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EDUCATIONAL AND RESEARCH ACTIVITIES

For the Period

July 1, 1970 to June 30, 1971

FORD NUCLEAR REACTOR

MICHIGAN MEMORIAL-PHOENIX PROJECT

THE UNIVERSITY OF MICHIGAN

Ann Arbor

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ABSTRACT

During the Academic year 1970-71, the Ford Nuclear Reactor (FNR) of 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. The continuous operating schedule of the reactor was maintained throughout the year. 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. During the period of July 1, 1970, to June 30, 1971, the continuation of this cycle made the FNR available for use approximately 86% of calendar time. The continuous schedule was temporarily suspended for an extended maintenance period during October, 1970 to permit modifications to the reactor primary water system. The following tabulation reviews the over-all utilization of the reactor during the past three academic years.

	<u>1968-69</u>	<u>1969-70</u>	<u>1970-71</u>
Operating Hours	7,453	7,818	7,571
Accumulated Megawatt Hours	14,384	13,558	14,244
Experimental Utilization (experiment hours)	90,658	93,085	101,508
Teaching Utilization (hours)*	1,540	960	3,018
Reactor Availability (% of calendar time)	85%	89%	86%

* 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:

1. 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.
2. The irradiation of various types of samples for period of one cycle or less.
3. 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 over the last three years after the long term irradiations have been subtracted.

	<u>1968-69</u>	<u>1969-70</u>	<u>1970-71</u>
Experimental Utilization	76,264	67,974	72,362

As can be seen from the above, the over-all utilization of the reactor for all types of experiments increased somewhat during 1970-71 over 1969-70 despite continuing reductions in University research program support funds.

Fuel and Heavy Water

The core of the FNR was increased in size during 1969 in order to increase burnup. Currently, standard fuel element burn-up levels of approximately 18% are obtained, while control elements are retired after a burn-up level of 36% is reached. This new replacement schedule resulted in the use of 6 control and 24 standard fuel elements during 1970-71.

During this academic year, 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

Radioisotope Production

During 1970-71, the FNR continued to assist 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:

88 samples containing a total of 10.6 curies of Bromine-82 labelled motor oil for engine oil consumption studies, and
207 samples containing 4.1 curies 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. University of Michigan Hospital - Ann Arbor, Michigan
2. Veterans Administration Hospital - Ann Arbor, Michigan
3. St. Joseph Mercy Hospital - Ann Arbor, Michigan
4. Hurley Hospital - Flint, Michigan
5. Henry Ford Hospital - Detroit, Michigan
6. Wayne County Hospital - Detroit, Michigan
7. Mount Carmel Mercy Hospital - Detroit, Michigan
8. St. John's Hospital - Detroit, Michigan
9. Edsel B. Ford Institute - Henry Ford Hospital - Detroit, Michigan
10. North Detroit General Hospital - Detroit, Michigan
11. Oakwood Hospital - Dearborn, Michigan
12. William Beaumont Hospital - Royal Oak, Michigan
13. Highland Park General Hospital - Highland Park, Michigan

Due to the need for high concentration, alumina free ^{99m}Tc , which cannot be produced by commercially available ^{99}Mo - ^{99m}Tc generators, an investigation of a solvent extraction method of production of ^{99m}Tc was begun during 1969 and completed in 1970. During 1970-71, 220 samples containing 44 curies of Tc-^{99m} have been supplied to the University Medical Center.

The availability of this production capability led to the laboratory developing the capability to supply Tc-99m labelled Human Serum Albumin. During 1970-71, 35 samples of this material containing 175 millicuries of activity was supplied to the University Medical Center.

The availability of high concentration, high purity Tc-99m suggested a study of the branching decay by beta transition of this isotope in a small fraction $(9.7 \pm 1.5) \times 10^{-7}$ of the ^{99m}Tc atoms. Results of γ -ray measurements of a shielded source of high purity ^{99m}Tc revealed a gamma ray at $322.4 \text{ Kev} \pm 0.2 \text{ Kev}$. This γ -ray follows the half-life of ^{99m}Tc and is explained by the beta decay of ^{99m}Tc to ^{99}Ru . This work was the result of collaboration between H. Griffin, a Chemistry Department faculty member and J. Jones of the Phoenix Memorial Laboratory.

