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MASTER

EDUCATIONAL AND RESEARCH ACTIVITIES

For the Period

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FORD NUCLEAR REACTOR

MICHIGAN MEMORIAL-PHOENIX PROJECT

THE UNIVERSITY OF MICHIGAN

Ann Arbor

May 1970

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ABSTRACT

During 1969, the Ford Nuclear Reactor (FNR) at The University of Michigan continued to serve as an integral part of the educational and research activities of the University. It also served other schools, hospitals, and industrial research organizations. By maintaining the continuous operating schedule of the reactor for the majority of the year and by improving laboratory and reactor irradiation facilities, the amount and types of services available to facility users were extended.

I. INTRODUCTION

The Ford Nuclear Reactor is operated by the Michigan Memorial-Phoenix Project of The University of Michigan. The Project, established in 1948 as a memorial to students and alumni of the University who died in World War II, encourages and supports research on the peaceful uses of nuclear energy and its social implications. In addition to the Ford Nuclear Reactor, the Project operates the Phoenix Memorial Laboratory (PML). These research laboratories, together with the Project's faculty research and graduate fellowship granting programs, are the means by which the Project carries out its purpose.

II. FACILITY OPERATION

General Operation

In January, 1966, a continuous operating cycle was adopted for the FNR at its licensed power level of 2 megawatts. This cycle consists of approximately 25 days at full power followed by three days of shutdown maintenance. The continuation of this cycle during the majority of 1969 made the FNR available for use approximately 82% of calendar time. The continuous schedule was temporarily suspended during the summer months of July and August. The following tabulation reviews the over-all utilization of the reactor during the past four years.

	<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>
Operating Hours	7566	7818	7820	7220
Accumulated Megawatt Hours	14,400	14,797	14,723	13,610
Experimental Utilization (experiment hours)	126,687	100,279	101,293	93,319
Teaching Utilization (hours)*	902	797	1540	960
Reactor Availability (% of calendar time)	86%	89%	89%	82%

*Those experiment hours accumulated in support of formal university courses utilizing the reactor.

The experimental utilization of the reactor is primarily composed of three major types of irradiations:

- a. the use of the reactor beam ports in neutron spectroscopy and other types of "beam" experiments. Six of the eight available ports are so used;
- b. the irradiation of various types of samples for periods of one cycle or less;
- c. the irradiation of small targets for many cycles for use as gamma sources in spectrographic studies.

The long-term presence of this last type of sample in the core tends to bias the effectiveness of using the experiment-hour as a measure of reactor utilization. The following is a comparison of the experiment-hours accumulated on the reactor after the long term irradiations have been subtracted.

	<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>
Experimental Utilization	73,247	76,825	76,264	67,368

As can be seen from the above, the over-all utilization of the reactor for all types of experiments was reduced somewhat during 1969. A major cause of this utilization reduction can be traced to reductions in the size of the graduate student body at the University as well as reductions in University research programs.

Fuel and Heavy Water Consumption

The operating core configuration for the FNR was increased in size during 1969 in order to reduce fuel element usage during 1969. Standard fuel element burn-up levels of approximately 18% are still obtained, while control elements are retired after a burn-up level of 36% is reached. These replacement levels in conjunction with the current operating schedule resulted in the use of 6 control and 24 standard fuel elements.

In 1969, the use of the Heavy Water Reflector Tank on one face of the FNR core required a throughput of 450 pounds of heavy water. Fresh heavy water is used to replace heavy water in the tank as the tritium level reaches the limit imposed by the reactor operating license.

Services

During 1969, the FNR continued to cooperate with the Phoenix Memorial Laboratory in producing radioisotopes and providing neutron activation analysis to research groups within the University, groups from other schools, and industrial research organizations.

The radioisotopes produced included:

170 samples containing a total of 17 curies of Bromine-82 labelled motor oil for engine oil consumption studies, and

71 samples containing 710 millicuries of sterile, carrier-free Fluorine-18 for medical research.

PML provides assistance to local hospitals by supplying them with short-lived Fluorine-18 isotope (1.87 hour half-life) used for bone scanning. To date, the following hospitals are being served:

1. U of M hospital - Ann Arbor, Michigan
2. Veterans Administrative Hospital - Ann Arbor, Michigan
3. Hurley Hospital - Flint, Michigan
4. Henry Ford Hospital - Detroit, Michigan
5. William Beaumont Hospital - Royal Oak, Michigan
6. St. Joseph Hospital - Ann Arbor, Michigan
7. Wayne County Hospital - Detroit, Michigan

33 samples containing 16.5 millicuries of Potassium-42 for medical research, and

8 samples containing 480 millicuries of Sodium-24 for industrial tracer work.

Due to the need for high concentration, alumina free ^{99m}Tc , not available through the use of commercially available ^{99}Mo - ^{99m}Tc generators, an investigation of a possible solvent extraction production of ^{99m}Tc has been pursued. This work is nearing completion and is expected to provide the University of Michigan Medical Center with high concentration, alumina free, Technetium-99m for research and diagnostic applications.

