QUARTERLY REVIEW

WINTER 1994

MICHIGAN MEMORIAL PHOENIX PROJECT
THE UNIVERSITY OF MICHIGAN

NUCLEAR REACTOR LABORATORY
FORD NUCLEAR REACTOR
PHOENIX MEMORIAL LABORATORY

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Seventh Year, No. 19

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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 to make them aware of the types of research in progress.

The Michigan Memorial Phoenix Project was founded on May 1, 1948, as a memorial to the 585 University of Michigan alumni, students, faculty, and staff members who died in World War II. The Project's charter is to explore ways and means by which atomic energy can be a beneficent influence in the life of man. Research support and services provided by the Nuclear Reactor Laboratory and a research grant program are the means by which the Project fulfills its charter.

NEW RESEARCH

FORD NUCLEAR REACTOR

University of Michigan

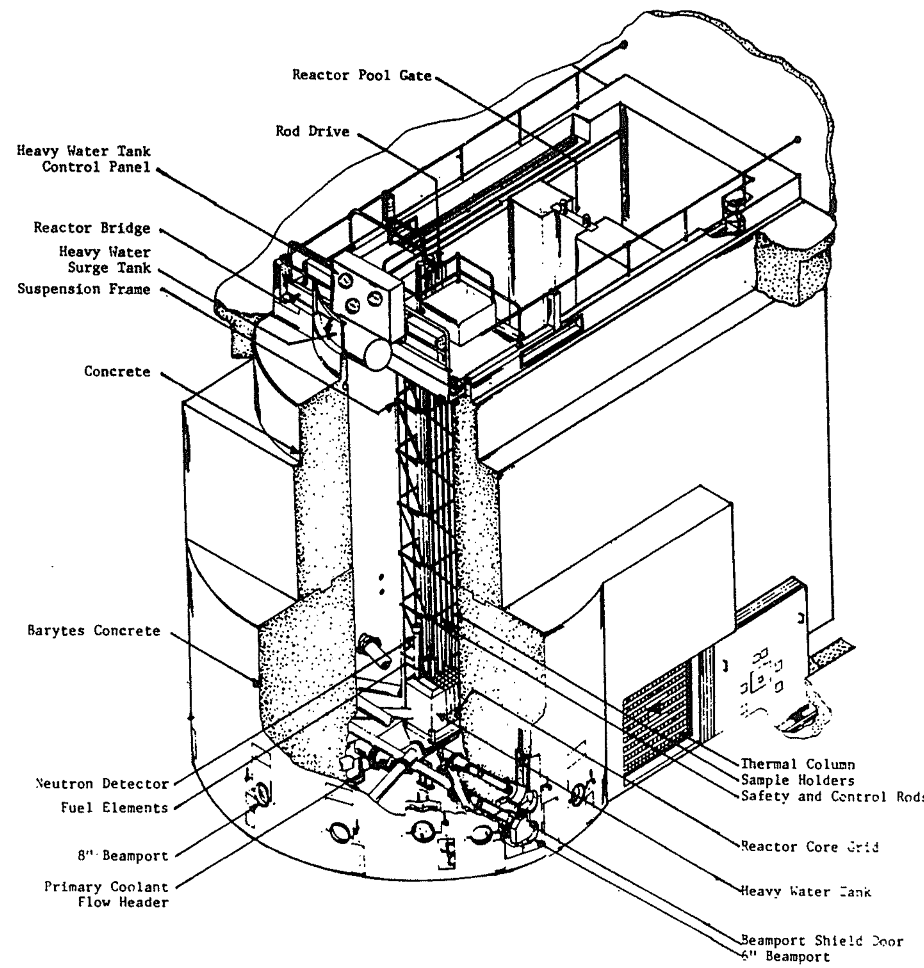
Chemical Engineering

Chris Fredd, a doctoral candidate in Chemical Engineering, is utilizing the reactor's E beamport to perform neutron radiography of flow through porous media, in particular cores containing carbonates and limestone. Mr. Fredd's advisor is Professor Scott Fogler. The title of his thesis is "Dissolution Porous Media".

Chemistry

Chemistry students Joseph Stayanoff, Jessica Ambrose, and Steven Feldgus irradiated rubidium nitrate, rubidium chloride, and cesium nitrate; dissolved the salts in an appropriate solution; and injected the solutions in a chromatographic column to study chemical separation processes. The project was sponsored by Professor Henry Griffin.

