NEW RESEARCH

FORD NUCLEAR REACTOR

University of Michigan

Chemistry

Professor Henry C. Griffin is testing the production of the positron emitter, cobalt-58, by the $Ni^{58}(n,p)Co^{58}$ reaction in the Ford Nuclear Reactor.

Nuclear Engineering

Ram Venkataraman, a doctoral candidate working for Professor Ronald F. Fleming, irradiated thin circular foils of iron and nickel in the reactor heavy water tank. The objective of the experiment is to obtain the ratio of the iron-to-nickel spectrum averaged cross-sections.

Ms. Yuni Dewaraja, a nuclear engineering graduate student working under Professor Ronald F. Fleming, is studying a new technique of neutron activation elemental micro-analysis. The technique uses an instrument developed by Dr. Ronald H. Fleming of Charles Evans and Associates, Redwood City, California. The instrument combines an energy sensitive germanium gamma ray

spectrometer and an electron multiplying microscopic imaging system. In use, the source electrons for the imaging system result from beta decay in a neutron activated sample. Decay events are position correlated to the sample surface by the electron imaging system. The gamma spectrometer provides gross isotopic information about the decay events. Real time processing the two data streams for coincidence between electron imaging events and gamma spectrometer events allows position sensitive elemental analysis to be performed.

Physics

Scott Peacor, a doctoral candidate working for Professor Ctirad Uher of the Physics Department, is conducting a detailed analysis of magnetic hysterisis in single crystal ytterbium-copper-oxygen superconductors. Irradiation introduces defects that are believed to pin (hold) magnetic vortices. Mr. Peacor is investigating pinning properties with a systematic analysis of the magnetification of irradiated samples. The title of Mr. Peacor's thesis is "Thermal Conductivity of High T_c Superconductors".

Eastern Michigan University

Professor K. Rengan from Eastern Michigan University is utilizing a gas jet in D beamport for two types of experiments. In the first one, the fission products are swept out continuously with a mixture of gases. The fission products delivered to a glove box are subjected to various chemical processes. The gas then flows through a charcoal reservoir and to the building exhaust.

In the second experiment, volatile fission products are swept out of the target chamber after they have accumulated over a period of time, to simulate the equilibrium mixture of iodine activities that result from a reactor accident. All of the nonvolatile products deposit on the walls of the sampling system; some volatile products partially deposit on the walls.

The Open University, Great Britain

Geological samples were irradiated for argon-argon age dating by Professor Simon Kelley of the Department of Earth Sciences.

University of California, Santa Barbara

A detailed experiment is being implemented to investigate the effects of neutron flux at lower temperatures. This experiment is designed to assess a number of irradiation and metallurgical variables that are relevant to power reactor programs. The first is the issue of flux effects that was raised recently by the unexpectedly-severe embrittlement observed in the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory (ORNL). A second issue is that of low-temperature ($T<100°C$) embrittlement. The irradiation temperature of the HFIR vessel was 60°C, and this may also be a factor in the accelerated embirttlement. Both temperature and flux effects are of interest in order to estimate the anticipated embrittlement of commercial reactor support structures. The experiment also will examine the post-irradiation annealing (PIA) and re-irradiation embrittlement (RIE) behavior of a number of materials. The materials to be evaluated in this latter aspect of the experiment include HFIR

surveillance and unirradiated archive material and the Neutron Shield Tank (NST) from the Shippingport reactor. Finally, this experiment will provide an evaluation of the relative sensitivity of the materials used in the HFIR pressure vessel and the Shippingport NST.

The material will be irradiated in the form of microhardness discs, minitensile specimens, and small coupons suitable for examination by small angle neutron scattering.

Materials Engineering Associates

Materials Engineering Associates is utilizing the Ford Nuclear Reactor for irradiation damage studies of power reactor pressure vessel steels.

Performance Contracting

Samples of insulation and insulation packaging materials were irradiated and analyzed for elements that could pose radiation exposure hazards when activated in neutron fields associated with power reactors.

NEUTRON ACTIVATION ANALYSIS

University of Michigan

Biophysics

Neutron activation analysis is being used by Professor Ruma Banerjee to understand the mechanism of catalysis by cobalamin independent methionine synthase to determine the roles, if any, that metals may play.

Chemical Engineering

Chien Sze, a doctoral candidate working under the direction of Professor Erdogan Gulari, is utilizing neutron activation analysis to measure trace quantities of gold, chlorine, platinum, and palladium in experimental catalysts. The catalysts are being designed to combust remnant methane in exhaust emissions. Ms. Sze's thesis title is, "Methane Oxidation Over Gold Catalysts".