The neutron activation analysis services offered included the processing of 2500 samples of beta alumina to determine the sodium contamination levels, and a feasibility study of oil analysis to test for metal-to-metal oil seal wear.

Special Education Programs

The Phoenix Project sponsored a two-day special course on "Trace Element Analysis with Neutron Activation in Metals, Plastics, Rubber, Semiconductors, and Chemicals." This course was offered to engineers and scientists in industry to provide them with information about applications of activation analysis to industrial problems. The staff for the course included the following scientists in the field of activation analysis.

Professor John Winchester
Department of Meteorology and Oceanography
The University of Michigan

Dr. Oswald Anders, Associate Scientist
Radiochemistry Research Laboratory
Dow Chemical Company
Midland, Michigan

Dr. Richard Marsh, Scientific Research Staff
Ford Scientific Laboratory
Ford Motor Company
Dearborn, Michigan

The Nuclear Reactor and Phoenix Laboratory facilities were used to demonstrate some of the state-of-the-art techniques and equipment.

Public Education Programs

The Phoenix Laboratory remained active in its program of assistance to other schools. An all day series of lectures and tours was presented to a group of honor students from Grand Rapids Jr. College. Guided tours of the facility were given to over 6,000 students and interested non-students during the year. During an Engineering College Open House Weekend, a total of 1,200 persons toured the facilities.

Higher Power Level Studies

In order to increase the utility of the reactor to University research groups, a study was initiated late in 1967 to determine the feasibility of operating the FNR at power levels as high as 10 megawatts. This study was continued during 1968 and 1969.

Such an increase in power level would enable University research groups, particularly the Physics and Nuclear Engineering Departments, to expand significantly their

research programs. The activation analysis programs of the Chemistry and the Meteorology & Oceanography Departments would also be broadened. The continued assistance of the AEC in fuel and heavy water requirements will be a major factor in any contemplated power level increase for the FNR.

III. FACILITY UTILIZATION BY UNIVERSITY DEPARTMENTS

General

During 1969, more than 95% of the utilization of the reactor was by student and faculty researchers from teaching departments in the University. The following tabulation compares the utilization by University groups for 1969 with 1966, 1967, and 1968.

<u>UNIVERSITY DEPARTMENT</u>	<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>
<u>Nuclear Engineering</u>	31,964	41,397	38,410	41,568
<u>Physics</u>				
Long term irradiations	53,041	23,454	25,029	25,951
Short term irradiations	24,216	18,175	19,226	9,928
<u>Chemistry</u>	9,987	6,449	5,427	7,150
<u>Other Departments</u>	1,171	2,817	1,729	4,593
	120,379	92,292	89,821	89,190
 Total Experimental Utilization for the year	 126,687	 100,279	 101,293	 93,319

While the departments of Physics, Nuclear Engineering, and Chemistry were the largest users, the departments of Environmental Health, Chemical and Metallurgical Engineering, Geology and Mineralogy, Meteorology and Oceanography, Biology, Zoology, The Rackham Arthritis Research unit, and the Kresge Radioisotope unit of The University Medical Center also made use of the reactor.

A further indicator of the level of utilization of the reactor is the number of transfers of radioactive materials from the reactor to other units of the University by Radiation

Control Service, the University's radiological safety organization, as well as the transfer of such materials to licensed organizations outside of the University. These are summarized below:

	<u>1964</u>	<u>1965</u>	<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>
Transfers to U of M Units	192	160	414	586	400	467
Transfers to other Organizations	70	124	263	358	405	541

Nuclear Engineering Department

The Nuclear Engineering Department, presently the largest user of the reactor in terms of experiment hours, has the largest commitment of faculty, graduate students, and equipment to research projects at the facility. The department also uses the facility in several formal courses.

The research programs that use the reactor are primarily neutron spectroscopy, radiation effects, and measurement of reactor core parameters.

In support of the programs in neutron spectroscopy, the department has built and operates:

- a. a triple axis crystal spectrometer for neutron inelastic scattering measurements;
- b. a four rotor velocity selector for neutron inelastic scattering measurements;
- c. a polarized beam crystal spectrometer for neutron elastic scattering measurements on magnetic materials;
- d. a fast neutron spectrometer using polyethylene radiators and solid state detectors for measuring fast neutron spectra.

During 1968, a new crystal spectrometer was designed, built, and installed for general purpose neutron scattering measurements. This unit which went into operation during 1969 replaced an older unit which had been used for the past several years. Plans for its use include Summer Engineering Institutes for the training of practicing engineers and scientists in the applications and techniques of neutron spectroscopy. A small neutron chopper was developed and successfully operated for use at this spectrometer.

The triple axis crystal spectrometer was in continuous operation throughout 1969. Research using this equipment was primarily directed towards study of the lattice dynamics of single crystal targets of: ZnS and CaWO_4 .