Doctoral candidates Michael Chemaly and Joseph Stayanoff performed a study of separation of mercury contamination from silver in solution. Silver nitrate and mercury nitrate were irradiated



Ford Nuclear Reactor Pool
Cutaway View

in the reactor, dissolved in an appropriate solution, and a solvent extraction process was tested. Professor Henry Griffin sponsored the work.

Nuclear Engineering

Two doctoral candidates, Jeff Martin and Jerome Gormley, performed a variety of irradiations to produce sources to characterize a Ring Compton Gamma Camera: (1) sodium hydroxide to produce a sodium-24 source; (2) copper wire to generate copper-64; and (3) cobalt wire to produce radioactive cobalt-60. Mr. Martin's thesis is entitled "Ring Compton Camera for Imaging Medium Energy Gamma Rays". Professor David Wehe is his advisor.

Dr. Menno Blaauw, a researcher from the Delph Reactor in the Netherlands, utilized a reactor beamport to determine neutron scattering effects in spheres made of glass filled with water, glass graphite, and polyethylene. Dissolved and deposited europium, lutetium, dysprosium, and holmium monitors were placed within the spheres to serve as flux monitors.

ICI Tracerco

Potassium bromide was irradiated to produce radioactive bromine-82 for use in oil well tracer tests.

NEUTRON ACTIVATION ANALYSIS

University of Michigan

Museum of Anthropology

Dr. John Alden utilized neutron activation analysis to determine the elemental composition of ceramics from a series of settlements of the Inca period in the Atacama Desert region of northern Chile. His goals are to distinguish clay compositions from each oasis and to identify patterns in the prehistoric production and exchange of pottery.

School of Public Health, Environmental Health Science

Ronald Woods, a master's degree student, irradiated soil samples to determine chlorine levels. He then determined PCB contamination levels by mathematical calculation. Professor Ronald Fleming is advising Mr. Woods. The title of his thesis is "Use of Neutron Activation Analysis to Determine PCB Concentrations in Soil".

University of Michigan, Dearborn

Chemistry Department

Robert Rood, an undergraduate sponsored by Professor John Iebessell and Dr. John Robbins of the Great Lakes Environmental Research Laboratory, is analyzing sediment samples from various lakes in the United States using neutron activation analysis. Of particular interest are contaminant metals and bromine.

Indiana University

Geology Department

Professor Andrew Barth is using neutron activation analysis to assist in geo chemical characterization of Southern California granite rocks. The geochemistry, particularly of rare earth element concentrations, provides insight into the age of the rocks and into events that lead to the formation of different granites at specific locales. Elemental concentrations and ratios provide information about the sources of magma for various granites and the geochemical processes that occurred during their emplacement and solidification.

University of Pittsburgh

Department of Geology and Planetary Science

Richard Risek is utilizing neutron activation analysis in his doctoral work. His advisor is Professor William Kneller of the University of Toledo. The title of his thesis is "Paleoenvironment Reconstruction of Harlem and Ames Coals". Elemental analyses of specimens from the Glenshaw Formation of the Upper Pennsylvanian greatly enhance the interpretation of the coals with respect to temporal and spatial changes in the depositional environment.

University of Toledo

Geology Department

Faculty and students utilized neutron activation analysis for elemental analysis related to a series of projects: (1) rock samples gathered from the St. Francois Mountains in Southeast Missouri collected by Elizabeth Light, a graduate student, and her faculty advisor, Professor V. Max Brown, for the purpose of studying the geochemistry and petrogensis of the Precambrian volcanic rocks in the mountains; (2) samples of Eocene limestone from ancient quarries in the Nile Valley, Egypt, by Professor James Harrell for a study of geochemical provenance signatures; if such signatures exist, they can be used to identify the geographic source areas of the limestone used in ancient Egyptian sculptures and monuments; and (3) samples of a variety of rock types collected from the Eastern Desert of Egypt by Professor Mohamed Askalany; the results are part of a general physico-chemical characterization of several geologic formations being mapped.

COBALT-60 IRRADIATOR

University of Michigan

Biological Chemistry

Professor Arie Goldlust irradiated human recombinant manganese superoxide dismutase protein to various gamma doses. The molecular weight of the protein can be determined by radiation inactivation based on the damage to its structure caused by ionizing radiation. The damage is reflected as a decrease in the biochemical activity and is directly proportional to the molecular weight and the dose received. Finding the molecular weight of the protein will help determine the functional size of this enzyme in humans.

