Ford Nuclear Reactor
Phoenix Memorial Laboratory

THE UNIVERSITY OF MICHIGAN
NUCLEAR REACTOR LABORATORY
QUARTERLY REVIEW

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2301 Bonisteel Boulevard
Ann Arbor, Michigan 48109-2100

## MICHIGAN MEMORIAL - PHOENIX PROJECT

The Michigan Memorial - Phoenix Project has been providing radiation laboratory and reactor services to The University of Michigan since it was established in 1948. This quarterly review has been started to make more faculty and staff members aware of the fact that these services are available, and to provide them with specific examples of the types of research and experimental programs being conducted.

### Project Charter

The Nuclear Reactor Laboratory includes the Ford Nuclear Reactor and the Phoenix Memorial Laboratory, and is operated by the Michigan Memorial - Phoenix Project. The Project, established as a memorial to students and alumni of the University who died in World War II, encourages and supports research related to peaceful uses of nuclear energy and its social implications. The Nuclear Reactor Laboratory and a faculty research grant program are the means by which the Project carries out its charter.

### Nuclear Reactor Laboratory

The primary purpose of the Nuclear Reactor laboratory is to provide University faculty with the special facilities needed for nuclear energy research and teaching. In addition, the facilities and services of the Laboratory are available for use by other colleges and universities, hospitals, industry, and electric utilities.

### Facilities and Services

The Ford Nuclear Reactor provides a source of high energy neutrons, low energy neutrons, and gamma rays that can be used for a variety of applications including: radiation damage and effects studies, neutron activation analysis, neutron radiography, neutron scattering studies, neutron spectroscopy, and radioisotope production.

A large cobalt-60 gamma source is located in the Phoenix Memorial Laboratory. The cobalt-60 facility is used for studies of the effects of gamma radiation, and for sterilization of a variety of materials including bone and tissue used in reconstructive surgery.

The Laboratory contains eight chemistry and two physics laboratories. In addition to standard equipment such as air, gas, vacuum, and water lines, the laboratories are equipped with radioactive drains to retention tanks, hoods that exhaust through particulate filters and filters that trap volatiles such as iodine, and utility supplies for portable glove boxes.

A variety of specially equipped laboratories are offered including a greenhouse, a darkroom, and a cold storage room. Services are available from machine and electronic shops.

Two large, shielded rooms called hot caves are available for remote handling, examination, and limited machining of highly radioactive materials. Each hot cave is equipped with master-slave manipulators, a remotely operated hoist, and ports for service connections.

**Laboratory Operating Schedule**

The Ford Nuclear Reactor Operates on a two-week cycle. The reactor is operated continuously at its licensed power level of two megawatts from Tuesday morning of the first week through Thursday midnight of the second week. Almost ten days of continuous operation are achieved. Approximately four days of shutdown time between the operating days are used for routine maintenance and system calibrations required by the reactor license. While normal facility hours during which technical assistance is available are 8:00 a.m. - 5:00 p.m. Monday through Friday, the Laboratory can be made available twenty-four hours a day, seven days a week to researchers.

The cobalt-60 irradiation facility operates on a continuous schedule. It is available for use twenty-four hours a day, seven days per week.

## FEATURE ARTICLE
## NEUTRON ACTIVATION ANALYSIS

Neutron activation analysis is an analytical technique for identifying and measuring trace quantities of a large number of elements in many types of materials. Sixty-six common and rare earth elements become radioactive when exposed to the neutron flux in a reactor. The subsequent radiation emitted by the decay of activated nuclei is different for each element and its measurement permits identification. Of the 66 radioactive elements, over 50 can be identified and measured quite readily. The method permits measurement of all detectable elements simultaneously; it is rapid and non-destructive.

Quantitative analysis of samples made radioactive in a reactor by reactions with neutrons is commonly called instrumental neutron activation analysis (INAA). This type of analysis is a delayed method; that is, a sample is activated, and the radiation emitted by the resulting radionuclides is measured after a certain delay time.

Another technique, called prompt neutron activation analysis (PNAA), involves placing the sample to be analyzed directly in a neutron beam. A detector adjacent to the sample but outside the beam measures gamma rays that are produced by neutron interactions with the sample. In many cases, when a sample is irradiated by neutrons, nuclear capture reactions are induced that produce new nuclides in high energy states ranging from 5 to 10 MeV according to the binding energy of the absorbed neutron. These highly excited states have very short half-lives. De-excitation typically produces prompt gamma rays that range in energy from 0.1 to about 10 MeV. For the identification by this process, it is immaterial whether the product nuclide is radioactive. PNAA is particularly sensitive for analyzing elements with high neutron absorption cross sections such boron, cadmium, gadolinium, and samarium.