The velocity selector was being rebuilt most of the year to obtain greater beam intensity. A new port plug was installed, and all systems were revitalized. Measurements indicated that the anticipated beam intensity increase of about 5 was obtained. Improved detectors led to a still greater increase in counting rate.

The chopper was used to determine the transmission of a Li^6 -loaded neutron scintillating glass neutron detector, which was used as the primary standard for absolute counting of neutrons in the pulsed moderator studies by K. F. Graham. The chopper was also used by an undergraduate student to measure the port leakage spectrum.

The following is a list of personnel in the neutron spectroscopy program and their publications and activities during 1969:

Faculty and Staff:

Prof. J. Carpenter
Prof. J. King
Prof. D. Vincent

Students:

T. Sampson	PhD, 1969
L. Feldkamp	" "
N. Lurie	" "
E. Gurmen	PhD Candidate
G. Sherwood	" "
D. Steinman	" "
D. Mildner	" "
N. Vogelatos	" "

Publications:

1. "Study of the Lattice Dynamics of Deuterated Polyethylene and Zinc Sulfide Using Coherent Neutron Scattering," L. A. Feldkamp, Phd Thesis, University of Michigan, (1969)
2. "Lattice Dynamics of Cubic Zinc Sulfide," L. A. Feldkamp, G. Venkataraman, and J. S. King, Solid State Communications, 7, 1571 (1969).
3. "Attenuation Correction Factor for Scattering from Cylindrical Targets," J. M. Carpenter, Rev. Sci. Inst., 40, 55 (1969).
4. "Pulsed Moderator Time-Dependent Neutron Spectra Using a Time-Focussed Crystal Spectrometer," J. M. Carpenter and K. F. Graham, Trans. Am. Nuc. Soc., 12, 191 (1969).

5. "Quasielastic Scattering of Thermal Neutrons by Liquid CH_3OH and CH_3SH ," T. E. Sampson and J. M. Carpenter, J. Chem. Phys., 51, 5543 (1969).
6. "Low-Energy Neutron Scattering from Hydrogen Chloride," N. A. Lurie and J. M. Carpenter, to be published in The Physical Review (1970).
7. "Thermal Neutron Inelastic Scattering by Methyl Alcohol and Methyl Mercaptan," T. E. Sampson, PhD Thesis, University of Michigan, (1969).
8. "Slow Neutron Scattering by Molecular Gases," N. A. Lurie, PhD Thesis, University of Michigan, (1969).

In research on radiation effects, the departmental programs stress the study of thermal neutron capture recoil damage. Targets irradiated in the reactor are analyzed for radiation effects by observing their thermo-luminescence spectra, electrical conductivity changes, electron spin resonance characteristics, and Mössbauer spectra. No publications for 1969 have been reported by this group.

The research program to determine the absorption cross sections of radioactive nuclei, initiated in 1968, progressed satisfactorily during 1969. As part of this program, a large sample rotating device for the long term irradiation of sample targets was completed and tested. This device should be put into use in 1970 on a regular basis.

A program in neutron radiography was started in 1969. A vertical beam facility was designed and installed using the heavy water reflector tank as a source. This facility provides a neutron beam with low gamma ray content and sufficient neutron intensity to permit extremely high resolution performance. At this time, the application of this facility is primarily directed towards problems in the fields of biology and medicine.

During 1969, a departmental program in fission fast neutron cross section measurements got underway. During 1970, it is expected that this program will make heavy use of reactor irradiation facilities for the preparation of large gamma ray sources.

The Nuclear Engineering Department also uses the reactor in conjunction with six formal courses:

NE 415: Radiation Detection and Measurement - I

In this course, the reactor is used as a source of short-lived radioactive sources.

NE 416: Radiation Detection and Measurement - II

This course, which requires NE 415 as a prerequisite, concentrates on individual student projects, many of which use the reactor.

NE 425: Applied Nuclear Radiation

This course is concerned with the technical application of radioisotopes and nuclear radiations. The reactor is used to provide sources for laboratory experiments.

NE 445: Nuclear Reactor Laboratory

In this course, experiments are performed to measure core power densities and fluxes, shim-safety rod calibrations, void coefficients, critical experiments, shutdown power, xenon-samarium transient, and other reactor operating parameters. Experiments are performed using the general purposes crystal spectrometer and the reactor pneumatic tube facilities.

NE 545: Neutron Laboratory

This course, which requires NE 415 as a prerequisite, concentrates on student projects. Examples are:

- a. complete core flux mapping at full power;
- b. measurement of the reactor transfer function at 2 MW;
- c. construction of a single high speed rotor for a neutron spectrometer.

NE 599: Master's Projects

While this is not a formal course, Master's degree candidates must complete some project as part of their degree requirements.

Physics Department

The Physics Department, during 1969, was the second largest user of the reactor in terms of experiment hours. This group uses the reactor primarily for irradiation of small samples used in nuclear structure studies. Measurements are carried out with curved crystal gamma ray spectrometers and multichannel analyzers with Ge (Li) detectors. Irradiations of targets of thorium, erbium, mercury, germanium, iridium, dysprosium, and other elements are in progress.

