Ford Nuclear Reactor
Phoenix Memorial Laboratory

THE UNIVERSITY OF MICHIGAN NUCLEAR REACTOR LABORATORY QUARTERLY REVIEW

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The Nuclear Reactor Laboratory Quarterly Review is published and distributed to University of Michigan faculty and staff members to inform them of the unique research capabilities of the Nuclear Reactor Laboratory and of the types of research in progress. Research projects started within the preceding quarter are listed first. A feature article that provides in-depth information about one particular technique or program follows. Updated descriptions of the remaining Nuclear Reactor Laboratory programs complete the Quarterly Review.

NEW RESEARCH

FORD NUCLEAR REACTOR

Geological Sciences

Associate Professor Alexander N. Halliday is utilizing the reactor to perform $^{40}Ar/^{39}Ar$ age dating of rocks. ^{40}Ar is produced in rocks by the radioactive decay of natural ^{40}K which has a half-life of about 1.28 billion years. Measurement of ^{40}Ar concentration which provides an indication of the amount of ^{40}K that has decayed, determination of the amount of ^{40}K that remains, and performance of radioactive decay calculations permit the determination of a rock's age.

The reactor is used to assist in determining the amount of ^{40}K currently in a rock. In the reactor, some of the ^{39}K present is converted to ^{39}Ar by the reaction $^{39}K(n,p)^{39}Ar$. Measurement of the amount of ^{39}Ar produced by neutron activation provides a means to determine the ^{39}K which in turn can be used to calculate the current amount of radioactive ^{40}K based on known fractional abundances of each isotope in potassium. The present amount of ^{40}K can be compared with the sum of the present amount and the amount that has decayed to determine a rock's age.

For example, based on the half-life of 1.28 billion years, if the sum of the amount of ^{40}K that has decayed and the current amount in a rock were determined to be 1,000 atoms and the current number of atoms were 500, half the atoms present would have decayed (one half-life), and the rock would be 1.28 billion years old. If the current number of atoms were 250, two half-lives would have passed, and the rock would be 2.56 billion years old.

Medical School - Physiology

Marc Post, a doctoral candidate, is working under the direction of Professor David C. Dawson to measure the unidirectional flux of Na^+ ions across turtle colon epithelium. Tissues are mounted as flat sheets separating two compartments of a plexiglass chamber. The sodium ion flux across the tissue is measured by adding radioactive sodium tracer ions to one compartment and sampling the other for radioactivity. The reactor is utilized to produce the radioactive sodium ions. Determination of the unidirectional sodium ion flux at different ambient concentrations enables the researchers to test hypotheses regarding the mechanisms of transcellular sodium ion movement. The title of Mr. Post's thesis is "Baselateral Na^+/H^+ Exchangers and Na^+ Channels".

NEUTRON ACTIVATION ANALYSIS

Medical School - Internal Medicine

Professor Steven J. Weiss and Vivek Reddy, a student researcher, are utilizing neutron activation analysis to measure organically bound chlorine and bromine in serum and milk. Initial samples are being irradiated and analyzed to test the methodology and limits of detection. Chemical separation techniques are being applied prior to irradiation to maximize sensitivity. If sufficient sensitivity can be attained, the methods developed may be applied to a variety of bodily fluids to test for environmental exposure to chlorinated and brominated chemical agents.

Medical School - Pediatric Cardiology

Professor Robert J. Levy and two students, Jim Boyd and Yash Pathak, are utilizing neutron activation analysis to detect iron in pericardium tissue. The project is an extension of initial research conducted by Dr. Levy to prevent calcification of transplanted pericardium tissue. Tissue samples are soaked in aqueous iron solutions; then implanted into rats. The rats are later sacrificed, the tissue recovered, and the amount of calcification determined. The iron analysis is performed to determine the initial iron concentration in the tissue.

NEUTRON RADIOGRAPHY

Chemical Engineering

Professor H. Scott Fogler and Jay Jasti, a post doctoral researcher, are utilizing neutron radiography at E beamport to study flow of oil and water through porous media such as sandstone (SiO_2).

COBALT-60 IRRADIATION SOURCE

Biophysics Research Division - Institute of Science and Technology

Dr. Jan Fronk, a post doctoral researcher, and Professor John P. Langmore, Biology Department, are irradiating cell nuclei from sea urchin embryo. They are investigating DNA structural changes caused by gamma irradiation.

Physics

Dr. H. Richard Gustafson, an associate research scientist in the Physics Department, is irradiating epoxy compounds and plastics with cobalt-60 gamma rays to observe radiation damage. The materials being irradiated will be used in the fabrication of electronics and detector components for the superconducting supercollider (SSC).