Publications:

1. Jones, J., and Griffin, H., "Beta Decay of ^{99m}Tc ," Radiochem. Radioanal. Letters 4 (1970).

Activation Analysis

In the area of activation analysis services, a simple, rapid neutron activation method for mercury in fish tissue was developed. The technique employs separation of the activated mercury as HgCl_4^{2-} complex on an anion exchange resin and direct counting of the resulting resin. Results showed that the analyses have a $\pm 10\%$ standard deviation for tissue samples containing mercury in the 0.05 to 10 ppm range, and the sensitivity has an approximate 3 ppb limit for the conditions employed. Mercury content in different fish species from a variety of locations and different fish organs were studied. Also, the results of replicate samples analyzed by a variety of different methods and in different laboratories were compared. The analytical technique was also used to determine Hg in other biological tissues such as hair and blood. During 1970-71, over 278 samples (primarily fish) were analyzed for mercury content using this analytical technique.

Publications:

1. Rottschaefer, J. M., Jones, J. D., and Mark, H. A., "A Rapid Method for Determining Trace Mercury in Fish via Neutron Activation Analysis," Environmental Science and Tech., 5, 336-338, (April 1971).
2. Jones, J. D., Rottschaefer, J. M., and Mark, H. A., "Determination de Traces de Mercure dans les Systemes Biologiques par Activation de Neutrons," Mikrochimica Acta, 3, 399-404, (1971).

A new research project "Historical Changes in Mercury Contamination in Great Lakes Walleyes" has been funded by the Bureau of Sport Fisheries and Wildlife, Department of Interior. The study will determine the validity of preserved fish specimens as indicators of past levels of mercury occurrence and measure the levels of Hg in the flesh of walleyes of the Great Lakes Basin in the period 1908-1935. A study of the current levels of contamination in the same species from some of the same localities in the basin compared to the past levels will be done. The Project Directors are J. Jones (PML) and G. Smith (University of Michigan Museums). Students involved directly in this project are Mr. Thomas Kelly, Department of Natural Resources and Mr. Richard Skinner, Student Assistant, Phoenix Memorial Laboratory.

Another new research project "Mercury Contamination in Fish Populations in the Huron River Basin, Michigan" has been funded by The Institute of Environmental Quality. The purpose is to establish the level of mercury contamination in fish tissues in relation to environmental sources and trophic structure of the aquatic communities, and to document the change in Hg levels and fish species' diversity correlated with population growth, land utilization, and industrialization in the area. The historical aspect of the study will depend on mercury measurements of museum specimens. This Project is also under the direction of J. Jones and G. Smith. The student involved in this study is Miss Christine Meek of the School of Natural Resources.

Facility Assistance

During 1970-71, The National Bureau of Standards Research Reactor at Gaithersburg, Maryland experienced a prolonged maintenance shutdown. In order that the NBS Activation Analysis Group projects could continue, members of that group came to the FNR and used the reactor and laboratory facilities for several weeks.

Public Education Programs

The Phoenix Laboratory remained active in its program of assistance to other schools and to the general public. An all day series of lectures and tours was presented to groups from Grand Rapids Jr. College, Kalamazoo College, Albion College, and Tri State University. Guided tours of the facility were given to over 6,000 students and interested non-students during the year.

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 and completed in 1970. The final report of the study is now undergoing internal review.

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 and 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 1970-71, more than 97% of the utilization of the reactor was by student and faculty researchers from teaching departments in the University. The following tabulation compares the utilization of the reactor by University groups over the last three academic years.

<u>UNIVERSITY DEPARTMENT</u>	<u>1968-69</u>	<u>1969-70</u>	<u>1970-71</u>
Nuclear Engineering	38,410	41,568	48,587
Physics	39,638	36,678	37,542
Chemistry	5,861	7,225	4,009
Other Departments	3,121	6,072	8,776
	<u>86,019</u>	<u>90,602</u>	<u>98,914</u>
Total Experimental Utilization for the Year	90,658	93,085	101,508

While the departments of Physics, Nuclear Engineering, and Chemistry were the largest users, the departments of Environmental Health, Dentistry, Geology and Mineralogy, Meteorology and Oceanography, Biological Chemistry, The Rackham Arthritis Research unit, the Kresge Radioisotope unit of the University Medical Center, and the Great Lakes Research Division of the University's Institute of Science and Technology 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>1968-69</u>	<u>1969-70</u>	<u>1970-71</u>
Transfers to U of M Units	400	467	645
Transfers to other Organizations	<u>405</u>	<u>541</u>	<u>504</u>
TOTAL - - -	805	1008	1149

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, neutron radiography, radiation effects, and measurement of reactor core parameters.

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

1. A triple axis crystal spectrometer for neutron inelastic scattering measurements.
2. A velocity selector for neutron inelastic scattering measurements and for use as a time-of-flight diffractometer.
3. A polarized beam crystal spectrometer for neutron elastic scattering measurements on magnetic materials.
4. 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. A small neutron chopper was developed and successfully operated for use at this spectrometer.