Department of Otolaryngology

Dr. Michael J. Disher is sterilizing operating room sponges.

Material Science and Engineering

John Anderson, a graduate student whose advisor is Professor David Martin, is irradiating silicone impants to sterilize them for implantation in mice.

<u>Eastern Michigan University</u>

Biology Professor Paul A. Volz, Mycology Laboratory, is irradiating mutant strains of chaetomium globosum (a soil fungus) and saccharomyces cerevisiae (brewer's and baker's yeast) to study the effects of gamma irradiation as part of a student's master's thesis.

<u>Quincy High School</u>

Shannon Bair, a tenth grade student at Quincy High School, Michigan, is irradiating Brasica rapa seeds for a Junior Academy of Science presentation at Michigan State University in 1994.

<u>Concover Environmental Control</u>

Mr. Tom Nachtman, President of Concover Environmental Control, is performing irradiation of spray-on polymer material up to 1 x 10^9 rad gamma. The polymer is used in landfills to cover and contain potentially hazardous waste. If it is sufficiently radiation resistant, it could be utilized at nuclear facilities to contain and control liquid and particulate contamination.

<u>DIFCO Laboratories</u>

Dr. Leon Strenkosk irradiated AST-10 cards for research and development.

<u>Performance Contracting</u>

Performance Contracting is an industrial firm that manufactures thermal insulation for steam pipes in nuclear power plants. This project involved accelerated, lifetime-equivalent radiation and thermal aging of plastic labels that are attached to insulation. The labels were irradiated to a gamma dose of 1 x 10^8 rad over a period of approximately 370 hours and then held at 200 degrees Fahrenheit for the same period of time.

<u>Public Service Electric and Gas</u>

Polymer materials with potential applications as sealants in nuclear power plant cable runs were irradiated up to a dose of $5x10^7$ rad gamma to determine their resistance to radiation.

TRANSCO Products

Grout materials were irradiated up to a dose of $2x10^8$ rad gamma to determine their resistance to radiation.

United States Department of Agriculture

Gerald Sims is sterilizing soil samples using gamma radiation. He then tests the samples to determine the extent and rate of degradation of pesticides in the soil. He is trying to determine the mechanism for degradation of pesticides in soil.

FEATURE ARTICLE

HEAVY SECTION STEEL IRRADIATION PROGRAM

Oak Ridge National Laboratory has contracted with the Ford Nuclear Reactor to provide an irradiation facility for the Heavy Section Steel Irradiation (HSSI) Program. The HSSI program is an extension of the on-going, broader Heavy Section Steel Technology (HSST) program. The HSSI program is principally sponsored by the U.S. Nuclear Regulatory Commission. The overall goal of the HSST program is the study of the mechanical properties of thick walled pressure vessels, particularly those used as nuclear power plant reactor pressure vessels. The research results are used by the Commission to formulate regulatory guidelines for fabrication, licensing and surveillance of reactor pressure vessels.

The mechanical properties of steel are affected by many factors including chemical composition, micro-structure and grain size, dislocation density, and flaw size. The HSSI portion of the HSST program investigates how the failure characteristics of heavy steel sections are affected by neutron exposure.

Normal ductile behavior of steel occurs when dislocations are generated and move under an applied stress. As the dislocations move, some collide and become tangled making further movement more difficult. Because of this "work hardening", a higher stress must be applied before further movement occurs. The ductile deformation process can continue until the applied stress reaches a level that causes rapid growth in a "critical flaw" and brittle fracture occurs. However, during ductile deformation, a large amount of energy is absorbed. The ability to deform in a ductile manner is desirable in a reactor pressure vessel. Ductile yielding can absorb enough energy to overcome that magnitude of a suddenly applied stress, such as postulated by the pressurized thermal shock scenario, and prevent catastrophic brittle fracture.