FEATURE ARTICLE

$^{40}Ar/^{39}Ar$ Age Dating of Rocks

Since the scientific study of geology began more than two hundred years ago, scientists have attempted to determine the age of the earth. In the latter half of the nineteenth century, the earth's age was estimated utilizing a conductive heat flow model developed by the British physicist, Lord Kelvin, based on an initially molten planet. From the model, he concluded that the earth was between 20 and 40 million years old.

The discovery of radioactivity by Becquerel in 1896 laid the foundation for direct measurement of the physical age of rocks and led to the development of the field of geochronology by isotopic dating.

The element, potassium, is utilized in age dating. Potassium is the eighth most abundant element; approximately one percent of the earth's crust is potassium. Natural potassium is composed of three isotopes: ^{39}K which is stable and 93.3% abundant; ^{41}K which is stable and 6.7% abundant; and ^{40}K which has a trace abundance of 0.012% and is radioactive with a half-life of 1.28 billion years. Radioactive ^{40}K is the key to age dating. If the amount of ^{40}K were known when a rock originally crystallized and the current amount were known, the decay time, which would be the age of the rock, could be calculated quite simply. For example, based on the half-life of 1.28 billion years, if the original amount of ^{40}K in a rock were 1,000 atoms and the current number of atoms were 500, half of the original atoms would have decayed (one half-life), and the rock would be 1.28 billion years old. If the current number of atoms were 250, two half-lives would have passed, and the rock would be 2.56 billion years old.

The current amount of ^{40}K in a rock is determined analytically by measuring the total potassium utilizing techniques such as atomic absorption and x-ray fluorescence and calculating the amount of ^{40}K based on its abundance.

The original amount of ^{40}K cannot be measured directly, but it can be implied as the sum of the current ^{40}K and the amount that has decayed. The amount that has decayed is determined by measurement of one of ^{40}K's decay products, ^{40}Ar. When radioactive ^{40}K decays, it decays to either calcium-40 (^{40}Ca) by electron emission or to argon-40 ($^{40}Ar_{(K40)}$) by positron decay. $^{40}Ar_{(K40)}$ is designated by the subscript, (K40), and is called radiogenic argon because it comes from the decay of ^{40}K. The quantity of $^{40}Ar_{(K40)}$ in a rock can be measured by vacuum extraction and mass spectroscopy. The implied original amount of ^{40}K is then compared to the current level of ^{40}K to determine a rock's age. This technique is called potassium-argon (K-Ar) dating.

K-Ar dating gives reliable ages on many rapidly cooled, igneous rocks. In some cases, age determinations from apparently identical rocks have been found to be different. Age differences were caused by differences in the diffusion behavior of radiogenic argon in different mineral structures during slow cooling and during heating and cooling cycles of the rock over its lifetime subsequent to its initial crystallization.

A modification of the K-Ar dating technique was developed to decipher the detailed thermal history of a given rock and, therefore, a given region of the earth's crust. When placed in a reactor's neutron flux, some of the ^{39}K atoms in a rock sample absorb high energy neutrons and undergo transformation to activated $^{39}Ar_{(K39)}$ by the reaction, $^{39}K(n,p)^{39}Ar_{(K39)}$. The subscript, (K39), indicates the argon originates from ^{39}K. The amount of $^{39}Ar_{(K39)}$ produced can be used to calculate the amount of ^{39}K present which, in turn, can be used to calculate the current amount of ^{40}K based on fractional abundances.

$^{40}K_{original}$ -------------------> $_{+1}e^{0}$ + $^{40}Ar_{(K40)}$
Natural Decay — Radiogenic

Rock's Age

$^{40}K_{current}$: ^{39}K + $_{0}n^{1}$ ---------> $_{1}p^{1}$ + $^{39}Ar_{(K39)}$
Reactor — Activated

Natural Ratio (1:7971)

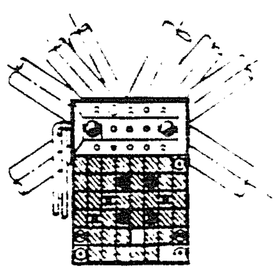
The ratio, $^{40}Ar_{(K40)}/^{39}Ar_{(K39)}$, provides, as described above, a means to measure the original to current ^{40}K ratio. Corrections must be made for absorption of atmospheric argon, conversion of some radiogenic $^{40}Ar_{(K40)}$ to ^{41}Ar in the reactor neutron flux, the fact that ^{40}K decays to both ^{40}Ca and ^{40}Ar, and the fractional production of ^{39}Ar by neutron absorption in ^{39}K, but these can be made quite accurately. This method, called argon-argon (Ar-Ar) dating, has two major analytical advantages over the K-Ar technique. Both argon isotopes can be measured using a single heating and vacuum extraction technique eliminating the need for a separate potassium analysis. In addition, isotope ratios can be measured with more precision than can the ratio of potassium to argon determined by separate analyses.