There are practical limits to neutron activation analysis. A number of elements are relatively insensitive to neutron absorption. Calcium is an example. Others, such as rhodium, decay rapidly and make the analysis that follows activation difficult. For other elements including argon, boron, holmium, krypton, lithium, neon, oxygen, silicon, sulfur, thalium, and xenon, techniques such as chemical concentration, filtration, special encapsulation, and special irradiation methods are necessary to perform neutron activation analysis.

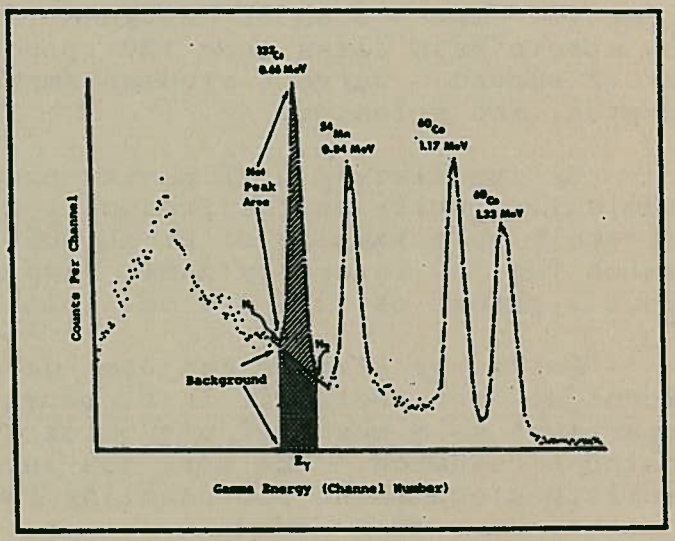
Radiochemical neutron activation analysis (RNAA) is a form of INAA in which some radiochemical separation of nuclides is performed to enhance sensitivity. Sensitivity is the lower limit of detection in parts per million (ppm) that can be achieved in an analysis. Sensitivity depends on the ability of an element to be activated and on interfering background radiation from other elements that tends to mask out the desired element's radiation. Radiochemical separation increases sensitivity by concentrating the elements being measured and reducing background radiation by removal of interfering elements.

Table 1 is a listing of neutron activation analysis sensitivities for 66 elements. Two values are given. Typical sensitivity is the lower limit of detection for an element found in a matrix of other elements such as in a geological sample. Absolute sensitivity is the absolute limit of detection for an element in a clean matrix such as ultra-pure demineralized water.

## Table 1 Neutron Activation Analysis Sensitivities

| Element | Sensitivity (ppm) Typical | Absolute | Element | Sensitivity (ppm) Typical | Absolute |
|---|---|---|---|---|---|
| Aluminum | 800 | 0.3 | Neodymium | 120 | 1 |
| Antimony | 2 | 0.01 | Nickel | 1,000 | 10 |
| Argon | -- | -- | Niobium | 6,000 | 10 |
| Arsenic | 30 | 0.1 | Osmium | 3 | 0.01 |
| Barium | 1,200 | 1 | Palladium | 300 | 0.01 |
| Bromine | 10 | 0.2 | Platinum | 3,000 | 10 |
| Cadmium | 70 | 0.5 | Potassium | 1,000 | 10 |
| Calcium | 10,000 | 200 | Praseodymium | 180 | 1 |
| Cerium | 10 | 0.1 | Rhenium | 2 | 0.01 |
| Cesium | 3 | 0.01 | Rhodium | -- | -- |
| Chlorine | 80 | 0.6 | Rubidium | 70 | 1 |
| Chromium | 25 | 0.1 | Ruthenium | 10 | 0.1 |
| Cobalt | 2 | 0.01 | Samarium | 0.6 | 0.01 |
| Copper | 200 | 0.1 | Scandium | 0.3 | 0.001 |
| Dysprosium | 3 | 0.01 | Selenium | 15 | 0.1 |
| Erbium | 25 | 0.1 | Silver | 10 | 0.1 |
| Europium | 0.3 | 0.001 | Sodium | 15 | 0.1 |
| Gadolinium | 20 | 0.1 | Strontium | 1,000 | 1 |
| Gallium | 15 | 0.1 | Tantalum | 1 | 0.01 |
| Germanium | 230 | 0.3 | Tellurium | 50 | 0.1 |
| Gold | 0.1 | 0.001 | Terbium | 2 | 0.01 |
| Hafnium | 2 | 0.01 | Thulium | 2 | 0.01 |
| Indium | 0.1 | 0.001 | Thorium | 2 | 0.01 |
| Iodine | 10 | 0.1 | Tin | 500 | 1 |
| Iridium | 0.1 | 0.001 | Titanium | 600 | 10 |
| Iron | 1,500 | 10 | Tungsten | 150 | 1 |
| Krypton | -- | -- | Uranium | 10 | 0.5 |
| Lanthanum | 2 | 0.1 | Vanadium | 10 | 0.1 |
| Lutetium | 1 | 0.001 | Xenon | -- | -- |
| Magnesium | 3,000 | 1 | Ytterbium | 4 | 0.1 |
| Manganese | 3 | 0.01 | Yttrium | 50 | 1 |
| Mercury | 5 | 0.01 | Zinc | 60 | 1 |
| Molybdenum | 40 | 0.2 | Zirconium | 900 | 5 |