Fast neutrons interact with steel by creating displacement cascades; trails of atoms that are knocked out of their normal lattice positions. As the density of displaced atoms increases, dislocation movement becomes more difficult; an effect akin to work hardening. In addition, the empty lattice positions that are created can diffuse through the steel and coalesce into micro-cracks. Together these effects cause embrittlement - a significant lowering of the large amount of energy that would otherwise be absorbed in ductile deformation before fracture occurs. Beyond lowering the amount of energy required to produce ductile fracture - called the "upper shelf energy" - neutron damage also increases the ductile-brittle transition temperature. Ductile-brittle transition temperature, a characteristic of ferritic steels, is a temperature below which brittle failure almost always occurs. Above the transition temperature, normal ductile behavior with its attendant ability to absorb a large amount of energy prior to fracture is exhibited. A typical structural steel has a ductile-brittle transition temperature of about 45 degrees Fahrenheit. Large amounts of neutron damage to a reactor vessel can raise the

transition temperature to 150 degrees Fahrenheit or more; a point where pressurized thermal shock becomes a realistic concern.

Pressurized thermal shock is the most severe postulated event that can affect a pressurized water reactor. Briefly, the scenario is as follows. A reactor coolant pipe ruptures when the reactor is operating under normal conditions at a pressure of about 2,300 psig and a temperature above 550 degrees Fahrenheit, well above the ductile-brittle transition. The rupture results in rapid loss of primary coolant, de-pressurization, and initiation of the emergency core cooling systems. The emergency core cooling water is at a much lower temperature than the vessel. This causes the vessel to cool. After the pipe rupture is isolated, heating from decay of residual fission products in the fuel causes the now cool vessel to rapidly re-pressurize. The rising pressure imposes a large stress on the vessel. This reapplied stress may be high enough to cause catastrophic brittle failure if, because of neutron damage or other factors, the vessel was cooled below its ductile-brittle transition temperature. Whether or not catastrophic failure occurs depends on a crack being present in the vessel that is larger that the "critical flaw size" for the applied stress. The higher the stress, the smaller the critical flaw size becomes. A catastrophic brittle failure of the pressure vessel would result in a loss of primary containment for the reactor core, severe core structural damage, a greatly inhibited ability to remove the residual decay heat, and possibly, a meltdown.

Under the HSSI program, test specimens of the steels used to fabricate reactor pressure vessels are irradiated in the neutron flux of the Ford Nuclear Reactor. The irradiation program is designed to simulate various stages in vessel life. At the reactor,

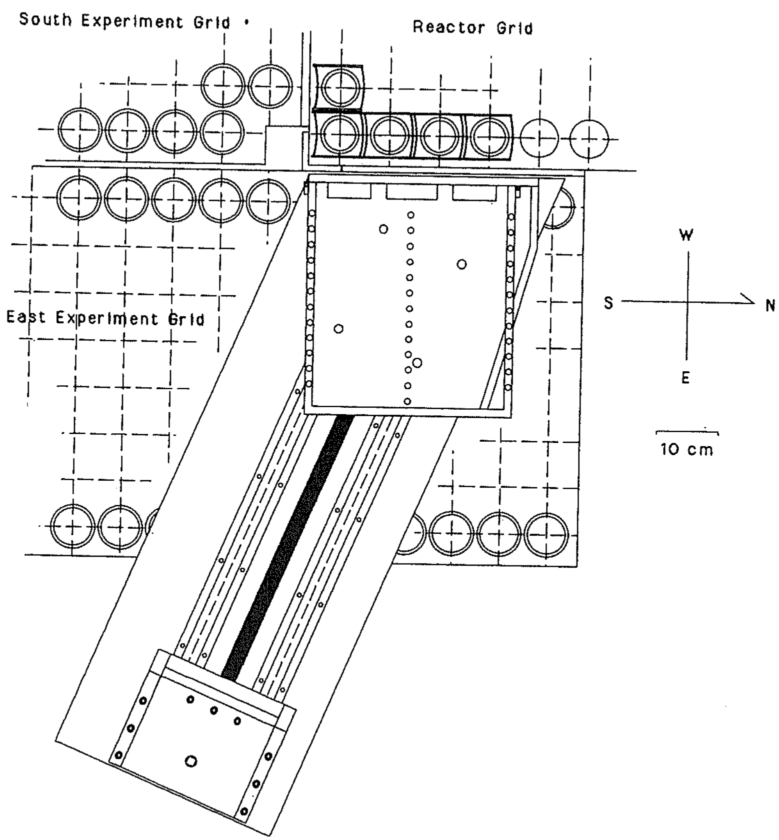


Figure 1
Schematic of Heavy Section Steel Irradiation Facility

test specimens are exposed to a flux level that is 10 to 50 times that experienced at a power plant. With this high exposure rate, the equivalent of up to forty years service can be created by an irradiation of between nine months and two years. Forty years is the minimum design life for a reactor pressure vessel.