But, the major advantage of the Ar-Ar technique is: after reactor irradiation, a rock sample need not be heated to total release of the argon present. It can be heated in stages at varying temperatures to cause argon release by thermal diffusion from various depths within the sample. The argon release at each step can be analyzed isotopically and a series of apparent ages that reflect the thermal history of the rock can be determined. A wealth of information concerning the geological history of the rock becomes available rather than a single age.

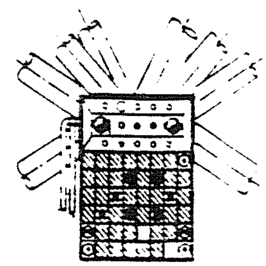
The effect of the discovery of radioactivity on age dating produced a certain irony. It destroyed the heat flow model that had been used for age dating by showing that the earth is not simply a cooling molten mass, but has an internal, radioactive energy source. At the same time radioactivity provided a means to accurately date the age of the earth which scientists now believe to be between four and five billion years.

Irradiation of geological samples for age dating is conducted at the Nuclear Reactor Laboratory for researchers from institutions around the United States including: Lehigh University, Ohio State University, the State University of New York (Albany), United States Geological Survey, the University of Georgia, and the University of Maine. Recently, Associate Professor Alexander N. Halliday of the Geological Sciences Department began a program of Ar-Ar age dating at the University of Michigan.

Much of the information in this article was extracted from GEOCHRONOLOGY AND THERMOCHRONOLOGY BY THE $^{40}AR/^{39}AR$ METHOD by Ian McDougall and T. Mark Harrison.



FORD NUCLEAR REACTOR



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 within the university of Michigan 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.

The reactor is heavily utilized by other colleges and universities, and for industrial research. Several other schools send chemistry, physics, and engineering classes for reactor and neutron activation analysis training laboratories. Neutron and gamma ray damage studies on materials such as vessel steels, neutron shield composites, and electric cable insulation used in power reactor construction are a major industrial research application.

Chemistry

Professor Henry C. Griffin is collaborating 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) fission 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 that contain radioactive 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.

Under the sponsorship of Ann Arbor Nuclear, Professor Adon A. Gordus has been carrying out a research program on the production of titanium trichloride from titanium tetrachloride using radiation. The object of the work is to produce high grade chemical energy from low grade radiation energy. The project has used both the reactor and the facility's cobalt-60 irradiator.

Eastern Michigan University Associate Professor Ellene Contis irradiated lanthanum oxide (La_2O_3) to produce lanthanum-40, a radioactive isotope that was used to determine the efficiency of an intrinsic germanium detector for a particular sample geometry. Professor Contis is conducting research related to her Ph.D. thesis at D beamport with Professor Henry Griffin. Her thesis is entitled "Assay of Fission Products".

Electrical Engineering and Computer Science

Rectifiers that can block 20 kV and thyristors that can block 10 kV are not presently available. Silicon substrates for devices with this capability must be of extremely high purity. The radial resistivity gradient must be uniform to plus/minus one percent and free carrier generation due to temperature must be suppressed.

Single crystal, P-type silicone with resistivity of 20,000 ohm-cm is neutron transmutation doped (NTD) in the Ford Nuclear Reactor to produce 500 ohm-cm, N-type silicon with plus/minus one and two percent radial gradients. The very small gradient in radial resistivity is necessary to prevent development of hot spots on thyristors through which current would flow. Melt down would result if hot spots were present. NTD devices will accommodate low temperatures (e.g., 77 degrees Kelvin). At this low temperature, free carrier generation due to temperature is greatly reduced.

Nuclear Engineering

Tim DeVol, a doctoral candidate working for Professor David K. Wehe, irradiated a small rectangular slab of material to produce a sodium-24 source for use in characterizing a radiation imaging camera response function.

The largest departmental research commitment at 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, development of low enrichment uranium reactor fuel for research and test reactors, 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 used to irradiate 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 in thorium-232.

Professor Knoll also investigated a new type of neutron detector. Tests 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 dispersions of small glass microshells (about 100 micron diameter) in plastic scintillators. The shell walls were about 1 micron thick. Helium-3 gas was trapped inside the microshells at high pressure. Protons produced in the neutron-induced reaction in the helium pass through the shell walls and create light pulses in the scintillator.