This group has been successful in its efforts to reactivate the older of two cyclotrons available at the University in order to supplement the sources which are available from the reactor. However, program reductions resulted in an over-all reduction in reactor utilization by this department.

Following is a list of the personnel involved in these programs and their related publications:

Faculty and Staff:	Prof. M. L. Wiedenbeck	
	Prof. J. J. Reidy	
Students:	D. Raeside	Post Doctoral
	J. Auer	PhD, 1969
	M. Ludington	" "
	S. Lin	" "
	J. Hill	PhD Candidate
	E. Helminski	" "
	W. Greenberg	" "

Publication :

1. "Gamma-Ray Spectroscopic Study of the Decays of ^{124}Sb and ^{126}I ," Ivan Paul Auer, PhD Thesis, University of Michigan, (1969).
2. "The Decay Schemes of ^{131}Ba and ^{192}Ir Nuclei," Sabrina Lin Lee, PhD Thesis, University of Michigan, (1969).
3. "The Decay of ^{160}Tb to Levels in ^{160}Dy ," Martin Arthur Ludington, PhD Thesis, University of Michigan, (1969).
4. "The Levels of ^{103}Rh Populated in the Decay of ^{103}Ru ," D. E. Raeside, J. J. Reidy, and M. L. Wiedenbeck, Nuclear Physics A134 347 (1969).
5. "The Decay of ^{75}Se ," D. E. Raeside, M. A. Ludington, J. J. Reidy, and M. L. Wiedenbeck, Nuclear Physics A130 677 (1969).

Chemistry Department

The Chemistry Department uses the reactor both as a research tool and in support of its formal course work.

The research activities include:

- a. activation analysis studies;
- b. high-energy chemical reactions in which the energy provided to the reacting atoms came from nuclear processes such as thermal neutron fission and then n , γ , recoil process;
- c. rapid and specific chemical techniques for isolation of radioactive products;
- d. beta and gamma-ray spectroscopy of short-lived fission products;
- e. study of de-excitation of fission fragments produced in neutron induced fission;
- f. development of very rapid (10-60 sec.) electrolytic separation techniques for radioactive isotopes with half-lives of the order of 2 to 100 seconds.

The Chemistry Department activation analysis programs are primarily performed in conjunction with the Anthropology Department. These programs include analyses of:

1. archeological obsidian fragments in order to match compositions with geological obsidian and thus determine prehistoric trade routes;
2. initial investigations of the composition of other minerals found in archeological excavations include flint, jasper, chert, hematite, and magnetite; and
3. over 4000 streaks on etched quartz. The streaks were obtained by rubbing the quartz against edges of coins. The compositions of the coins obtained from these analyses provide data for economic historians to use in their research on ancient and medieval cultures.

Studies of the decay properties of fission product nuclides continued during 1969 and emphasized γ - γ correlations measured with a 4-parameter analyzer. At present, this research group is studying the decay of Tc-99m, Mo-101, Mo-102, Tc-101, I-134m, I-136, and Cs-138. In a separate study, the chemical effects on the half-life of beta decay are being studied.

Faculty and Staff:

Prof. A. Gordus
Prof. H. Griffin
Prof. H. Mark

Students:

M. Rottschaefer PhD Candidate

The activation analysis studies also involved approximately 16 undergraduate chemistry honor students, 1 graduate chemistry student, and 4 graduate anthropology students.

Publications:

1. "Identification of the Sources of Hopewellian Obsidian in the Middle West," J. B. Griffin, A. A. Gordus, and G. A. Wright, American Antiquity, 34 (No. 1), 1-14 (1969).
2. "Extents of Utilization of Lake Van Obsidian Sources Between 7500 and 3500 B.C.," G. A. Wright and A. A. Gordus, American Journal of Archaeology, 73, 75-77 (1969).
3. "Preliminary Report on Obsidian Samples from Veratic Rockshelter, Idaho," G. A. Wright, J. B. Griffin, and A. A. Gordus, Tebiwa, 12, 27-30 (1969).

4. "Preliminary Report on Obsidian Samples from Archaeological Sites in North-western Alaska," J. B. Griffin, G. A. Wright, and A. A. Gordus, Arctic, 22, 152-155 (1969).
5. "Source Areas for Obsidian Recovered at Munhata, Beisamoun, Hazorea, and El Khiam," G. A. Wright and A. A. Gordus, Israel Exploration Journal, 19, 79-88 (1969).
6. "Transitions in ^{107}Pd Following 22-min ^{107}Rh Decay," H. C. Griffin and W. R. Pierson, Phys. Rev., 183, 991 (1969).
7. "The Emission of K-X-Rays in Slow Neutron Fission of ^{233}U , ^{235}U , and ^{239}Pu ," P. D. LaFleur and H. C. Griffin, Inorg. Nucl. Chem. Letters, 5, 845 (1969).
8. "Rapid Isolation of Individual Rare Earths from Fission and Identification of ^{152}Nd ," M. A. Wakat and H. C. Griffin, Radiochem. Radioanal. Letters, 2, 351 (1969).