During 1970, this unit was used to determine the oxygen positions in CaMoO_4 , SrMoO_4 , SrWO_4 , and BaWO_4 to an accuracy of $\pm .003\text{\AA}$ to $\pm .005\text{\AA}$. It is planned to extend these comparisons to other scheelite-type structures.

The triple axis crystal spectrometer was in continuous operation throughout 1970-71. 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 rebuilt during 1969 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.

During this report period, the four-rotor velocity selector, formerly used for inelastic scattering studies, was made over into a time-of-flight diffractometer. The major alteration was to remove two of the four rotors. There remain a fiberglass rotating collimator, which reduces the fast neutron background, and a NIMONIC-90 rotor, with 40 inch slit curvature, both of 10 inch diameter and of the Harwell design. Rotors are operated at speeds of 480 and 240 cps. The shielding, detectors, and electronics remained essentially unchanged.

The detectors, which are $\text{Li}^6\text{F-ZnS}$ scintillators have been installed in a time-focussed orientation, and the flight paths before and after the sample have been arranged to be equal. Two banks of detectors are in use: 175 in.^2 at 90° and 100 in.^2 at 20° scattering angles. These arrangements provide the needed capabilities for study of the structure of non-crystalline solids. In those materials, only modest resolution is required because the diffracted intensity is not sharply varying.

The following is a list of personnel in the neutron spectroscopy program and their publications and activities during 1970-71:

Faculty and Staff:

Prof. J. Carpenter
Prof. J. King
Prof. (Adjunct) S. Werner

Students:

E. Gurmen	PhD, 1971
G. Sherwood	PhD, 1970
D. Steinman	PhD Candidate
D. Mildner	PhD Candidate
N. Vogelatos	PhD Candidate
C. Pelizzari	PhD Candidate

Publications:

1. Sherwood, G., "U-235 Fission Spectrum Measurement with a Telescope Spectrometer," Univ. of Mich. Thesis, (1970).
2. Gurmen, E., "Investigations of the Effect of Magnetic Field and Temperature on the Very Low Energy Spin-Waves in Fe and Fe (Ni) Alloys Using Two New Small-Angle Neutron Scattering Techniques," Univ. of Mich. Thesis, (1971).
3. Graham, K., "Measurements of Time-Dependent Thermal Neutron Spectra in Pulsed Moderators Using a Time-Focussed Crystal Spectrometer," Univ. of Mich. Thesis, (1971).
4. Carpenter, J. M., and Lurie, N. A., "Low-Energy Neutron Scattering from Hydrogen Chloride," J. Chem. Phys., 54, 12, 5193-F, (June 15, 1971).
5. Carpenter, J. M., "Pulsed Moderator Studies Using a Time-Focussed Crystal Spectrometer," Nuc. Inst. and Meth., 85, 163 (1970).
6. Carpenter, J. M., and Graham, K. F., "Slow-Neutron Leakage Time Distributions of Some Small Hydrogenous Moderators," Trans. Am. Nuc. Soc., 13, 692, (1970)
7. Carpenter, J. M., and Graham, K. F., "Pulsed Moderator Studies Using a Time-Focussed Crystal Spectrometer," Trans. Am. Nuc. Soc., 13, 762, (1970) (invited paper).
8. Carpenter, J. M., and Lurie, N. A., "Sum Rule for Interference Scattering from a Rigid Rotor," J. Chem. Phys., 52, 5967, (June 1970).
9. Vincent, D. H., and Sampson, T. E., "An Absolute Measurement of the Efficiency of a BF₃ Proportional Counter," accepted for publication in Nuc. Inst. and Meth., (1971).
10. Werner, S. A., Toth, R. S., Arratt, A., Shinozaki, S. S., and Sato, H., "Studies of Au₄X Ordered Alloys: Electron and Neutron Diffraction, Resistivity, and Specific Heat," J. Appl. Phys., (March 1969).

11. Werner, S. A., Kendrick, H., King, J. S., and Arrott, A., "Rapid Inverting of the Polarization of a Neutron Beam Using Large Amplitude Oscillating Magnetic Fields," Nuc. Instr. and Meth., 79, 82-92, (1970).
12. Werner, S. A., and Atoji, M., "A Neutron Diffraction Search for a Charge Density Wave in Potassium Metal," Solid State Communications, (1970).
13. Werner, S. A., "Choice of Scans in Neutron Diffraction," submitted to Acta Crystallographica (1971).
14. Werner, S. A., Wiener, E., Gurmen, E., and Arrott, A., "Direct Observation of the Angular Distribution of Neutrons Scattered at Small Angles by Spin Waves," J. Appl. Phys., 41, 3, 1363, (1970).