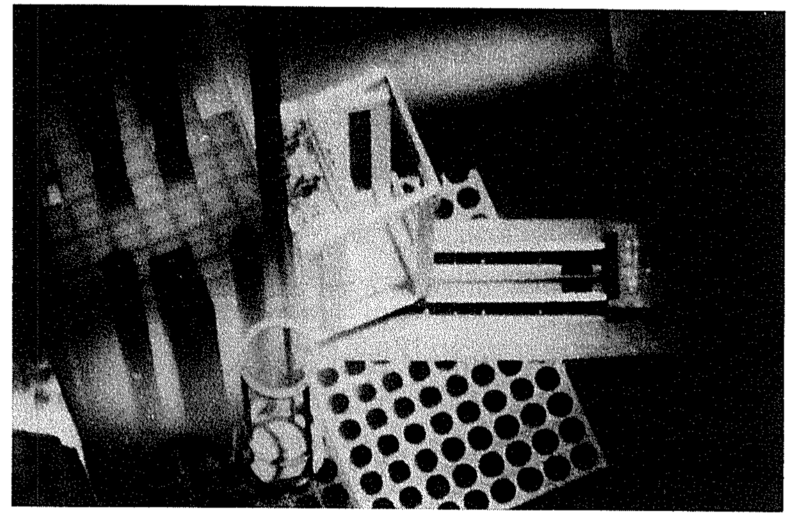


Figure 2
Heavy Section Steel Specimens in Place Against
East Reactor Face

A variety of test specimen types are being irradiated. These include: 1) tensile bars which allow the yield strength (the applied stress at which ductile deformation begins) and the ultimate tensile strength (the higher stress at which the speicmen fractures due to work hardening) to be measured; 2) Charpy V notch specimens which are used to determine the ductile-brittle transition temperature and lower and upper shelf energy (the energy required to break the specimen below and above the transition temperature); 3) crack arrest specimens which measure the stress and energy required to cause a pre-existing crack to propagate; and 4) compact tension specimens which measure fracture toughness (the stress level at which a thick specimen due to geometric effects fails in a brittle rather than ductile manner).

The irradiation facility at the Ford Nuclear Reactor is unique in that relatively large compact tension and crack arrest specimens can be accommodated. The large capacity allows specimens that actually mimic the steel in six to eight inch thick reactor pressure vessels to be irradiated and tested. Measurements made on large test specimens more accurately reflect the true characteristics of a pressure vessel inasmuch as geometric correction factors are minimized or even eliminated.

Beyond the irradiation facility itself, Oak Ridge National Laboratory has fabricated an elaborate console for controlling and monitoring the specimens during irradiation. Specimen irradiation is performed at an average temperature of approximately 550 degrees Fahrenheit. The elevated temperature is necessary for the specimens to accurately reflect the conditions in a power plant reactor pressure vessel. At 550 degrees Fahrenheit, thermal energy available in the vessel steel causes diffusion of displaced atoms and eliminates a significant fraction of the neutron damage through self-annealing. The atom diffusion rate and, in effect, the rate of self-annealing are exponential functions of temperature. Irradiation at a much lower temperature, such as the typical Ford Nuclear Reactor pool temperature of 110 degrees Fahrenheit, would result in specimens with a great deal more neutron damage than would occur in the pressure vessels that are being simulated. For the same reason, the irradiation temperature cannot be allowed to exceed the design temperature, otherwise the amount of neutron damage will be understated relative to an actual pressure vessel. The console maintains the specimen capsule irradiation temperature through a combination of reactor gamma heating, electrical zone heating, and control of heat loss from the capsule.