In addition to these activities, the department uses the reactor in the following courses:

- Chem 555: Radioisotope Techniques
This is a course for graduate chemistry students in activation analysis and radiation chemistry.
- Chem 399: Intro. To Research (Honors)
Under this program, several Honors Program students participated in the activation analysis program related to the study of archaeological artifacts.
- Chem 391: Physical Chemistry Laboratory (Honors)
In this course, students perform a series of activation and gamma spectrum measurements.

In addition to these regularly scheduled courses which use the reactor and laboratory facilities, one chemistry professor used the reactor in two freshman courses: Chemistry 107 and Chemistry 191. Students in these courses irradiated ammonium-halide unknowns in the reactor and determined the halogen half-life in order to identify the halogen.

Other Departments

Researchers in the Department of Meteorology and Oceanography are using neutron activation analysis in support of a study of circulation and rain scavenging processes in severe convective storms of the Plains States.

The group conducting this project included:

Faculty and Staff:

Prof. A. Dingle
Prof. K. Bhatki (on deputation
leave from Tata Institute of Funda-
mental Research, Bombay, India)

Students:

R. Borys U-M undergraduates
D. Curtin in Meteorology
J. Fairbent

Publications:

1. "Detection of Indium as an Atmospheric Tracer by Neutron Activation," D. F. Gatz, A. N. Dingle, and J.W. Winchester, J. Applied Meteorology, 8, 229-235 (1969).
2. "A Pilot Experiment Using Indium as Tracer in a Convective Storm," A. N. Dingle, D. F. Gatz, and J. W. Winchester, J. Applied Meteorology, 8, 236-240 (1969).
3. "Tracer Experiments in Convective Storms: in situ research on nucleation," A. N. Dingle, Proc. Seventh Int'l Conf. on Condensation and Ice Nuclei, Prague, Czechoslovakia, and Vienna, Austria, 18-24 Sept., 1969.
4. "Tracer Indium Determination in Rain Samples by Neutron Activation and Radiochemical Analysis," K.S. Bhatki and A.N. Dingle, Radiochemical and Radioanalytical Letters, (in press), 1970.
5. "Particle Sizes Produced by Indium-Emitting Pyrotechnic Flares," A. N. Dingle and G. W. Wambolt, Trans. Amer. Geophys. Union, 50, 166 (1969).

This department is also conducting studies, using activation analysis to evaluate the halogen contents of natural and pollution aerosols, atmospheric precipitation, and surface water. The halogens are added to the atmosphere naturally, largely as sea spray. The pollution source for these elements is the combustion of leaded gasoline which normally contains tetraethyl lead and organic chlorine and bromine compounds. The geographical area under study includes the Great Lakes region with special interest directed towards the halogen inputs and outflows of Lake Michigan.

Faculty:	Prof. J. Winchester	
	J. Robbins	Postdoctoral Assoc.
	R. Dams	" "
	M. Tiffany	Research Ass't.
Students:	R. Loucks	PhD, 1969
	T. Yokoyama	MS, 1969
	C. Winkelhaus	PhD Candidate
	K. Rahn	" "
	G. Nifong	" "

Publications:

1. "The Halogen Composition of Aerosol Particles Over Lake Michigan," R. H. Loucks, J. W. Winchester, W. R. Matson, and M. A. Tiffany, *Modern Trends in Activation Analysis, Conference Proceedings, U. S. National Bureau of Standards Special Publication 312, 36-42, (1969).*
2. "Natural and Pollution Sources of Iodine, Bromine, and Chlorine in the Great Lakes," M. A. Tiffany, J. W. Winchester, and R. H. Loucks, *Journal of the Water Pollution Control Federation*, 41, 1319-1329 (1969).
3. "The Application of Neutron Activation Analysis to Geochemical Studies of Mineral Resources," J. W. Winchester and J. A. Catoggio, *Nuclear Techniques and Mineral Resources, Symposium Proceedings, International Atomic Energy Agency, 435-449 (1969).*
4. "Pollution Pathways in the Great Lakes," J. W. Winchester, *Limnos* 2, No. 1, 20-24 (1969).
5. "Pollution Contributions to the Atmospheric Inventory of Chlorine and Bromine in Aerosols over Continental U. S. A.," R. H. Loucks and J. W. Winchester, *Trace Substances in Environmental Health-III, Conference Proceedings, University of Missouri, 233-250, (June 1969).*
6. "Surface Water Inputs of Iodine, Bromine, and Chlorine to Lake Huron," M. A. Tiffany and J. W. Winchester, *Twelfth Conference on Great Lakes Research, Proceedings, (May 1969) (in press).*
7. "Water Pollution in Lake Michigan by Trace Elements from Pollution Aerosol Fallout," J. W. Winchester and G. D. Nifong, A. M. Beeton and H. E. Allen, editors, *Advances in Chemistry Series, Am. Chem. Soc., 1969 (submitted).*
8. "Chlorine and Bromine in Continental Aerosols," R. H. Loucks and J. W. Winchester, *J. Geophys. Res.*, (in press, 1970).
9. "Surface Water Inputs of Iodine, Bromine, and Chlorine to Lake Huron," M. A. Tiffany and J. W. Winchester, *Twelfth Conference on Great Lakes Research, Ann Arbor, Michigan, May 5-7 (1969).*