Michigan State University

Neutron Activation Analysis of pottery and clay samples from the O'Neil site in northern Michigan is being performed in order to address questions of prehistoric Native American exchange and population movement. An attempt will be made to determine whether all of the pottery found at the site was made from local clays or whether some was made from non-local clays and brought to the site as finished vessels. The analytical results will be used to test the hypothesis that pottery was not being produced during short-term occupations of the O'Neil site. The work is part of a master's degree project for Janet Dunn; her advisor is Professor William Lovis of the Anthropology Department.

South Dakota State University

Sustained release Al^{3+} and Fe^{3+} polymeric implantable devices are being evaluated for the prevention of bioprosthetic heart

valve calcification. Al^{3+} and Fe^{3+} in polymer samples from pre and post in vitro and pre and post in vivo studies are being analyzed for Dr. Yash V. Pathak utilizing neutron activation analysis.

NEUTRON RADIOGRAPHY

University of Michigan

Civil Engineering

Blake Tullis and his advisor, Professor Steven Wright, are using real time neutron radiography to study the role of fingering in water transport through soil. The purpose of this study is to investigate the role of fingering in the use of surfactants (detergent) to clean up petroleum spills and gasoline released from leaking underground tanks. The title of Mr. Tullis' thesis is "The Role of Fingering During Aquifer Remediation with Surfactants".

Susan Powers, a doctoral candidate working under the direction of Professor Linda Abriola-Webber, is using neutron radiography to visualize the distribution of non-aqueous phase liquids (NAPL) trapped as discreet blobs within soil samples. NAPLs are liquids, typically hydrocarbons, that are immiscible in water. This scenario is typical of the contamination resulting from a leaking underground storage tank or hazardous waste landfill. Determination of the distribution of entrapped organics will help to predict the potential extent of contamination and to provide input for the design of an efficient aquifer cleanup system. The title of Ms. Powers' thesis is "Dissolution of Non-aqueous Phase Liquids in Saturated Sub-surface Systems".

COBALT-60 IRRADIATOR

University of Michigan

Biology

Assistant Professor Rolf A. Bodmer is observing fruit fly mutations caused by low doses of gamma rays.

Mechanical Engineering

Constantine Kyriazis, under the direction of Dr. Johann Borenstein, is observing gamma ray effects on an ultrasonic sensor. The ultrasonic sensor is used in a radioactive environment as part of a robotics system. Mr. Kyriazis is using the cobalt-60 irradiator to simulate the gamma environment to which the ultrasonic sensor is subjected. He will be observing any alterations in its operational behavior.

Physics

Professor Dan Amidei is studying gamma radiation damage to silica microstrip detectors and readout electronics using the cobalt-60 irradiator. The knowledge gained during this study will be applied to radiation hardened detectors and electronics in the field of high energy physics.

Professor David Gidley is gamma irradiating polycarbonate samples to investigate the lifetime of positrons in the samples. Positron lifetime is dependent on the density and size of voids in the polymer. Gamma irradiation should break bonds, reduce the polymer chain length, and thus generate more voids. Various gamma doses and dose rates will be studied.

University Hospital - Pediatrics/Cardiology

Dr. Robert J. Levy is utilizing the cobalt-60 gamma source to sterilize polyurethane implants for use in experimental open heart surgery in dogs. The polyurethane specimens to be used will contain Sotalol, a Food and Drug Administration approved medication, for long term use in animal implants.

Michigan State University

Deming Li is studying the degradation of polycyclic aromatic hydrocarbons (PAHs) in soil for the Michigan Biotechnology Institute (Professor Henry Wang) and Michigan State University (Professor Robert Hickey). Soil is gamma sterilized prior to adding PAHs. The degradation of PAHs is observed over time. Various agents are added to the soil in an attempt to decrease the degradation time.

Michigan Technological University

Dr. G. David Mendenhall, Professor of Chemistry at Michigan Technological University, and Stephen E. Amos of Himont U.S.A., Inc. are collaborating on a research project involving gamma irradiating polypropylene in the cobalt-60 gamma irradiator. The polypropylene is stabilized against radiation damage with various additives and they are estimating the effects of these additives at various doses. They are observing the reduced chemiluminessence emission of the stabilized polymer after gamma irradiation. Light emission and reduction of physical properties are both caused by free radicals so they should be able to determine the equivalent radiation damage. The plastics being tested are used or may be used to make various products such as medical supplies that are sterilized using gamma irradiation.