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

Professor Wehe and a nuclear engineering student, Jim Fox, performed fast flux measurements in the reactor's vertical neutron beam tube. The fast flux will ultimately be used to test proton recoil detectors. Neutron flux was measured by neutron activation of cadmium covered indium and nickel foils.

In addition, the Department of Nuclear Engineering used the Nuclear Reactor Laboratory facilities for tours, classes, laboratories, and preparation of radioactive sources associated with the following courses:

Nuclear Engineering 100	Nuclear Energy in Modern Society
Nuclear Engineering 311/312	Elements of Nuclear Engineering
Nuclear Engineering 315	Nuclear Instrumentation Laboratory
Nuclear Engineering 400	Elements of Nuclear Energy

Nuclear Engineering 445	Nuclear Reactor Laboratory
Nuclear Engineering 499	Research in Nuclear Engineering
Nuclear Engineering 515	Nuclear Measurements Laboratory

Physics

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

Mr. Joseph Rogers, a graduate student working under the direction of Dr. William E. Frieze and Professor Arthur Rich, has begun irradiation of high purity nickel to establish the potential of cobalt-58 as a positron source. When nickel-58 absorbs high energy neutrons in the reactor core, cobalt-58 is produced. Cobalt-58 is a positron emitter. Major problems associated with nickel as a positron source are high levels of radioactive interference from cobalt isotopes other than cobalt-58 that occur during activation and depletion of the cobalt-58 itself by thermal neutron absorption.

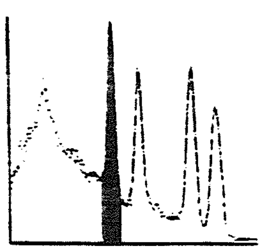
Professor Henry Griffin of the Chemistry Department has been working in cooperation with members of the Physics Department to develop techniques for chemical separation of radioactive sodium-22 from an aluminum matrix as a means of producing intense positron sources for positron research. The 800 MeV proton accelerator at Los Alamos National Laboratory produces sodium-22 almost as a byproduct of high energy proton research. Aluminum blocks are placed behind primary targets in the proton beam. Protons that do not interact with the primary target, hit nuclei within the aluminum block. By a series of (p,n-p) and (p,2p) interactions, the entire spectrum of elements from aluminum down to helium is produced from the original aluminum within the block. Of the radioisotopes produced, all are short lived except beryllium-7, carbon-14, and sodium-22.

The aluminum block which remains predominantly aluminum, but contains a large number of sodium-22 as well as other sodium atoms, is placed in an enclosed, helium filled system and heated in a graphite cup. At 98 C, the sodium melts. At 660 C, the aluminum melts and the sodium vaporizes. Aluminum and sodium have a desirable characteristic for this application in that they separate from each other very much as oil separates from water in solution. Helium circulation within the system is utilized to sweep the sodium vapor from the vaporization chamber to a condensing chamber where it is condensed on a cool plate. The condensed vapor is dissolved off the plate surface with water to produce a liquid solution containing radioactive sodium-22 that is ready for use.

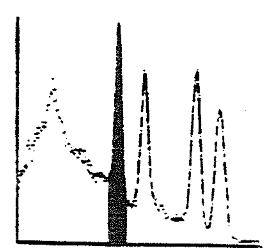
The reactor was utilized to irradiate an aluminum block and to produce sodium-24 homogeneously within the block by the reaction: ${}_{13}Al^{27}(n,alpha){}_{11}Na^{24}$. This test block was used to test the sodium extraction process. The actual sodium-22 separation will be conducted in the facility's hot cells which are shielded rooms specifically designed for handling highly radioactive materials.

Professor Byron Roe of the Physics Department sponsored the irradiation of lead fluoride crystals for the Enrico Fermi High Energy Laboratory in Illinois. Lead fluoride has been suggested as a suitable material for a Cerenkov radiation detector for the superconducting supercollider (SSC). The current irradiations were done to examine radiation hardness of lead fluoride to fast neutrons. Pure samples of lead fluoride were irradiated in the reactor's pneumatic tube system. The objective was to attain fluences of approximately $1x10^{14}$ neutrons/cm^2 from neutrons with energies greater than 1 MeV. Thermal neutron activation was minimized by encapsulating the samples in boron nitride; boron has a high absorption cross section for thermal neutrons.

Barry Wissman, a graduate student working for Professor David Gidley and Dr. William Frieze of the Physics Department, irradiated sodium chloride crystals up to $1x10^9$ rads gamma to induce stresses along cleavage planes and make cleavage easier. The crystals are used as substrates for vapor deposition of thin metal films.



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-seven 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 67 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.