10. "Water Pollution in the Great Lakes by Trace Elements from Pollution Aerosol Fallout," J. W. Winchester, 157th Meeting, Am. Chem. Soc. paper WATR - 34, (April 1969).
11. "Particle Size Distribution of Chlorine and Bromine in Mid-Continent Aerosols from the Great Lakes Basin," R. H. Loucks and J. W. Winchester, paper F-12, CACR Symposium on Atmospheric Trace Constituents and Atmospheric Circulation, Heidelberg, Germany, (September 8-13, 1969)
12. "Sources and Sinks of Air Pollution Trace Metals in Lake Michigan," J. W. Winchester, J. A. Robbins, and R. F. Dams, American Nuclear Society meeting, San Francisco, (2 December 1969).
13. "Activation Analysis in Mineral Prospecting," J. W. Winchester, Panel Meeting on Nuclear Techniques and Mineral Resources in Developing Countries, International Atomic Energy Agency, (8-12 December 1969).
14. "Particle Size Distribution of Chlorine and Bromine in Mid-Continent Aerosols from the Great Lakes Basin," R. H. Loucks, PhD Thesis, Department of Meteorology & Oceanography, U of M, (September 1969).
15. "Selenium in the Great Lakes," T. Yokoyama, MS, Department of Applied Chemistry, Keio University, Tokyo, Japan, 1969, (Research conducted at Phoenix Memorial Laboratory).

The Department of Internal Medicine continues to use reactor produced Fluorine-18 as a diagnostic tool for locating bone tumors.

The Department of Surgery, in conjunction with the Department of Internal Medicine, has used Potassium-42 in blood volume studies.

The Rackham Arthritis Unit developed a technique during 1968 which combines neutron activation analysis and paper chromatography, and which can be applied to qualitative and quantitative estimates of sugar nucleotides in normal, inflammatory, and aging mammalian connective tissues. These nucleotides are thought to be participants in the biosynthesis of acid mucopolysaccharides which undergo pronounced shifts in type and amount during the aging process of mammalian connective tissue. That method has now been applied for qualitative and quantitative estimation of sugar nucleotides in a number of biological tissues (in particular developing chick embryo tissues). In addition, studies with bovine liver have revealed the presence of a family of sugar nucleotide oligosaccharides previously found only in milk (UDP - AcGm - Gal - N - AN). The finding that nucleotide oligosaccharides are of wider occurrence than currently believed suggests that such compounds may participate as "activated intermediates" in the biosynthesis of serum glycoproteins (as opposed to nucleotide monosaccharides).

In addition, experiments designed to test the feasibility of preparation of ^{32}P labelled nucleotides and sugar nucleotides by neutron activation have been initiated. Preliminary studies have met with success and reasonable yields (10% plus) of the activated compounds may be isolated.

During 1969, the Department of Zoology completed the study which involved the insertion of radioactive wires under the skin of mice before releasing them into large natural enclosures. By measuring the radiation from the wire, the nature and extent of the daily activities of the mice can be observed and correlated with seasonal changes. The study also investigated the changes in these activities exhibited by mice exposed to different amounts of radiation.

This work was summarized in:

"Activity Patterns in the Meadow Vole, *Microtus Pennsylvanicus* Ord," under field conditions, F. C. Evans and M. Katznelson, Bull. Ecol. Soc. Amer., 50, (2): 106 (1969).

The final report on this project was published by the University's Office of Research Administration in January as:

"Seasonal Effects of Light, Temperature, and Radiation on Activity Patterns of the Meadow Vole, *Microtus Pennsylvanicus*," F. C. Evans, Office of Research Administration, University of Michigan, Report No. 07306-2-F: vi 20 pp.

The Department of Chemical and Metallurgical Engineering produced microporous films to study liquid phase diffusion of molecules. These films were prepared by exposure of thin mica films to fission fragments from U-235 fission. The fragments would have defects in the films which are etched out with hydrofluoric acid leaving holes about 100 Å in diameter.

The student conducting this research completed his doctoral requirements and reported the results in his thesis:

"Restricted Diffusion of Non-electrolytes Through Artificial Mica Membranes with Known Pore Geometry," R. Beck, Doctoral Thesis, University of Michigan, 1969.

A researcher from the Department of Microbiology, although not a regular user of radiation services, was able to make use of activation analysis in his studies. Animal cells

grown in vitro, i.e., outside the living body in an artificial environment are extremely susceptible to the toxic effects of trace amounts of heavy metals such as copper. This susceptibility is increased when the growth milieu is devoid of animal serum which often acts as a protective as well as a nutritive agent.