Raven Biological Laboratories

Bacillus pumilus spore strips are being irradiated in the cobalt-60 irradiator to determine the lethal gamma dose value for various bacillus pumilus lots. Long term lethal dose values of some older lots are being studied to determine shelf-life of spore strips. In the future, the laboratory may be sterilizing media that will be used for culturing strips in a new culturing technique Raven Biological is developing. Various materials such as the plastics that will be used in this new culturing system will be irradiated to study the effects of gamma sterilization.

FEATURE ARTICLE
POSITRON RESEARCH AT THE UNIVERSITY OF MICHIGAN

Positron Beam Microprobe

In the past several years, condensed matter researchers have seen the introduction of a number of new techniques for the study of solids on a microscopic scale. Not only have traditional electron microscopic techniques been changing and evolving, but a number of other spectroscopies and probes have been extended to microscopic dimensions. Another technique for the study of solid state and materials science systems to microscopic dimensions utilizes positron beams. By combining a positron beam of microscopic diameter with the traditional uses of positrons in the study of lattice defects, a scanning positron beam defect microprobe might be developed that would permit a whole new range of studies of the defect and impurity structures of crystalline solids; studies which should yield information unavailable by any current methods.

One of the primary research interests for a positron microbeam is the imaging of defects associated with interfaces in solid state devices. These defects have a major influence on both the electrical characteristics of working devices, and on the failure modes of devices, whether normally or under extreme environmental conditions such as elevated temperature or high radiation. A positron microprobe would be able to produce detailed images of defect distributions in devices without any damage to them, images which would provide a much clearer picture of defect dynamics. Moreover, fine enough microprobe resolutions should be possible within a few years so that even the highest density electronic circuits currently envisioned could be studied.

Defect Imaging in Solids

The usefulness of a positron microbeam stems from two characteristics of positrons that have been implanted in a solid. These are: (1) defect sensitivity and (2) diffusion. Because of their positive charge, positrons have a strong probability of becoming trapped in negatively charged (i.e. open volume) defects in a crystal lattice. Trapped positrons can be detected in a number of ways; ways which are also sensitive to the type and size of the defect involved, as well as possibly to the presence of impurity atoms associated with the defect. The positron images are pictures of the defect and impurity structure of the lattice. In addition, it has been shown that motion of thermalized positrons in lattices can be well described by a diffusion process closely similar to that used to describe the motion of electrons and holes in semiconductors. This similarity would permit the study of dynamic charge transport mechanisms in solid state devices and of static or slowly varying structural features. The close connection of lattice structure and impurity distribution, particularly near interfaces, with the dynamic quantities (diffusion length, recombination time, and mobility) that determine the performance of solid state devices would make a positron defect

microprobe a particularly suitable method for the characterization and study of these devices.

Depth Profiling in Semiconductors

The method of depth profiling with positrons is a powerful technique for measuring defect concentration as a function of depth below a sample surface. This method has been pioneered using ordinary positron beams, but its full power would come into play when it is combined with the two-dimensional imaging capabilities of a positron microprobe. Full, three-dimensional images of defect and impurity distributions in crystals would be produced. For example, defect concentrations associated with interfaces could be imaged separately from defect concentrations in surrounding bulk material without any need to section a sample.

Depth profiling involves varying the energy of the incident positron beam to change the mean implantation depth of the particles. In this way, the particular signal under study can be measured as a function of depth from the surface and as a function of position in the rastered area (i.e. a three-dimensional image can be generated). The stopping distribution of a monoenergetic beam of positrons is similar to that found for a similar beam of electrons. It has been shown that this distribution can be reasonably well approximated by a differentiated Gaussian function, and that good depth profile results can be obtained by subtracting these distributions for different energies, provided the feature of interest is less than several microns below the surface.

Fatigue, Crack Formation, and Other Studies

Beyond the study of defects and impurities in solid state devices, there are other areas in materials science and solid state physics that would benefit from a positron microprobe.

A field of particular practical significance is the study of fatigue and precursors to crack formation. Although the defect dynamics that precede cracking are extremely complex, there is some hope that a positron microprobe might provide new insights into the underlying mechanisms. One might consider a series of defect images of an initially well annealed sample under progressively larger amounts of stress, prior to the point when cracking can be observed optically. Although many positron signals suffer from problems of saturation in the presence of large defect concentrations, others such as diffusion length do not saturate and can be used in conjunction with signals that do saturate to eliminate the problem. If the right combination of signals can be found, one might obtain a detailed picture of the changes in concentrations of various defect types in the region in which a crack is ultimately observed to occur. This would be a powerful tool in understanding the defect dynamics that lead to the formation of the crack.