Table 1 Neutron Activation Analysis Elements

Aluminum	Dysprosium	Lanthanum	Praseodymium	Terbium
Antimony	Erbium	Lutetium	Rhenium	Thulium
Argon	Europium	Magnesium	Rhodium	Thorium
Arsenic	Gadolinium	Manganese	Rubidium	Tin
Barium	Gallium	Mercury	Ruthenium	Titanium
Bromine	Germanium	Molybdenum	Samarium	Tungsten
Cadmium	Gold	Neodymium	Scandium	Uranium
Calcium	Hafnium	Nickel	Selenium	Vanadium
Cerium	Holmium	Niobium	Silver	Xenon
Cesium	Indium	Osmium	Sodium	Ytterbium
Chlorine	Iodine	Palladium	Strontium	Yttrium
Chromium	Iridium	Platinum	Tantalum	Zinc
Cobalt	Iron	Potassium	Tellurium	Zirconium
Copper	Krypton			

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 - a single user system capable of simultaneously analyzing many parameters associated with a single experiment and (2) Nuclear Data 6700 - a multi-user system which can receive inputs from many detectors associated with many experiments, but can analyze only a single parameter associated with any experiment.

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, krypton, neon, oxygen, silicon, sulfur, thallium, and xenon, techniques such as chemical concentration, filtration, special encapsulation, and special irradiation methods are necessary to perform neutron activation analysis. For the remaining elements in the periodic table, alternative analytical techniques must be utilized.

Chemical Engineering

Krishnan Balakrishnan, under the direction of Professor Johannes W. Schwank, performed neutron activation analysis of platinum-tin bimetallic catalysts

An alumina supported platinum-tin system is used in the petroleum industry as a reforming catalyst (i.e., in the production of aromatic and cyclical hydrocarbon compounds from a crude oil feed). The relative amounts of platinum and tin can affect the microstructure of the metal particles in the catalyst, which in turn can influence the product distribution, stability, and activity of the system. A small amount of chlorine, which is always present in the catalyst as a remnant of the preparation procedure, can also alter the product distribution towards isomeric compounds.

Neutron activation analysis enables the determination of an accurate value of the bulk composition of the catalyst. This information is crucial in the quantitative analysis of the various characterization techniques used to understand the catalyst mechanism. Also, it is of interest to compare the amount of these elements present in the bulk with that of surface compositions determined by other methods.

Steven Blaine, a graduate student in the Chemical Engineering Department, is investigating reaction pathways in the degradation of lubricants for his Ph.D. thesis. Mr. Blaine is using the Nuclear Reactor Laboratory's neutron activation analysis capabilities to assist in measuring the amount of aldehyde buildup in lubricants. Aldehydes are oxidation products that result from the breakdown of hydrocarbon based lubricants. Samples of lubricant are treated with Tollen's Reagent which reacts with aldehydes to precipitate silver. The silver precipitate is separated and reacted with nitric acid to form an aqueous solution. The silver content of the solution is then quantified by neutron activation analysis. The silver values are used to back-calculate the amount of aldehyde in the lubricant and thus the extent of degradation of the lubricant. Mr. Blaine is working under the direction of Professor Phillip Savage.

Professor Scott Fogler of the Chemical Engineering Department is performing research on spent shale with a grant from the Institute of Gas Technology. Spent shale is a by-product of hydrocarbon recovery from oil bearing shales. A part of Professor Fogler's research is directed at finding methods to neutralize the environmental impact of heavy metals in spent shale. One method being studied is acid leaching of the shale to remove heavy metals for recovery or separate disposal. Professor Fogler is using neutron activation analysis to help determine the effectiveness of the acid leaching process. Samples of leaching solution are being analyzed for barium and chromium, two of the metals of most concern.

Chemistry

Steve Roeder, a doctoral candidate in chemistry working for Professor Adon Gordus, utilized neutron activation analysis to assist in the determination of chemical compounds formed in a titanium tetrachloride ($TiCl_4$) system that is subjected to intense gamma radiation in the facility's cobalt-60 irradiator. The objective of the system is to convert titanium tetrachloride to titanium trichloride from which intense chemical energy can be produced, thereby utilizing low grade radiation energy to produce high grade chemical energy. Elemental analysis assists in measuring the amount of conversion that has taken place.

Professor Adon A. Gordus used neutron activation analysis to determine the yield of alkali elements reduced from alkaline chloride solutions by gamma induced radiolysis. The research is directed at finding suitable compounds for direct conversion of electromagnetic radiation (gamma radiation) into chemical potential energy.