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 Mossbauer spectra. Some extension of this program into the fast neutron effects area is currently underway.

The purpose of one of these research projects is to make use of the Mossbauer effect to study precipitation processes and fast neutron irradiation effects in copper-rich, Cu-Fe alloys. Experiments are being conducted to examine the effects of heat treatment, cold work, and fast neutron radiation on low iron content Cu-Fe alloys. The well known characteristics of the Mossbauer resonance spectra for the precipitate phases (i.e., relative areas, isomer shift, and hyperfine splitting) will be used to determine the functions and type of precipitate (coherent gamma phase or incoherent alpha phase) formed as a function of various heat treatments, cold working, and fast neutron exposure. Irradiations will be carried out in the FNR for periods from one to three cycles to achieve fast neutron exposures of 10^{18} to $5(10)^{19}$ nvt.

The following is a list of personnel in the radiation effects program and their publications during 1970-71:

Faculty:	Prof. C. Kikuchi	
	Prof. D. Vincent	
Students:	T. Gould	PhD Candidate
	B. Desai	PhD Candidate
	S. Irizarry-Milan	PhD Candidate
	Y. Yu	PhD Candidate

Publications:

1. Kikuchi, C., and Koehler, H. A., "Identification of Three Trapping Centers in Calcium Tungstate," *Physica Status Solidi*, **43**, 423, (1971).
2. Kikuchi, C., and Barnes, C. E., "Thermal Neutron-Induced Recoil Defects in P-Type Cadmium Telluride," *Radiation Effects*, **2**, 243, (1970).
3. Vincent, D. H., Merrithew, P. B., and Rasmussen, P. G., "The Temperature Dependence of the Quadruple Splitting of Several High-Spin Iron (II) Compounds," accepted for publication in *Inorganic Chemistry*, (May 1971).
4. Kikuchi, C., "Thermal Neutron Damage in CdS and CdTe," International Conference on Radiation Effects in Semiconductors (August 1970).
5. Kikuchi, C., "ESR and ENDOR Investigations of Radiation-Induced Metastable Paramagnetic Centers in CaWO_4 ," *Bull. Inst. Chem. Res.*, Kyoto University, **48**, 10 (1970).

A research program to determine the absorption cross sections of radioactive nuclei was initiated in 1968. During the last year the efforts in the program of measuring neutron cross sections of radioactive nuclides have concentrated on a search for the inelastic scattering reaction from isomeric states. This necessitated the development of in-core irradiation facilities and of the capability for fast neutron spectroscopy in the 10-200 Kev range using a proton recoil detector. The calibration of this detector was achieved using the $\text{N}^{14}(\text{n}, \text{p})\text{C}^{14}$ reaction with thermal neutrons from a crystal spectrometer and with resonance filters in the $1/\text{E}$ flux component of the neutron radiography beam from the D_2O facility. No positive results have yet been obtained in the search for the isomeric de-excitation reaction.

During 1969, a departmental program in fission fast neutron cross section measurements began. Short-lived photoneutron sources will be activated in the FNR and transferred to a heavily shielded laboratory in the adjacent PML building. Here these sources of mono-energetic neutrons will be used in precision cross section measurements on isotopes which are of interest as nuclear data standards, e.g. U-235 and Li-6. In these experiments, the neutron flux is determined absolutely by use of a manganese bath facility.

The primary motivation for this work is the need for improved nuclear data for fast reactor calculations.

Faculty:	Prof. G. Knoll	
Students:	D. Gilliam	PhD Candidate
	W. Stephany	PhD Candidate

Publications:

1. Knoll, G., and Gilliam, D. M., "Counting Heavily Etched Fission Fragment Tracks in Polycarbonate," Trans. Am. Nuc. Soc., 13, 526 (November 1970).

A program in neutron radiography was started in 1969. The objective of this program is to develop the experimental and analytical techniques necessary to produce neutron radiographs with spatial resolution approaching one micron. This would represent an improvement by more than an order of magnitude over the highest resolution achieved in conventional neutron radiography, and may lead to applications in microradiography of biomedical sections. Reactor vertical beam tube facilities have been completed and techniques developed for conventional neutron radiography. Current efforts are directed toward necessary modifications in beam, foil, and emulsions required for high resolution work, as well as projection microscope techniques to accurately measure density profiles.

Faculty:	Prof. G. Knoll	
Students:	M. Flynn	PhD Candidate
	A. Osterman	N. E. Undergraduate
	S. Buchbinder	Psychology Undergraduate

Publications:

1. Knoll, G., Flynn, M. J., and Poznanski, A. K., "Neutrography in Medical Research and Pathology," ANS Topical Meeting on Neutron Sources and Applications, CONF-710402, 11-49 to 11-58, (April 1971).

