the neutron flux at the Ohio State reactor is insufficient to allow the analysis of 50 to 150 milligram samples. A suite of well analyzed international rock standards has been irradiated at the University of Michigan's Ford Nuclear Reactor and the gamma ray spectra have been measured at Ohio State. This has established the analytical precision, accuracy, and detection limits necessary. Eventually it is planned to analyze a large number

of volcanic rock samples and some mineral separates from the late Cenozoic McMurdo volcanic group and Jurassic Ferrar group of Antarctica. The McMurdo volcanic group consists of rocks ranging from parental basalts through phonolite. Rare earth element concentrations will be used to elucidate the hypothesized fractional crystallization process whereby the phonolite evolved from the basalt. Basaltic rocks from the Ferrar group are believed to be derived from the earth mantle at a depth of about 30-50 km. Rare earth element data will assist in evaluating several proposed models with their formation and subsequent modification prior to eruption.

Osmium (Os) Determination in RNA Sections

The object of the research is to chemically modify the tyrosine-specific species of transfer RNA isolated from yeast. The modification consists of attachment of an osmium bipridyl moiety to isopentenyl adenosine, a particular modified base located on the three side of the anticodon. Neutron activation analysis is used to confirm the site of modification. This molecule may then be used after crystallization as an isomorphous heavy metal derivative to solve the phasing in of an X-ray diffraction analysis of the three-dimensional structure of this RNA species. If this particular project is successful, further modification of the molecule with the osmium bipyridyl reagent may be attempted as a probe of the tertiary structure in solution.

Zinc Analysis in Fish Organs

An objective of this research was to determine the uptake of zinc by various organs of the common bluegill. The organs chosen were the heart, brain, liver, gill tissue, and opercular bone.

Samples were irradiated in the University of Michigan's Ford Nuclear Reactor. Following activation, the samples were allowed to decay for one week prior to measurement to ensure that certain elements which

become highly radioactive such as sodium and aluminum had decayed to safe levels that would not interfere with the determination of the zinc content of the samples. The zinc content of the samples was determined by gamma scintillation technique using several single channel and one multichannel analyzers.

4.5 Wayne State University

Europium Oxide (Eu_2O_3) Source

The purpose of this project was to look for changes in resonance fluorescence scattering under changing source conditions. Some effects were noted, but more runs are needed for confirmation.

Nuclear Resonance Fluorescence Scattering

This project is part of an overall program to produce various radioactive sources to look for possible changes in resonance fluorescence scattering under changing source conditions.

Iron-Nickel Alloy Irradiation

The purpose of this project is to study possible effects on the electron capture decay rate of cobalt-58 and iron-55 with changing internal magnetic fields. Slight effects have been noted.

Undergraduate Project

1. K. Beard, "A Study of the Angular Dependence of Nuclear Fluorescence from Europium-152m in Glass and Single Crystals," Senior Independent Project, Kalamazoo College, 1978.

Master's Thesis

1. J. Peters, "A Study of Possible Effects on Electron Capture in Passing through the Curie Point of a Magnetic Material," Master's Thesis, Wayne State University, 1978.

5. FACILITY UTILIZATION FOR INDUSTRIAL RESEARCH

5.1 Battelle Memorial Institute

Reactor Vessel Material Radiation Damage Tests

Battelle Memorial Institute is currently conducting a light water reactor vessel material crack propagation study for the Nuclear Regulatory Commission to obtain data on the effects of fast neutron induced damage. Eight double cantilever beam specimens are being irradiated adjacent to the core of the University of Michigan's Ford Nuclear Reactor to achieve a fast neutron ($E \geq 1.0$ MeV) exposure of 3×10^{19} neutrons/cm^2.

5.2 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/cm^2 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/cm^2 and 7×10^{9} Rad gamma caused significant dimensional changes and weight decreases, greatly increased hardness and loss of flexibility, and produced continued hydrogen and methane evolution.

5.3 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.

Publications

1. J. W. Bryson, J. C. Lee, R. R. Burn, "Neutron Transmission Through BORAL Shielding Material: Theoretical Model and Experimental Comparison," Department of Nuclear Engineering and Michigan Memorial - Phoenix Project, The University of Michigan, April, 1978.