Many other types of studies can be imagined that also would benefit from measurements made with a positron microprobe: (1) annealing studies of multilayer structures; (2) grain growth; (3) precipitate formation in alloys; (4) impurity segregation at defects and resulting embrittlement; (5) interfacial solubility of dissimilar materials; (6) islanding in overlayer growth; (7) effects of edges and steps on surface chemistry; (8) angular correlation

and doppler studies of bulk material and surfaces; (9) formation of electron-positron plasmas; (10) laser spectroscopy of positronium states; (11) formation of anti-hydrogen atoms from stored anti-protons; and (12) production of polarized anti-protons from polarized anti-hydrogen atoms which were formed from polarized positrons.

<u>Positron Sources</u>

At the present time the highest intensity radioactive, source-based positron beam is a copper-64 beam at the Brookhaven National Laboratory Reactor. Research programs are being conducted by the University of Michigan Physics Department to develop sodium-22 and cobalt-58 positron sources; and possibly a high activity iodine-126 source.

Sodium-22 Positron Source

Professor Henry Griffin of the Chemistry Department has been working at the Nuclear Reactor Laboratory 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 by-product 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 radionuclides produced in the Los Alamos accelerator, all are short lived except beryllium-7, carbon-14, and sodium-22. One means by which sodium-22 is produced from aluminum-27 is:

$_{13}Al^{27}\ (p,\alpha+d)_{11}Na^{22}$

The aluminum block, which remains predominantly aluminum, but contains a large number of sodium-22 and 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 that contains positron-emitting sodium-22 ready for use.

Cobalt-58 Positron Source

A project to produce cobalt-58 positron sources includes developing the methods to prepare multicurie sources of cobalt-58 and using those methods to prepare many individual sources. The development and subsequent productions are being carried out at the Nuclear Reactor Laboratory.

Tests which have been completed show that in-core locations in the Ford Nuclear Reactor can produce at least 30 millicuries of cobalt-58 per gram of irradiated nickel by the reaction:

$_{28}Ni^{58}(n,\ p)_{27}Co^{58}$

Very large amounts of nickel can be irradiated so it is technically possible to produce and maintain an inventory of one to twenty curie of cobalt-58 sources required for conventional positron beams (1 curie) and by a positron microprobe (15 curies). Irradiation of 100 gm of Ni for 100 days in an interior core location would produce about 9 curies of cobalt-58.

The conventional method of dissolving Ni metal is to use nitric acid followed by hydrochloric. An electrochemical method will be attempted that can eliminate the nitric acid because nitric acid must be removed before the chromatography, and it increases the amount of waste.

Following irradiation in the reactor, the nickel target is placed on a carbon electrode in an electrodissolution apparatus. Twelve molar hydrochloric acid is added, and the nickel is dissolved at five amperes of current for 50 hours. The hydrochloric acid solution is adjusted to nine molar. The dissolved nickel solution is drawn through an anion exchange resin at 2-3 milliliters/minute. Cobalt ions (Co^{2+}) attach to the resin; the nickel solution is passed to waste. The resin is rinsed with nine molar hydrochloric acid to remove any residual nickel. Co^{2+} ions are washed from the resin with water and collected in a centrifuge tube. The pH of this solution is adjusted to six with sodium hydroxide. The solution is drawn through a small bed of cation resin, washed with water and ammonia solution, and drawn into a plating cell where the cobalt is plated on to the tip of a copper rod over a period of about 30 hours to produce the source.

NUCLEAR REACTOR LABORATORY
Profile of Services

Neutron Irradiation Services

In-core, pneumatic tube, and beamport irradiations with high energy (fast) and low energy (thermal) neutrons. Thermal neutron range: 8×10^6 to 1.5×10^{13} $n/cm^2/sec$.

Neutron Activation Analysis

Identification of trace quantities of sixty-two elements including most metals and rare earth elements utilizing a technique that is almost non-destructive and requires very small sample volumes.

Gamma Irradiation Services

Gamma irradiations utilizing a large cobalt-60 source to sterilize bone and cartilage for reconstructive surgery and to study radiation effects on materials.