The Nuclear Engineering Department also uses the reactor in conjunction with several formal courses. Those courses which used the reactor during the past academic year are listed below.

NE 415: Radiation Detection and Measurement -

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.

A publication which resulted from development of an NE 415 laboratory experiment was:

1. Knoll, G., and Vogelatos, N., "Measurement of the Tm-171 Isomeric Lifetime as a Teaching Laboratory Experiment," J. Nuc. Energy, 24, 227, (September 1970).

During 1970-71, some limited use was made of the reactor in providing demonstrations for nuclear engineering undergraduate students. This type of reactor usage may be expanded during the 1971-1972 year.

The departmental program directed towards development of a gas filled Cerenkov Detector for use as a reactor power monitor progressed satisfactorily during 1970-71. The detector design discriminates against low-energy fission product decay gamma rays by the Cerenkov effect. Efforts to date have been aimed at producing a small-diameter device. The principle holds the promise of a rapidly responding long-lived, wide-range device of simple construction without the problems associated with electrical signal transmission.

The detector, at its present stage of development, consists of a 10-foot long, .277" I.D. highly polished aluminum tube, the lower end of which is located in or near the reactor core. Ultrapure (99.99%) CO_2 at 400 psig and 30°C , used as the radiating medium, provides a practical beta energy threshold of about 3.0 Mev. Cerenkov light generated in the lower end of the tube is reflected up the tube, where it passes through a pressure-retaining end window of UV transmitting glass and is focussed by a lens onto the .040" diameter photocathode of a Bendix Channeltron Photon counter, used in a current-output mode.

The results of measurements at FNR in the presence of the fission products generated by 30 days operation at 2 MW, shows a deviation from proportional response below a few KW. This deviation is due to non-Cerenkov (scintillation and possibly other) responses of the gas and is the next question to be addressed.

Faculty:

Prof. J. Carpenter

Student:

R. Humphries PhD Candidate

Publications:

1. Carpenter, J. M., and Humphries, J. R., "Gaseous Cerenkov Detector Reactor Power Monitor," to be published in Trans. IEEE (1971).

Physics Department

The Physics Department, during 1970-71, 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)³ 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. Despite program reductions over the last two years, an over-all increase in reactor utilization by this department was possible during this report period.

The following publications by Physics Department faculty and students are related to this program:

1. Roeside, D. E., and Wiedenbeck, M. L., "Measurement of Angular Correlation Solid Angle Corrections for a Coaxial Ge (Li) Detector," Nucl. Instr. and Meth., 78, 331, (1970).
2. Roeside, D. E., "Precision Gamma Ray Energies in the Energy Interval Between 45 and 1275 Kev," Nucl. Instr. and Meth., 87, 7, (1970).
3. Roeside, D. E., and Ludington, M. A., "Experimental and Calculated Photpeak Efficiencies for a Coaxial Ge (Li) Detector," Nucl. Instr. and Meth., 93, 389, (1971).
4. Ludington, M. A., and Roeside, D. E., "Precision Energy Measurements of Gamma Rays Occurring in the Decays of Dy-165 and Os-193," Nucl. Instr. and Meth., 94, 195, (1971).

Another experimenter from the Physics Department used the reactor and laboratory facilities to make Tungsten-187 sources. These sources are used to investigate the possibility of observing the precision of angular correlation radiation pattern associated with a 479-72 Kev gamma cascade of Re-187 by means of current correlation and power spectrum analysis rather than employing coincidence techniques. The method, if proven feasible, will enable measurements of nuclear interactions of half-lives up to 1/10 of a second.

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:

1. Activation analysis studies.
2. Rapid and specific chemical techniques for isolation of radioactive products.
3. Beta and gamma-ray spectroscopy of short-lived fission products.
4. Study of de-excitation of fission fragments produced in neutron induced fission.

Work is continuing on the project which involves the use of activation analysis of historical objects. Ancient and medieval silver coins and metallic art objects were analyzed for their silver, copper, gold, zinc, antimony, and arsenic contents by irradiating minute streaks of metal obtained by rubbing etched quartz tubing against the metal objects. These analyses permitted determining the approximate composition of the metallic objects without the necessity of removing the objects from a museum or coin room. As a result, it was possible to get cooperation from the curators of museums in England, France, Italy, Iran, and Russia, as well as the United States. The level of gold impurity in the silver, which is usually less than one percent, was found to cluster at certain values for various periods and geographic regions, as given by the mintmarks and dates on the coins. These gold data can serve to suggest the general location of ancient silver sources and, hence, likely locations for finding silver sources today. Further, certain types of modern forgeries, both of coins and art objects, can now be determined by comparing their gold-impurity levels to those in authentic coins and art objects.