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

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

Ms. Lorraine Yu, under the direction of Professor A.H. Francis, is investigating the physical properties of semi-conductor materials for her doctoral thesis. Transition element impurities are known to change the physical properties of semi-conductor materials. Ms. Yu is using neutron activation analysis to determine the concentrations of various transition elements in crystals of SnS_2 and $CdPS_3$ semi-conductor. The crystals, some of which are doped with transition elements, are grown in Ms. Yu's laboratory. The types and levels of impurities will be related to changes observed in physical properties such as conductivity of the semi-conductors.

Geological Sciences

Students of Professor Eric J. Essene from Geology 455, Determinative Methods in Mineralogical and Inorganic Materials, visited the Nuclear Reactor Laboratory for an introduction to trace element analysis using neutron activation analysis. The students were shown the theoretical basis of activation analysis. After the introductory lecture, the laboratory's sample analysis equipment and facilities were demonstrated.

Andrew Nyblade, a geological sciences graduate student working for Professor Henry N. Pollack, is studying radiation induced heat generation in the South and East African continent due to naturally occurring radioactive uranium, thorium, potassium, and their daughter isotopes. Radiation emanating from samples of igneous and metamorphosed igneous rocks is being measured using the gamma-ray spectroscopy facilities of the Nuclear Reactor Laboratory. The resulting gamma-ray spectra are being used to quantify the concentrations of the radioisotopes. Mr. Nyblade's samples were obtained from surface outcrops and deep mines principally in Zimbabwe.

Mr. Andrew Zimmerman, a graduate student in Geological Sciences working under the direction of Professor Robert M. Owen, is using instrumental neutron activation analysis to investigate the geochemistry of marine sediments from the Indian Ocean basin to establish their geological history. This study is a part of Mr. Zimmerman's doctoral research.

Kelsey Museum of Archaeology

Ms. Elizabeth Higashi is researching the characteristics of conical glass vessels that were unearthed in Karanis, Egypt. These archaeological specimens were excavated by University of Michigan Researchers in the 1920's and 1930's at Karanis which is an archaeological site approximately thirty miles from Cairo in the vicenity of present day Sayoum, Egypt. The glass vessels and fragments were brought back to the University and are now a part of the extensive Egyptian collection at the Kelsey Museum. Ms. Higashi is having trace element analysis performed on selected specimens in an attempt to characterize the glass type used to make the vessels. If the glass composition is found to be unique to Karanis, this information may be helpful in classifying other archaeological glass specimens found in the region.

Nigel Pollard, a graduate student in Archeology, is researching the origins of large ceramic transport amphoras that were recovered from the ancient town of Karanis. Amphoras were used in ancient times to transport commodities such as wine and olive oil. Recovered amphora fragments are being classified by fabric, the macro and microstructural features in the fragments, and also by chemical composition. The Kelsey Museum is looking to match the amphoras found in Karanis with known sources of the vessels and with other finds in the Mediterranean region. The information gained may help unravel ancient trading patterns. Neutron activation analysis is one method being used to help determine the chemical composition of the amphoras.

Medical School - Biological Chemistry

As part of research funded by the National Institutes of Health, Mr. William Epperly, a doctoral candidate working under the direction of Professor Eugene E. Dekker, utilized activation analysis on samples of the enzyme, threonine dehydrogenase. It is believed that the enzyme requires bound metallic ions such as zinc in order to function as a metabolic agent. The analysis will be used to help characterize threonine dehydrogenase by providing qualitative and quantitative information on the metals present in the enzyme.

Ms. Sonya Roman is studying the concentration of platinum in the ear and in kidneys that is a side effect of the administration of the cancer treatment drug, cisdiaminedichloroplatinum. Elevated levels of platinum in the cochlea of the inner ear and in the kidneys are known to cause both hearing loss and kidney damage. Neutron activation analysis is being used by Ms. Roman to determine the platinum uptake in the cochlea and in kidneys of guinea pigs as a function of dosages of cisdiaminedichloroplatinum. Ms. Roman is a Biological Chemistry Department doctoral student under the direction or Dr. Jochen Schacht.

Medical School - Pediatric Cardiology

Quantative analyses for aluminum in laboratory animal pericardium tissue using neutron activation are being performed for Dr. Robert J. Levy, Department of Pediatric Cardiology. Calcification of pericardium tissue is a major problem affecting the longevity of artificial heart valve implants in children. Aluminum is known to inhibit calcification. The analyses are being used to find the level of aluminum in pericardium tissue that will inhibit calcification thus leading to development of longer lasting artificial heart valves.