Following irradiation in a reactor, a sample emits a spectrum of gamma rays corresponding to decay of all the radioactive isotopes created in the sample. It might be expected that a line spectrum would result because of the discrete nature of the gamma ray energies. However, gamma rays interact with a detector by differing means, among them Compton scattering and pair production. Quite often, only part of the initial gamma energy will be detected and converted to a pulse. As a result, the spectrum will be a continuum that represents a record of all types of interactions within the detector.




The most important feature of the gamma ray spectrum is the total absorption peak so named because it results from pulses generated by the total absorption of an isotope's gamma ray energy by the detector. Most of these pulses arise from photoelectric interactions so it has become customary to refer to this peak simply as a photopeak. The photopeak contains two important pieces of information: (1) the centroid, a measure of gamma ray energy; and (2) the area, a measure of source activity. The centroid energy enables an element to be identified. After the element is identified, the area under the photopeak permits determination of the quantity of an element in a sample.

## FORD NUCLEAR REACTOR OPERATION

The Ford Nuclear Reactor typically operates at full power, two megawatts, for ten days followed by four days of shutdown for maintenance. At full power, typical values of reactor neutron fluxes and gamma dose rates at experiment locations around the core are:

Thermal Neutron Flux ($n/cm^2/s$).....$1x10^{13}$
Fast Neutron Flux > 1 MeV ($n/cm^2/s$).....$3x10^{12}$
Gamma Dose Rate (rad/hr).....$6x10^7$

Much of the reactor utilization comes from the Nuclear Engineering Department, primarily because of laboratories and long term neutron beam experiments that involve continuous use of the reactor for gathering data. The Chemistry Department is also a regular user. A number of other departments use the facility for special projects.

Chemistry

Professor Henry C. Griffin has been involved with Professor K. Rengan of Eastern Michigan University in setting up and utilizing a gas-jet system for collecting uranium-235 fission products at D beamport. The system is designed for the collection and study of low atomic mass (less than 120) products with half-lives as short as 0.2 second. Current studies emphasize isotopes of bromine, krypton, and selenium.

By irradiating high purity nickel oxide (NiO) in the reactor and chemically purifying the products, Professor Griffin has prepared extremely pure samples of nickel-65. These samples were used in a search for low intensity gamma rays; preliminary results indicate that about 3 gammas of 2094 keV are emitted in one million decays.

Professor Griffin has been developing chemical separation techniques for sodium-22 in cooperation with members of the Physics Department as a means of producing intense positron sources for positron research. The work has involved the reactor and the facility's equipment for handling radioactive materials.

Nuclear Engineering

The largest departmental research commitment to the Laboratory facilities is maintained by the Department of Nuclear Engineering. During 1987-1988, this department used the laboratory and reactor for ten formal University courses and conducted extensive, on-going research projects in the areas of neutron spectroscopy, radiation effects in materials, and cross section measurements.

Under the neutron spectroscopy program directed by Professor John S. King, a wide angle, two-circle, powder-diffraction spectrometer has been modified for utilization as a fully computerized, single-crystal, four-circle diffractometer. Recent studies have involved powder diffraction on order-disorder alloys. A change in the powder diffraction pattern is expected in association with heat treated metal alloys.