In the course of attempting to grow a strain of mouse connective tissue cells in a serum - free medium, problems arose with a toxicity of unknown origin. The investigations included an activation analysis of the glass distilled water used in media preparation. Water from the still and water that had been stored for a period in glass and polyethylene carboys was activated in the reactor and the product analyzed on a 4096 channel analyzer. The information obtained indicated that the water was not the source of toxicity and provided a rapid means of eliminating a possible problem area.

A student of radiological health in The School of Public Health did an experiment which attempted to show a significant difference of the neutron activation spectra between normal urine and urine of patients with urinary calculi. This research was not completed.

A researcher from the Department of Internal Medicine has pursued a project to measure the amount, turnover, and metabolism of thyroid hormones in cell components, as a step toward understanding the mechanism of hormone action. That group has devised a system for measuring iodine in tissue components using activation analysis. After resolving the differences in results obtained by their previous work which was based on a chemical analysis, the group plans to begin a series of experiments to study the participation of the thyroid hormone in the events of mammalian acclimatization to cold.

Engineering Summer Conferences

Each year the College of Engineering offers short courses for engineers and scientists. During 1969, a Conference which made use of the reactor as part of its laboratory work was:

Elements of Nuclear Power Reactor Engineering

Chairman: Prof. F. G. Hammitt

This Institute covered reactor core design theory and fuel cycles, reactor materials and instrumentation, radiation protection and health physics, shielding theory, and the thermal aspects of power reactor systems. It was attended by approximately 20 engineers, the majority of whom were employees of electric utility companies.

IV. FACILITY UTILIZATION BY OTHER UNIVERSITIES

The Institute of Mineral Research at Michigan Technological University has conducted autogenous grinding tests and investigated the mechanisms of size reduction. Autogenous grinding produces liberation of desired minerals by means of the ore grinding itself in a tumbling mill. The mechanisms of size reduction are more complex than in conventional grinding in which a feed already crushed to small sizes is ground by steel media.

The usual method of analysis had been to make measurements on large numbers of individual sizes so as to arrive at a statistical average.

Another method is to tag individual feed fragments and recover them in successive stages of the grinding to measure their degradation. One obvious method of tagging fragments is to activate some element in the ore minerals so that the fragment can be identified in successive stages of the grinding process.

Ore pebbles in which iron was the principal constituent were sent to the reactor for activation and these activated pebbles were traced through the grinding process by stopping the mill at regular time intervals, finding the pebbles among the other components of the mill charge, and making measurements of their degradation. After further evaluation of this experimental technique, the Institute may decide to adopt this tagging method as their principal experimental method. This decision is expected during 1970.

Wayne State University has been conducting a program in the study of properties of low lying nuclear energy levels, primarily the lifetimes of these states (in the range 10^{-6} to 10^{-14} sec). They use nuclear resonance fluorescence (requiring strong sources 100 mc) and delayed coincidence techniques. Nuclei studied during 1969 include Xe^{130} , Cu^{65} , Fe^{59} , and various rare-earth nuclei. The nuclear resonance fluorescence mechanism was also used to study the local crystal environment of Eu^{152} doped into single crystals of CaF_2 . The crystals are grown and then placed in the Ford Reactor to produce 100 mc of Eu^{152} .

The following is a list of publications and theses in which the FNR was used:

1. "Nuclear Resonance Fluorescence in Cu^{65} ," J. Pone, Jr., Master of Science Thesis, Wayne State University, Detroit, Michigan, (1969).
2. "Dependence of Nuclear Resonance Fluorescence Yield on Crystal Orientation: Eu^{152} (963 keV) in CaF_2 ," P. S. Strong, Master of Science Thesis, Wayne State University, Detroit, Michigan, (1969).
3. "Fast Timing Characteristics of Some Bendix Continuous Strip Electron Multipliers," M. I. Green, G. B. Beard, and P. F. Kenealy, Bull. Am. Phys. Soc., Series II, 15, 99 (1970).
4. "Dependence of Nuclear Resonance Fluorescence Yield on Crystal Orientation: Eu^{152} in CaF_2 ," P. S. Strong, G. B. Beard, and P. F. Kenealy, Bull. Am. Phys. Soc., Series II, 15, 107 (1970).
5. "Nuclear Resonance Fluorescence in Xe^{130} ," P. F. Kenealy, G. B. Beard, and K. Parsons, (to be presented at the April, 1970 meeting of the American Physical Society and submitted to Nuclear Physics for publication).

Several projects initiated in 1969 are still in progress (Fe^{59} , La^{140}) and will be published at a later time.

V. FACILITY UTILIZATION BY INDUSTRIAL RESEARCH LABORATORIES

General Motors Corporation

The General Motors Corporation Research Laboratories (GMRL) as well as several of the operating divisions of the corporation continue to use motor oil labelled with Br-82 from the FNR in engine oil consumption studies. This material has also been used in a study of methods of removing waste oil from water.