Neutron Radiography

Radiographic imaging of low density materials such as plastic, oil, water, and gasoline contained in heavy materials and porous media that cannot be imaged with ordinary x-rays.

Radioisotope Preparation

Production and distribution of large quantities of investigational drugs containing iodine-123, iodine-125, and iodine-131 to almost 150 hospitals and medical research institutions for diagnosis and therapy of adrenal gland cancer and adrenomedulla diseases.

Radiochemical Production

Preparation of bromine-82 labeled motor oil for use in engine oil economy research programs, and bromine-82 labeled toluene for use in oil refinery flow tests.

Testing Programs

Accelerated neutron and gamma aging of reactor materials; fast neutron damage effects in reactor vessel steels; and quality assurance tests of irradiated materials including neutron attenuation properties, strength, gas evolution, radionuclide content, and changes in physical parameters.

Training

Neutron activation analysis and reactor operations laboratories for university students, advanced high school students, and electric utility engineers and reactor operators.

NUCLEAR REACTOR LABORATORY DIRECTORY

Hours of Operation

Monday-Friday Sept. 1 - April 1 8:00 a.m. - 5:00 p.m.
May 1 - August 1 7:30 a.m. - 4:00 p.m.

Facilities can be made available 24 hours a day, if required.

Tours

Monday-Friday 9:00 a.m. - 4:00 p.m.

Tours should be scheduled at least 24 hours in advance

Telephone Numbers

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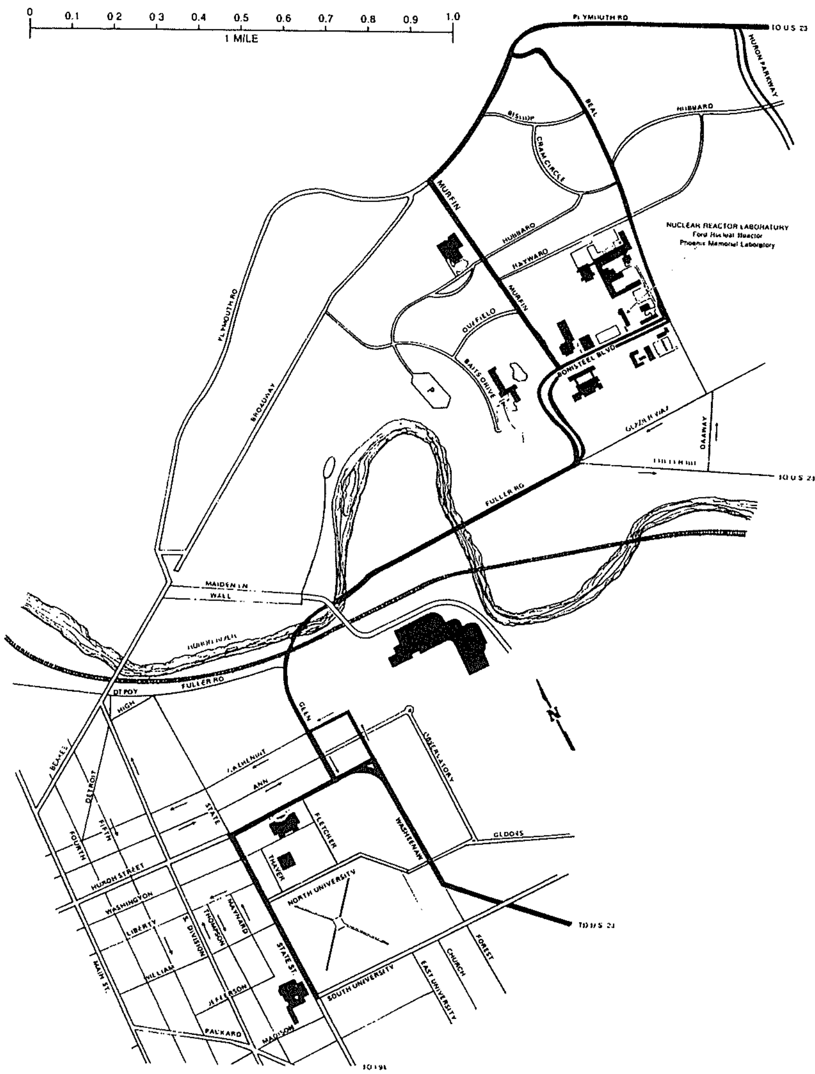

Nuclear Reactor Laboratory Location
University of Michigan Central and North Campus

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