Under sponsorship by the U.S. Department of Energy, Professor Glenn F. Knoll directs the cross section measurements activities. This is a large project involving the absolute measurement of fast fission and capture cross sections of several different isotopes. The reactor is relied upon for irradiation of sodium, gallium, and antimony sources to produce activities ranging from 10 to 40 curies each. These gamma sources are then coupled with targets of deuterium or beryllium to produce monoenergetic neutrons. Current work is focused on the measurement of neutron capture cross sections in uranium-238 and thorium-232.

Tests conducted at A beamport by Professor Knoll consisted of placing samples of several different scintillation materials in a neutron beam to measure detection efficiency and pulse height spectra. The samples consisted of a dispersion of small glass microshells (about 100 micron diameter) dispersed in a plastic scintillator. The shell walls were about 1 micron thick. Helium-3 gas is trapped inside the microshells at high pressure. Protons produced in the neutron-induced reaction in the helium were expected to pass through the shell walls and create light pulses in the scintillator.

Under the radiation-effects-in-materials program directed by Professor Dietrich H. Vincent, J beamport is being used for thermal neutron profiling of helium-3 implanted in crystalline and amorphous metals. The purpose is to determine the spatial distribution of helium and its redistribution as a function of isochronal and isothermal annealing. The variation of helium release with temperature and concentration is studied to ascertain possible helium-metal interaction mechanisms for fusion reactor first wall or blanket materials.

Professor David Wehe supervised students who used the reactor for projects involving response of rhodium self-powered neutron detectors in steadily changing fluxes, gamma ray spectroscopy, and two dimensional radiation imaging of one of the reactor demineralizers.

Physics

Professor Joachim Janecke used the reactor to produce radioactive argon-41 for calibration of a Physics Department beta particle detector.

Professors Michael Bretz and Ctirad Uher are investigating the use of the high energy neutron radiation effects to produce room temperature superconductors in ceramic materials. Current interest is centered on yttrium(1) - barium(2) - copper(3) oxide compacts.

## NEUTRON RADIOGRAPHY

Neutron radiography is a method of recording geometric patterns of transmitted neutron intensity somewhat similar in technique to x-ray radiography. However, the results are generally quite different because neutrons tend to interact strongly with light atoms whereas x-rays tend to interact with heavy ones. The radiographs thus produced show different detail than would be obtained by x-rays. For example, light materials inside structures of certain dense materials, such as lead, bismuth, and uranium, which are difficult to penetrate using x-rays, can be imaged using neutrons. Details of plastic, oil, water, fractures, and voids inside steel or lead can be observed with good resolution.

Two neutron radiography facilities are in operation. A three-inch diameter neutron beam with a length/diameter ratio of 300 can provide extremely fine resolution of small objects. A larger beam associated with E beamport can produce full eight-inch by ten-inch radiographs with excellent resolution. This beam has a length/diameter ratio of approximately 50 and neutron intensity variations of not more than plus or minus ten percent from the average over the exposed film. The products of these facilities meet accepted industry standards.

The laboratory can also perform real time neutron radiography (RTNR) which is useful in dynamic analysis of some systems and, possibly, in medical applications where observations of parts of the human body are needed.

Chemical Engineering

Professor Scott Fogler, Chairman, Chemical Engineering, used Real Time Neutron Radiography (RTNR) to study flow through porous media. Water and oil flow through porous sandstone, water replacing oil, oil replacing water, gas replacing water, and water replacing gas in porous sandstone have been observed. RTNR was also used to image acidizing of sandstone and the injection of woods metal into the acidized structure. These experiments model oil recovery methods and techniques.

Civil Engineering

Professor Steven Wright has used real time neutron radiography to study water flow through soil. This is primarily of interest in the progression of contaminants into a water system. Further work is planned for 1988.

Nuclear Engineering

The vertical Neutron radiography port was utilized by Professor Dietrich Vincent for cross section measurements as part of course NE 425, Nuclear Materials Laboratory.

## NEUTRON ACTIVATION ANALYSIS

The highly sensitive analytical technique of neutron activation analysis is available as a service performed by the laboratory staff. Alternatively, it can be performed directly by investigators using the laboratory's facilities. In addition, samples can be irradiated and returned to users so that they may perform their own analyses on their own equipment.

The Nuclear Reactor Laboratory has two primary analysis systems: (1) Nuclear Data 6660 which is a single user system capable of simultaneously analyzing many parameters associated with a single experiment and (2) Nuclear Data 6700 which is a multi-user system which can receive inputs from many detectors associated with many experiments, but can analyze for a single parameter associated with any experiment.