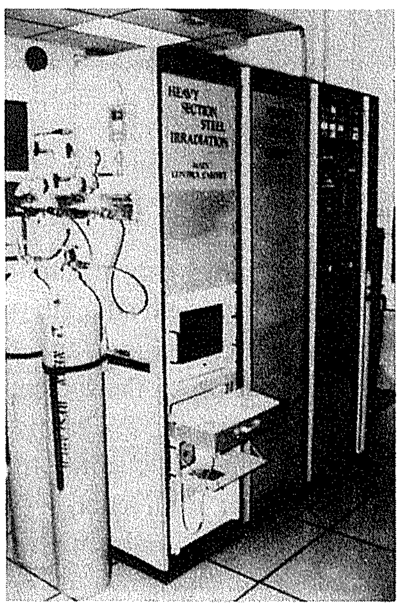


Figure 3
Heavy Section Steel Irradiation
Control and Monitoring Cabinets

In addition to studying the embrittlement effects of accumulated neutron exposure, the HSSI program will investigate the possibility of extending a pressure vessel's life. Future specimens will be irradiated and subsequently annealed at temperatures that can be realistically achieved in a pressure vessel with the reactor shut down. A portion of the specimens will be tested to see how well the steel recovered. Others will be re-irradiated to examine how embrittlement behavior might change following a vessel anneal.

To date, a mock-up capsule to measure the fast neutron fluence rate and one capsule of actual test specimens have been irradiated. A second capsule is currently being irradiated and is well on the way to completion. Although not yet funded, many more capsule irradiations are planned.

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.

Radiopharmaceutical Preparation

Production and distribution of large quantities of investigational drugs containing iodine-123, iodine-125, and iodine-131 to 154 hospitals, in 41 states, D.C., and Peurto Rico as well as 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, argon-41, sodium-24, and lanthanum-140 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 30 8:00 a.m.- 5:00 p.m.
May 1 - Aug. 31 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 48 hours in advance.

Telephone Numbers:

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Radiochemical Production

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Cobalt-60 Irradiation
Radioisotope Preparation

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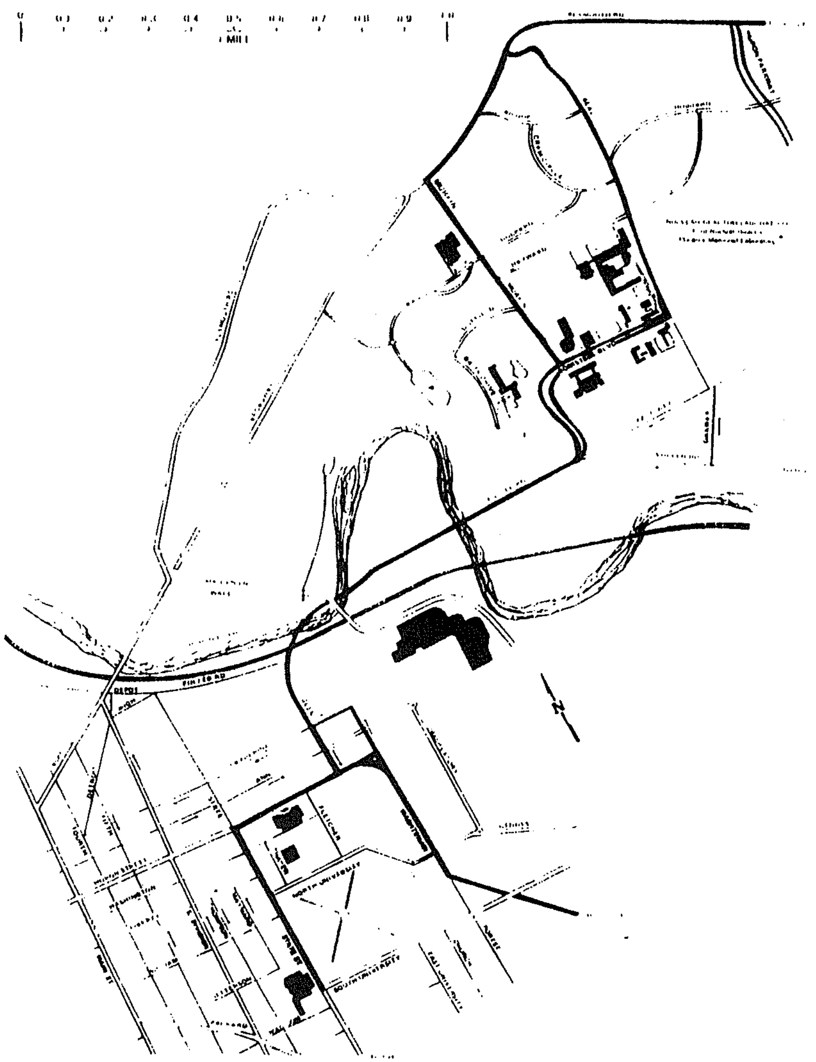

Nuclear Reactor Laboratory Location
University of Michigan Central and North Campus

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