Publications relative to this work include:

1. Gordus, A., "Non-destructive Analysis of Silver Coins: A Study of Sasanian and Umayyad Coinage," Bull. de la Soc. Francaise de Numismatique, 25, 543-44, (1970).
2. Gordus, A., "Neutron Activation Analysis of Archaeological Artefacts," Proc. of Royal Society-British Academy Symp. on the Applications of the Natural Sciences to Archaeology, London, Dec., 1969; Phil. Trans. Roy. Soc., London, 167-176, (1970); also published by Oxford University Press, (1971).

3. Gordus, A., "Rapid Non-Destructive Activation Analysis of Silver in Coins," Science and Archaeology, MIT Press, Chapter 10, 145-155, (1971).
4. Gordus, A., Griffin, J. B., and Wright, G. A., "Activation Analysis Investigation of the Geologic Origins of Prehistoric Obsidian Artifacts," Science and Archaeology, MIT Press, Chapter 16, 222-234, (1971).
5. Griffin, J., and Gordus, A., "A Preliminary Study of the Source of Hopewellian Obsidian in the United States," Actes du VII^e Congres International des Sciences Prehistoriques et Protohistoriques, Prague, Editions de l'Academic Tchecoslovaque des Sciences, Czechoslovakia, 57-63, (1970).

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.

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. In this program, stable In-114 was introduced as a tracer into updrafts feeding convective rainstorms and samples of the rain were collected and analyzed to give the patterns of deposition of In-tracer in area and in time. The analysis was done by neutron activation and radiochemical separation followed by beta analysis.

Another program of this department dealt with the geographical distribution of air contaminants and developing the techniques of nondestructive neutron activation analysis so as to give measurements of some 30-odd elements found in samples taken from the air. Both high-volume filter samples and size-stratified impactor samples were subjected to gamma spectrometric analysis to give nominal size distribution data as well as chemical evaluations.

Publications:

1. Rahn, K., "Sources of Trace Elements in Aerosols," Univ. of Mich. Thesis (1971).

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.

Members of the Rockham Arthritis Research Unit have developed a technique (1968-71) combining neutron activation and paper chromatography and have applied the methodology to qualitative and quantitative estimation of sugar nucleotides and acid mucopolysaccharides found in normal, inflammatory and aging connective tissues. (Sugar nucleotides are phosphorous-containing intermediates involved in the biosynthesis of naturally occurring carbohydrate polymers.)

The techniques have now been successfully applied to several studies.

1. Qualitative and quantitative estimation of sugar nucleotides in a number of biological tissues (including developing embryonic tissues) are now being made. 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-NAN). The finding that nucleotide oligosaccharides are of wider occurrence than currently reported in the literature suggests that nucleotide oligosaccharides may participate as "activated intermediates" in the biosynthesis of serum glycoproteins and acid mucopolysaccharides (as opposed to nucleotide monosaccharides).
2. Experiments designed to test the feasibility of preparation of ³²P labeled nucleotides and sugar nucleotides by neutron activation have been initiated. Preliminary studies have met with success and reasonable yields (10 percent plus) of the activated compounds may be isolated.

3. Studies for the resolution and detection of submicrogram quantities of acid mucopolysaccharides on paper chromatograms were initiated. Nearly all acid mucopolysaccharides contain ester-bound sulfate (SO_4^-) attached to the hydroxyl groups of sugar residues. The sulfate molecule is readily activated to ^{32}P and may be quantitatively determined by autoradiographic and/or liquid scintillation counting techniques.

A researcher from the Department of Internal Medicine continues to pursue a program 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.

The naturally occurring isotope, I-127, has been measured by neutron activation, post-irradiations extraction of I-128 plus I-127 (added carrier), and timed scintillation counting of aqueous solution utilizing Cerenkov radiation. With extrapolation of the counts to zero time (end of irradiation) and measurement of chemical recovery by weighing of precipitated Ag-I, there are about 300 cpm above background per nanogram I, in the range of 0 to 30 ng. The precision for samples of NH_4I is $\pm 2.6\%$ coefficient of variation. The accuracy has been verified with a chemical method. The use of Cerenkov radiation simplifies sample preparation. 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.

Publications:

1. Hoch, F. L., Kuras, R. A., and Jones, J. D., "Iodine Analysis of Biological Samples by Neutron Activation of I-127, with Scintillation Counting of Cerenkov Radiation," Anal. Biochem., 40, 1, 86-93, (March, 1971).