Atmospheric and Oceanic Science

Annette Olivarez and Professor Robert M. Owen utilized neutron activation analysis to measure trace elements in geological sediment specimens.

Biology

Professor Wayne Frasch used neutron activation analysis to measure manganese in proteins associated with photosynthesis in plants.

Professor Peter Kaufman performed silicon analysis in biological materials.

Chemical Engineering

Amit Sachdev, under the direction of Professor Johannes W. Schwank, analyzed platinum catalysis specimens by neutron activation analysis to determine chlorine, tin, and platinum concentrations. Platinum and tin are basic catalysis materials. Chlorine is an unavoidable contaminant that enhances catalytic action.

Chemistry

Neutron activation analysis was performed on metal rubbings from ancient and medieval coins by Professor Adon A. Gordus to determine elemental content. This can provide information about the origin of the coins, the contained metals, and the cultures associated with them.

Neutron activation analysis also was performed by Professor Gordus on hair samples to obtain information on body chemistry and the impact of environmental pollution on hair chemistry.

Dr. Richard Fronko, a research fellow in the Chemistry Department, in association with Professor James Penner-Hahn, is utilizing neutron activation analysis to determine manganese content in Mn-Catalase protein. The analysis is being used to help characterize Mn-Catalase. The goal of Dr. Fronko's research is to describe the structure of the Mn-Catalase protein.

Kelsey Museum of Anthropology

Anthropological specimens were analyzed for trace elements as a means of authentication.

Medical School - Biological Chemistry

Professor David Ballou has been investigating the degree of substitution of cobalt, nickel, copper, iron, and zinc at active sites in enzymes.

Medical School - Human Genetics and Internal Medicine

In a test program at University Hospital, copper-65 was administered orally to normal patients and to patients suffering from comparatively rare Wilson's disease. Wilson's disease patients have an abnormally high uptake of copper. Stool and urine samples were analyzed for copper by neutron activation analysis to determine whether this technique could be used as an early detection method for the disease.

Physics

Professor Joachim Janecke has performed neutron activation analysis of osmium and rhenium solutions that are used in chemical deposition processes of these elements. Before and after deposition solutions were analyzed to measure the magnitude of the deposits.

Professor Ronald Clark used neutron activation analysis to measure the degree of intercalation of elemental cesium, potassium, and rubidium into graphite.

School of Public Health

Professor James Martin analyzed environmental and power plant related samples for trace elements using neutron activation analysis.

University Hospital - Pediatric Surgery

A study under the direction of Dr. John Wesley and Robert Drongowski involving trace element analysis of blood from infants that had received intravenous feeding has been ongoing for several years. The object is to relate specific elements to premature birth and health problems.

## COBALT-60 IRRADIATION SOURCE

A cobalt-60 source of approximately 10,000 curies is available for gamma irradiations. Typical applications include sterilization of bone and cartilage for human grafts and transplants; sterilization of animal food for germ-free animal colonies; mutation of cells; and studies of radiation effects on chemical systems, electronic and reactor components, food, seeds, and plants.

The peak dose rate at the center of the source is about $1x10^6$ rad/hour. Typical sterilization dose rates at distances near 25 centimeters from the source are about 50,000 rad/hour. Typical sterilization doses are $2x10^6$ rad.

Biology

Professor Tahir M. Rizki sponsors a graduate student who is observing mutations caused by low doses of gamma rays on fruit flies.

Professor John Pringle is sponsoring a graduate student who is observing the mutagenesis of S-Cerevisiae yeast cells by gamma radiation.

Chemical Engineering

Professor Dale Briggs and two graduate students are investigating coal liquification. A liquid slurry of coal is irradiated in a sealed container at elevated temperature in the center well of the Cobalt-60 irradiator. Radiation acts as a catalyst to promote total liquification of the slurry.

Chemistry

Professor Adon A. Gordus is working in collaboration with Ann Arbor Nuclear on an extensive, ongoing project that involves conversion of low grade radiation energy to high grade chemical energy. A solution of liquid titanium tetrachloride is pumped in a closed system past the cobalt-60 irradiator. Some of the tetrachloride is converted to trichloride. The titanium trichloride can be extracted and made to react exothermally to provide concentrated chemical energy.

In related work, graduate students are testing other chlorine compounds including cesium tetrachloride, tin dichloride, and zirconium tetrachloride.