BORAL Neutron Transmission

Routine neutron transmission measurements have been performed on various sizes, thicknesses, boron-10 loadings, and boron carbide grain size samples of BORAL material for purposes of correlating physical characteristics with neutron transmission.

BORAL Radiographs

Routine radiographs have been taken of one inch square BORAL coupons as part of a Brooks and Perkins quality assurance program. The coupons are samples from BORAL sheets which are utilized in nuclear reactor spent fuel storage racks.

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 exposed to fluences that approximated PWR and BWR storage pool fluences. Samples were tested dry and with 25 ml distilled water, 70 ml 2,000 ppm boron solution, and 20 ml 2,000 ppm boron solution injected within the stainless steel 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 2,000 ppm boron solution.

Radiolysis of Trace Quantities of Moisture in BORAL

BORAL plates have been observed 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 correlate gas evolution, moisture quantities, and neutron dose.

5.4 Chrysler Corporation

Transmission Seal Radiographs

Neutron radiographs of automobile transmissions seals were taken in an attempt to identify the source of deterioration of the rubber seals at the point of bonding to their metal encasements. Investigators had theorized that the metal was sharp-edged at the point at which the rubber seal was bonded to it, and that vibration caused the metal edge to act as a knife to cut the seal. Neutron radiographs gave a much better picture of the internal bond than conventional X-rays, but conclusive evidence as to the cause of the seal failure was not obtained.

5.5 Consumer's Power Company

Reactor Operator Training Program

An intensive two-week reactor operator training program was conducted for 12 Consumer's Power Company reactor operators in June, 1978. The program was a combination of classroom lectures, reactor experiments,

practical training, and reactor startups.

The lectures were presented to familiarize trainees with the Ford Nuclear Reactor facility, process systems, and nuclear instrumentation and control systems. Additional lectures provided background for experiments, reactor operations, and maintenance sessions. The heart of the lecture series was designed to provide the operators with essential background information in reactor physics and kinetics, reactor fuel and core parameters and operating characteristics, reactor operations, nuclear instrumentation and control, health physics, and radiation shielding.

Emphasis was placed upon experiments and reactor operations that illustrated reactor operating principles and provided the trainees with maximum hands on experience. In addition to performing reactor startups and shutdowns, trainees performed subcritical multiplication, control rod calibration, power level determination, negative temperature coefficient measurement, power defect measurement, reactor flux profile, radiation shielding, and radioactive contamination detection and cleanup experiments.

5.6 Detroit Edison

Reactor Operator Training Program

An intensive two-week reactor operator training program was conducted for 14 Detroit Edison Company reactor operators in December, 1977. This two-week program was followed by a second two-week program for 12 reactor operators in January, 1978. The program was a combination of classroom lectures, reactor experiments, and practical training.

Lectures were presented to familiarize trainees with the Ford Nuclear Reactor facility, process systems, and nuclear instrumentation and control systems. Additional lectures provided background for experiments, reactor operations, and maintenance sessions. The heart of the lecture series was designed to provide the operators with essential background information in reactor physics and kinetics, reactor fuel and core parameters and operating characteristics, reactor operations, nuclear instrumentation and control,

health physics, and radiation shielding. Emphasis was placed on experiments and reactor operations that illustrated reactor operating principles and provided the trainees with maximum hands on experience. In addition to performing reactor startups and shutdowns, trainees performed subcritical multiplication, control rod calibration, power level determination, negative temperature coefficient measurement, power defect measurement, reactor flux profile, radiation shielding, and radioactive contamination detection and cleanup experiments.

5.7 Dow Corning

Neutron-bombarded Float-zone Silicon for High Power Devices

The reactor staff has continued its cooperative activity 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 4,000 volt thyristors.

Semiconductors doped by neutron transmutation exhibit radial resistivity 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 more nearly 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. R. Burn, G. Cook, J. Jones, and J. Baker, "Phosphorous Doping of Floatzone Silicon by Thermal Neutron Irradiation," Proceedings of the American Nuclear Society, Reactor Operations Division Meeting, Chatanooga, Tennessee, August, 1977.

5.8 E Systems, Incorporated

Gamma Irradiation and Damage Study of Pipe Snubber

This project involved the gamma irradiation of a hydraulic pipe snubber in the Ford Nuclear Reactor spent fuel storage racks. The total irradiation time was 180 hours to obtain a cumulative gamma dose of 1.5×10^7 rad.