Engineering Summer Conferences

Each year the College of Engineering offers short courses for engineers and scientists. During 1970-71, a Conference which made use of the reactor as part of its laboratory work was as follows:

Elements of Nuclear Power Reactor Engineering

Chairman: Prof. F. G. Hammitt

This conference 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 12 engineers, the majority of whom were employees of electric utility companies.

IV. FACILITY UTILIZATION BY OTHER UNIVERSITIES

During 1970-71, the irradiation services provided to other universities increased to 2331 experiment hours from the 2260 experiment hours accumulated during the previous period. Direct technical assistance to other schools was approximately 40 man-hours during the report period. It was possible to maintain this support level to other schools despite budget stringencies because of funding assistance provided through the Reactor Sharing Program of the A. E. C. (Contract No. AT(11-1)-2117). A request for additional assistance under this program has already been made so that the level of support given area schools can be expanded further.

The staff projections for services to be requested during the next academic year by area colleges and universities are approximately 5000 sample hours of reactor irradiation and 80 hours of technical assistance.

At the present time, the heaviest user of the sample irradiation service is Wayne State University. The following is a description of the projects which utilize this service.

1. Nuclear Resonance Fluorescence in Xe-130. - The reactor facility was used to irradiate samples of I-129 to produce ~ 100 mc of I-130 which subsequently decays to levels in Xe-130. Over the period of the investigation, ten irradiations were required. The mean life of the 536 Kev (2+) first excited state of Xe-130 was found to be $(1.3 \pm 0.3) \times 10^{-11}$ sec. From this result and the relative transition probabilities determined previously in a Coulomb-excitation experiment, the absolute transition probabilities for the first excited states of Xe-128 and Xe-132 were also obtained. This information is used to confirm or dispute the accuracy of models of nuclear structure; these models are generally quite sensitive to tests which involve lifetimes and transition probabilities.

Publications:

1. Kenealy, P. F., Beard, G. B., and Parsons, K., Phys. Rev. C2, 2009, (1970).
2. Nuclear Resonance Experiments in the Rare-earth Region of the Periodic Table. - Several different projects involving the use of NRF in rare-earth nuclei were conducted. Mr. Tom Patterson, a graduate student, attempted to obtain gaseous rare-earth chelates, organo-metallic compounds, as sources for NRF experiments. One of the limiting factors in most NRF experiments is that the source must be gaseous if lifetimes $>$ than $\sim 10^{-14}$ sec. are involved. Several irradiations were performed, but this interesting approach proved the complex organic molecule to be too sensitive to radiation damage. Under bombardment by the neutron and gamma-ray flux, the molecules dissociated into liquid or solid compounds.

Mr. Patterson is at present irradiating various samples (e.g., Ge-73, Se-81) in a search for suitable sources for his continuing NRF investigations.

3. Electronic Lifetime Measurements and the Fast-timing Characteristics of Some Channel Electron Multipliers. - The work described here is being carried out by Mr. M. I. Green, a graduate student, for his PhD thesis. He has extended the capabilities of the fast timing experiments ($\sim 10^{-9}$ sec.) to previously inaccessible energy levels by use of continuous-strip electron multipliers, CEM, (which are sensitive to very low energy electrons and photons) and have discovered a method of improving the time resolution of this type of detector by a factor of 2. Without the complication of energy selection or collimation of the source radiation to the detector, it becomes possible in certain favorable cases with the high-efficiency, low-background CEM to procure lifetime information to test nuclear models in previously inaccessible areas. An example of this is the determination of the lifetimes of high spin levels in Er-166.

Mr. Green has extensively used the facilities of the reactor to produce sources of Fe-59 and Tm-170 for calibration purposes and to produce Ho-166 and other isotopes for his research into the lifetimes of high-lying energy levels in the rare earth nuclei.

Preliminary publication of some of the results appeared in:

1. Green, M. I., Kenealy, P. F., and Beard, G. B., Bull. Am. Phys. Soc., 15, 99 (January, 1970).
2. A paper describing the technique is to be submitted to Nuclear Instruments and the results of the lifetime measurement will be submitted to either the Physical Review or Nuclear Physics.

4. Dependence of Nuclear Resonance Fluorescence Yield on Crystal Orientation (Eu-152-InCaF). - This work resulted in a master's thesis by Mr. Paul Strong and is being continued by a graduate student, Mr. Yi-thai Wu. Numerous irradiations have been needed in this investigation of the effects of the crystalline solid-state on the NRF yield. The investigation of channeling and the impurity sites in these crystals are the goals of this investigation. Because the Eu-152 has a short half-life (~9 hours), the availability of the reactor facility enabled them to pursue this line of inquiry which otherwise would have had to be abandoned. Preliminary results were published:

Strong, P. S., Beard, G. B., and Kenealy, P. F., Bull. Phys. Soc., 15, 107 (January, 1970).
5. Mössbauer Effect (Te-121 > Sb-121). - They have irradiated a source of enriched Te in order to obtain a Te-121 source for use in Mössbauer experiments which are being carried out. These are in a preliminary state at this time.
6. Calibration Standards. - The reactor facility has provided them with sources of calibration standards when needed. Many times, calibration in a particular energy region is needed and can be obtained by irradiating an appropriate source. The nearness of the reactor makes this feasible for short-lived isotopes as well as for longer-lived ones.