The reactor is also used to assist GMRL in:

- a. the irradiation of tungsten carbide tools for use in tool wear studies;
- b. neutron activation analysis for the evaluation of materials.

Ford Motor Company Scientific Laboratory

Research staff members of the Ford Motor Company Scientific Laboratory, in cooperation with the Department of Nuclear Engineering, operate a crystal spectrometer at the FNR for neutron elastic scattering studies. They also use the reactor as a source of irradiated materials, and have established a large activation analysis program in conjunction with Phoenix Memorial Laboratory personnel.

The programs using the crystal spectrometer involve:

- a. studies of the effects of pressure, temperature, magnetic fields, and various solutes on the antiferromagnetism of chromium;
- b. studies to demonstrate that antiferromagnetism does not contribute to the metal to semi-conductor transition in transition metal sesquioxides (Ti_2O_3 and V_2O_3); and
- c. studies of the alloy $\text{Fe}_{70}\text{Ni}_{30}$.

The group has devised a new technique to observe the small-angle, inelastic scattering from spin waves which employs two Si crystals in the parallel position with the ferromagnetic sample interposed between them. Using this technique, they are investigating the surface of the spin wave stiffness as a function of applied magnetic field and temperature in pure Fe and the disordered alloy $\text{Fe}_{50}\text{Ni}_{50}$.

These studies have resulted in the following publications:

1. "Neutron Diffraction Measurement of the Lattice Parameter of Potassium Metal at 5.2°K", S. A. Werner, E. Gurmen, and A. Arrott, Phys. Rev. 186 705 (1969).
2. "The Determination of Errors in Polarized Neutron Diffractometry," H. Kendrick, S. A. Werner, and A. Arrott, Nuclear Instruments and Methods, 68, No. 1 (1969).

Papers prepared in 1969 and accepted for publication:

1. "Rapid Investing of the Polarization of a Neutron Beam Using Large Amplitude Oscillating Magnetic Fields," H. Kendrick, J. S. King, S. A. Werner, and A. Arrott, (to be published in Nuclear Instruments and Methods).
2. "Direct Observation of the Angular Distribution of Neutrons Scattered at Small Angles by Spin Waves in Fe-Ni Alloys," S. A. Werner, E. Wiener, E. Gurmen, and A. Arrott, (to be published in Journal of Applied Physics).

The Ford Scientific Laboratory has also used the reactor to support studies in:

- a. determination of sodium in an alumina ceramic;
- b. the determination of zinc in airborne particulates, especially the possibility of their source being the wear of tire treads;
- c. the determination of bromine and lead as indicators of auto exhaust emission particulates;
- d. the continuation of research toward the goal of chemical analysis of solid surfaces;
- e. the determination of aluminum in borosilicate glass;
- f. the determination of oxygen-16: Oxygen-18 ratios by activation analysis; and
- g. the determination of fluorine by indirect activation analysis.

Publications:

1. "Precision Determination of Gadolinium in Cadmium Fluoride by Neutron Activation Analysis," R. H. Marsh and W. Allie, Analytica Chimica Acta, 45, 179-182 (1969).

Other Organizations

Irradiations of targets have also been performed for several Michigan industrial research groups including the Dow Chemical Company, Dow-Corning Corporation, Bendix Corporation, Energy Conversion Devices, Inc., and the Ford Institute for Medical Research.

During 1969, the Physics Department of the Edsel B. Ford Institute for Medical Research, Detroit, Michigan, was engaged in the final data collection and assembly of material for a beta excited x-ray study published as, "A Compilation of Beta Excited X-ray Spectra," by L. E. Preuss, principal investigator, C. Artman, and C. Bugenis. This work was partially funded by the Atomic Energy Commission. Specifically in 1969, Part III of this study was completed, is currently in print, and will be published in 1970.

Research for the compilation involved the preparation of several types of sources in which target metal atoms were excited by a beta emitting isotope yielding the characteristic K-shell radiation of the metal and the bremsstrahlung associated with beta absorption

in a target. The emission spectra of these sources were studied using a flow gas proportional counter, NaI(Tl) crystal, Nuclear Data 512 channel analyzer, and associated instrumentation. The data was then reproduced and published in graphic form as energy vs number of counts.

Also included in Part III were a few studies of sources different in nature but related to the above mentioned sources. Such a source was ^{185}W , in which an emission spectra is produced by ^{185}W betas interacting with the W atoms of the emitter to give a self-excited spectrum. The ^{185}W used for this study was obtained from the Ford Nuclear Reactor.

VI. CONCLUSION

During 1969, as in previous years, the operation of the FNR has provided major assistance to a wide variety of University research and educational programs, programs of other universities, and programs of industrial research laboratories. The continuous operating schedule of the reactor enables a sustained high level of participation by University research groups.

The continued support by the Atomic Energy Commission through the University Research Reactor Assistance Program has been instrumental in maintaining this continuous operation of the reactor facility.