Museum of Anthropology

Mr. Timothy R. Pauketat, a graduate student in the Department of Anthropology, is using neutron activation analysis along with thin section observations to classify pottery shards collected from the Cahokia Site in south western Illinois. The Cahokia Site, located on the eastern shore of the Mississippi River across from present day St. Louis, Missouri, was the center of the Cahokia Chiefdom from approximately 900 to 1300 A.D. Mr. Pauketat is researching the regional dynamics of the Cahokia Chiefdom for his doctoral thesis. The specific objective of the pottery study is to classify shards as being of local or distant origin by analysis of the mineralogical and chemical make-up of the pottery clay. From this information inferences may be made about trading relationships between the Cahokia Chiefdom and other Native American tribes in the region. Mr. Pauketat is conducting Ph.D. research for Professor Henry Wright. His thesis is entitled "Regional Dynamics of a Chiefdom".

Nuclear Engineering

The Nuclear Engineering Department utilized the Laboratory's gamma energy spectroscopy facilities for two formal courses. The NE 445, Reactor Laboratory, under Professor David K. Wehe performed activation analysis on bare and cadmium shielded iron wires in order to characterize the axial neutron flux of the Ford Nuclear Reactor. NE 499, Research in Nuclear Engineering, taught by Professor Dietrich Vincent, performed two experiments using the Laboratory's spectroscopy facilities. One experiment was performed to familiarize students with qualitative and quantivative analysis utilizing gamma ray induced x-ray fluorescence. The second experiment determined the diffusivity of gold in copper by neutron activation analysis of sections of a copper ingot into which gold had been diffused.

School of Public Health

Professor James Martin, under contract from Consumers Power Company, is performing analysis of resins, water samples and smears. The samples are associated with Consumers Power spent reactor fuel storage facilities. Dr. Martin is using passive counting to analyze the samples for the fission product cesium-137. Neutron activation analysis is being used to measure iodine-129 concentrations in Iodine extractions obtained from the samples.

COBALT-60 IRRADIATION SOURCE

The 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; studies of radiation effects on mutation of cells, chemical systems, electronic and reactor components, food, seeds, and plants.

The peak dose rate at the center of the source is about 1.32×10^6 rad/hour. Typical dose rates at distances near 25 centimeters from the source are of the order of 100,000 rad/hour and typical sterilization doses are 2×10^6 rad.

Atmospheric, Oceanic, and Space Sciences

Engineers in atmospheric, oceanic, and space sciences at the Space Physics Research Laboratory are studying radiation effects on electrically programmable read only memory (EPROM) integrated circuits. During Co-60 irradiation, operation of the computer chips is continually tested until they fail. They will be used in instrumentation such as the high resolution doppler imager (HRDI) on the Upper Atmospheric Research Satellite (UARS).

Biology

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

Professors William Anderson and Alfred Sussman irradiated oat, soybean, and corn seeds from low to high gamma doses for use in class projects for course Biology 301.

Chemical Engineering

Professor H. Scott Fogler is sponsoring a Ph.D. student, Ray Lappan, who is experimenting with the effects of polysaccharides on bacteria transport and retention in porous media. Ray Lappan is sterilizing an aluminum apparatus that is used to run leuconostac bacteria through a ceramic block to determine the transport and retention of the bacteria.

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. It can be made to react exothermally to provide concentrated chemical energy.

Dr. Gordus is sponsoring a graduate student, Steve Roeder, 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.

Medical School - Internal Medicine/Gastroenterology

A research associate working for Dr. Richard Boland is sterilizing mouse embryogenetic fibroblast cells with low doses of cobalt-60 gamma irradiation. The sterilized cells will be used as feeder cells for the production of mouse hybrodoma cells. The mouse hybrodoma cells are then used to produce monoclonal antibodies for gastric mucin in mice and rats.

Christopher Rusnell, an undergraduate student in Biology, used the cobalt-60 source to sterilize polystyrene tubes for use in invitro cell culture and transfection experiments. Mr. Rusnell is working for Dr. Jorge Gumucio.

Cell sterilizations are performed for Professor Tadataka Yamada on a regular basis for studies involving collagenase.

Physics

Barry Wissman, a graduate student working for Professor David Gidley and Dr. William Frieze of the Physics Department, irradiated sodium chloride crystals up to $1x10^9$ rads gamma to induce stresses along cleavage planes and make cleavage easier. The crystals are used as substrates for vapor deposition of thin metal films.

Marty Marcin, Ph.D., is irradiating fused silica fibers (optical fibers). They transmit ultraviolet light primarily in the blue range and are used for laser calibration of scintillator tiles on a calorimeter. The fibers are subjected to various doses of Co-60 irradiation up to $1x10^6$ rad to study the changes in their transmission capabilities.