Dr. Gordus is sponsoring another graduate student in a coal liquification project. A coal-cyclohexane solution is irradiated at ambient temperature. Hydrogen transfers from the cyclohexane to the coal. This assists in coal liquification during subsequent processing.

Professor Paul G. Rasmussen is sponsoring a graduate student on a project involving solid-state polymerization of dicyanomidozale by gamma ray radiation.

Mechanical Engineering

Dr. Massoud Kaviany is sponsoring a graduate student who is irradiating a porous stainless steel block to determine the amount of ethanol present. The volume of ethanol can be determined using gamma attenuation data. These blocks will be used as wicks in a combuster.

Physics

A lithium fluoride crystal was irradiated for Professor Ronald Clarke in order to facilitate cutting the crystal by producing cleavage planes.

Gamma rays were used by Professor James Van House in damage studies of sodium chloride crystals and nickel foils.

School of Dentistry, Department of Oral Bacteriology

Dr. K. Makinen uses gamma rays to sterilize a synthetic substrate for collangenase. The substrate is made from a human amino acid peptide derivative.

School of Public Health, Epidemiology

Professor G. I. Higashi is conducting an ongoing test program involving schistosomiasis cercariae in an attempt to develop live vaccines.

University Hospital, Internal Medicine

Cell culture tissues were irradiated for Dr. William Kelley in an attempt to mutagenize one gene.

Under a National Institute of Health grant, Dr. David Hollis utilized gamma radiation in the examination of cell culture growth on the extracellular matrix. A model was developed to study growth factors on primary proximate tubule cells.

University Hospital, Microbiology and Immunology

Dr. Garth Jones is working under an Environmental Protection Agency grant to study the survival of irradiated microorganisms in aqueous solution.

University Hospital, Pediatrics

Dr. Thomas Glover has irradiated a human lymphoblastoid cell line established from a patient with Bloom's syndrome to induce deletion mutations at the HPRT locus.

In addition, Dr. Glover conducted an irradiation-response study of neurotibiomatosis lymphoblastoid cells and human lymphoblastoid cells to determine relative rates of chromosome aberrations.

University Hospital, Plastic and Reconstructive Surgery

Dr. Jeffrey Kyllo irradiated human cartilage for implantation in human reconstructive surgery.

University of Michigan, Dearborn
Natural Sciences

Dr. Miriam Zolan irradiates cell cultures to various gamma doses for a study involving isolation and characterization of radiation-sensitive mutants of copernus cinereus on fungus.

## RADIOPHARMACEUTICAL PRODUCTION

Two radioiodine compounds, NP-59 and MIBG-diagnostic, are produced by the radiopharmaceutical program at the Nuclear Reactor Laboratory.

NP-59, a derivative of cholesterol, is an adrenal scanning agent used in the detection of abnormalities in the adrenal gland. NP-59 is synthesized monthly for distribution outside the University.

MIBG-diagnostic, a radioiodinated analog of guanethidine antihypertensive drug, is an adrenal medulla scanning agent used in the detection of disease in the adrenomedulla. MIBG is synthesized twice monthly for distribution outside the University.

### Radiopharmaceutical Production Summary

Radiopharmaceuticals are produced weekly and shipped to 119 hospitals in 34 states and the District of Columbia in the United States and 11 hospitals in Ontario and Quebec, Canada.

## RADIOCHEMICAL PRODUCTION

Preparation of radioisotopes for research is performed at the Laboratory. Elemental bromine-82 is produced by irradiating liquid bromine in the reactor. The radioactive bromine is combined with motor oil and used in engine wear tests.

## NUCLEAR REACTOR LABORATORY

**Hours of Operation**

Monday-Friday 8:00 a.m.-5:00 p.m.
Facilities can be made available 24 hours a day, if required.
Tours should be scheduled at least 24 hours in advance.

**Telephone Numbers**

| | | |
|---|---|---|
| Director | William Kerr | (313) 764-6213 |
| Manager | Reed Robert Burn | 764-6224 |
| Assistant Manager, Operations | Gary M. Cook | 764-6222 |
| Assistant Manager, Research<br>Neutron Activation Analysis<br>Radiation Damage Studies | Philip A. Simpson | 764-6221 |
| Senior Research Associate<br>Neutron Radiography | John T. Lindsay | 936-1583 |
| Research Associate<br>Cobalt-60 Sterilization<br>Radioisotope Preparation | Robert B. Blackburn | 936-1582 |
| Information and Tours | | 764-6220<br>764-6223 |

Further information and assistance can be obtained by calling any of the staff members listed above.