5.9 Environmental Research Group (ERG)

The Environmental Research Group is an analytical consulting laboratory which utilizes neutron activation analysis as one of the powerful tools in analyzing metals and halogens in practically any type of material. Using the Ford Nuclear Reactor as the neutron source for activation, ERG has successfully completed several projects for complete or partial scan of all the elements that can be analyzed using this method. Some of the special projects completed in 1977-78 were analysis of antimony in human blood samples and trace element analysis of minerals in water samples.

5.10 Ford Motor Company Scientific Laboratory

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.

Gadolinium (Gd)-153 and Cadmium Sources

These sources are used for X-ray fluorescence analysis on a variety of samples including catalytic converter substrate materials.

Neutron Radiography

Neutron radiography was utilized to study defects in a wide range of cast materials, including ceramic turbine blades and steel connecting

rods.

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. Neutron Activation Analysis is used to determine impurities that remain in magnet materials after a purification process.

Arsenic in Polyurethane Foam

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

Aluminum - Silicon Irradiations

Many prototype and existing automobile parts are made with aluminum - silicon alloys. The silicon content in most of these alloys ranges from 5 to 20% with the silicon content determining the major characteristics of the alloy. Silicon content has been determined in this project by neutron activation analysis. The 1,273 keV gamma ray of aluminum-29 produced by silicon-29 (n, p) aluminum-29 was measured. The detection limit is approximately 1% silicon in a one gram alloy sample.

Fluorine-18 Analysis in Gas Tank Samples

Plastic gasoline tanks for trucks are blow molded using a mixture of fluorine and dry nitrogen gases. The amount of fluorine reacting with the polyethylene in the gas tanks is measured by routine neutron activation analysis.

5.11 General Motors Research Laboratories, Analytical Chemistry

Radioisotope Methods

This project is concerned with the application of radioisotopes to applied research and development programs. Major research programs include the determination of platinum on air filters, oil economy studies for various engine parameters, evaluation of the wear characteristics of bearings, dies, and cutting tools, determination of the noble metal distribution in the ceramic substrates of catalytic materials, and trace element analysis by nuclear techniques. The analytical methods used, which include neutron activation analysis, autoradiography, and radioactive isotopes as tracers, require neutron irradiation services from the Ford Nuclear Reactor.

This research supports continuing efforts by General Motors to improve the performance and service life of automotive products. The radiometric methods, as adapted and applied to material research investigations, provide unique information that cannot be obtained readily by other means.

Neutron Activation

Neutron activation analysis has been used to determine the amount of noble metals on experimental catalysts. It is also being used to determine the sodium oxide content and the zirconium-hafnium ratio of solid electrolytes to be used in new electrochemical devices. Variations in tin and calcium content of battery grids have been studied by neutron activation analysis.

Radiometric Oil Economy

Improved oil economy was required for automotive engines, and attention was focused on the performance of valve stem seals and oil control rings. Their performance has been evaluated in the past by field tests normally lasting one month or more, but the radiometric method requires

only two days per test and offers better control by making all comparisons using the same engine. Based on the radiometric oil economy measurements, the seals and rings showing the best performance have been released for production engines.

Autoradiographic Techniques

An important aspect of automotive catalyst research concerns the control of noble metal (platinum, palladium, or rhodium) distribution in ceramic substrates. Autoradiographic techniques have proved to be a valuable method for characterizing the distribution of the noble metals, singly or combined, providing detail and sensitivity not otherwise available.

Radiometric Wear Studies

A radiometric method was developed for evaluating the wear characteristics of die materials that can be used in extruding ceramic monolithic structures for production catalysts. As little as 0.1 μg of die wear can be detected by measuring the radioactivity of the extruded material after the die material had first been made radioactive by irradiation in a nuclear reactor. Research revealed that steel dies coated with titanium carbide have the longest life for extruding ceramic materials.

Publications

1. W. H. Lange, "Autoradiographic Techniques for Determining Noble Metal Distribution in Catalysts," Research Publication GMR-2164, May, 1976.
2. R. F. Hill and W. J. Mayer, "Radiometric Determination of Platinum and Palladium Attrition from Automotive Catalysts," IEEE Transactions on Nuclear Science, Vol. NS-24, p.25-49, December, 1977.