School of Public Health - Epidemiology

Professor G. I. Higashi is conducting an ongoing test program involving schistosomiasis cercariae in an attempt to develop a live vaccine. Cercariae are irradiated up to gamma doses of 50,000 rad. The biological damage done by the radiation slows their reproduction rate. Subsequent to irradiation, the cercariae are injected into mice. Under normal circumstances, they would multiply faster than the mice's immune systems could resist them and they would be lethal. Those injected after they have been irradiated multiply slowly enough that the mice's immune systems are able to resist them.

University Hospital - Otolaryngology

Rib cartilage is harvested from human cadavers within twenty-four hours of death and frozen. The cartilage is stripped of muscular attachments, cut to size, placed in jars filled with a 0.9 percent sodium chloride solution, and the jars are sealed. Sterility is achieved by irradiation of the cartilage in the facility's cobalt-60 irradiation source. The specimens are used in reconstructive surgery of the ear and nose. Dr. Shan Baker is the director of the project; the work is directly administered by Ms. Catherine Roberts.

University Hospital - Pediatrics

Dr. Madhavan Nair sponsors a graduate student who is using HIV^+ serum in research involving killing assay work. Co-60 irradiation is used as a second method of inactivation of the serum which has been heat inactivated prior to irradiation.

University of Michigan Dearborn - Natural Sciences

Professor Miriam Zolan of the Biology Department irradiated cell cultures to various gamma doses for a study involving radiation repair and meiosis of coprinus cinereus, an ashen colored spore found on the underside of mushroom caps. Meiosis is the process used by eukaryotic organisms to produce gametes, specialized cells with half the normal complement of chromosomes that combine in sexual reproduction to create new, genetically unique individuals.

Professor Zolan is studying the molecular regulation of meiosis. She has isolated several mutant strains of coprinus cinereus that cannot repair cell damage from radiation. Two of these mutant strains also have defects in meiosis, suggesting that the two processes are linked.

Currently she is working to locate the defective gene or genes that give these mutant strains their radiation sensitivity. Once she identifies the gene, she plans to clone the gene and use it to study the genetic and biochemical control mechanisms of meiosis. She also can produce large quantities of the protein produced by the cloned gene. These biochemical tools will permit her to trace the gene's expression and its role in meiosis.

NEUTRON RADIOGRAPHY

Neutron radiography is analogous to x-ray radiography in that a beam of radiation is used to create images, generally on film. Images are formed by placing objects in the beam that alter the intensity of radiation reaching the film.

Neutron radiography can be used to complement x-ray radiography. X-rays interact with electrons in matter. The heavier the element, the larger the number of electrons around the nucleus, and the greater the amount of x-ray attenuation. While x-rays will easily penetrate light materials such as water, oil, and human tissue, they are readily absorbed by heavier materials such as aluminum, iron, and lead.

Neutrons interact with the nuclei of atoms. The effect on neutrons of a specific atom is not as predictable as is the effect on x-rays. If a general rule can be made for neutrons, it is that lighter elements tend to stop them, and they more easily penetrate heavier elements. There are many exceptions to the rule. Cadmium, gadolinium, hafnium, indium, and silver are all relatively heavy elements, and they also are excellent neutron absorbers. From an imaging point of view, neutrons tend to act just the opposite of x-rays.

Neutrons are uniquely suitable for imaging many heavy materials and for imaging light materials within heavy materials. Paint within a metal can, oil inside a steel pipe, and polyethylene imbedded in lead cannot be seen by taking an x-ray radiograph. All three can easily be imaged using neutron radiography.

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, and oil replacing water have been observed. RTNR was used to image acidizing of sandstone and the injection of woods metal into the acidized structure. RTNR also is being used to image the amount of oil left behind after water flooding and the effect of surfactants on recovery of the remaining oil. These experiments model oil recovery methods and techniques.

RADIOPHARMACEUTICAL PRODUCTION

Two radioiodine compounds, NP-59 and MIBG-diagnostic, are produced regularly 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 twice monthly for distribution within and outside the University.

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

Radiopharmaceutical Production Summary

Diagnostic radiopharmaceutical samples are produced at least four times monthly and have been shipped to 138 hospitals in 38 states, the District of Columbia, and Puerto Rico in the United States and 7 hospitals in four provinces in Canada in the past twelve months. Larger quantities of radioiodine compounds are produced as therapeutic radiopharmaceuticals for use in hospitals in Connecticut, Michigan, and Pennsylvania.

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. Currently, engine wear tests using brominated motor oil are being conducted on the General Motors Saturn engine.

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

Mondays-Friday 9:00 a.m.-4:00 p.m.
Tours should be scheduled at least 24 hours in advance.

Telephone Numbers

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

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

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