At Eastern Michigan University, a Chemistry Department faculty member, K. Rengan, has recently initiated a series of research projects including:

1. Decay scheme studies of fission products, initially concentrating on the Ce-Pr chain.
2. Fission studies concentrating on fission yields.
3. Application of activation analysis to biological samples. In this connection, he conducted a "Biology Workshop" on June 8, 1971; using the reactor and laboratory facilities. The workshop was for the staff and students of Eastern Michigan University.

This same faculty member is formulating a new course at Eastern Michigan University - Chemistry 485: "Radioisotope Techniques" for chemistry and biology majors. The reactor will be used to produce the necessary short-lived radioisotopes, and for activation analysis. This course has been approved and will be offered for the first time in the Fall, 1971 semester.

A Master's student in the Physics Department at Eastern Michigan University conducted his master's thesis research using the reactor facilities. Staff personnel assisted him in his indoctrination to the facility and gave assistance to his graduate advisor during the student's research period.

If this program of thesis research assistance continues to be beneficial to area schools, it will be expanded in future years.

Several of the schools made use of the program of "all day tours" provided by the facility. These are lecture/demonstrations conducted by staff personnel on the uses of radioisotopes, activation analysis techniques, and laboratory techniques for students from other schools. The schools taking advantage of this program included:

Grand Rapids Jr. College
Albion College
Concordia College
Tri-State College

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 labeled with Br-82 from the FNR in engine oil consumption studies.

The reactor is also used to assist GMRL in:

1. Radioactive seals for engine wear studies.
2. Radioactive samples for high temperature corrosion studies.
3. Neutron activation analysis for the evaluation of materials.
4. Radioactive tool bits for tool wear studies.

This last project resulted in a GMRL general distribution publication:

Hill, R., and Skunda, M., "Radiometric Tool Wear Tests on Cold Formed Spark Plug Shells: Evaluation of Machinability and Machining Parameters," GMR 1013, (August, 1970).

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:

1. Studies of the effects of pressure, temperature, magnetic fields, and various solutes on the antiferromagnetism of chromium.
2. 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).
3. Studies of the alloy $Fe_{70}Ni_{30}$.
4. Investigation of the magnetic correlations and atomic ordering in $Cu(Mn)$ alloys.

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 Fe_5Ni_5 .

The publications associated with this program were previously reported in the section on the Nuclear Engineering Department.

In addition to these projects, a neutron interferometer of the type developed by Bonse and Hart for x-rays is being investigated. Large perfect crystals in InSb and Si are being examined for the neutron optical elements.

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

1. Determination of sodium in an alumina ceramic.
2. The continuation of research toward the goal of chemical analysis of solid surfaces.
3. The determination of aluminum in borosilicate glass.
4. The determination of zinc in airborne particulates, especially the possibility of their source being the wear of tire treads.
5. The determination of bromine and lead as indicators of auto exhaust emission particulates.

A manuscript reviewing some results of the tire studies has been submitted to the Journal of the Air Pollution Control Association. Lab personnel will give a talk on this work at the 162nd ACS National Meeting this September in Washington. Since the write-up was completed, much further work has been done, supporting the conclusion of the paper that the amount of airborne particulate debris from tires is small; where the rest of the 700,000 tons of tire tread rubber consumed annually in the U. S. disperses is still indeterminate. Another conclusion of this paper is that while the particulate matter from engine exhaust is far greater than that from the tires, the engine exhaust does not account for most of the particulate material dispersed by motor vehicles. The sources of this dispersed particulate material is still under investigation.

The Laboratory also has been using activation analysis of aerosol samples collected on filters as a reference procedure to evaluate the capability of x-ray fluorescence using semi-conductor detectors as a means of on-line analysis of atmospheric aerosol. The x-ray procedure, if found feasible and, if ready in time, will be used in a 3-month experiment in Pasadena next summer in collaboration with investigators from a number of other organizations. The development of this apparatus is being done mostly at the Radiation Laboratory in Berkeley. An Eastern Michigan University faculty member is helping with this project.

Publications in progress at this time include a paper concerning the determination of neoprene in rubber by activation analysis and one on the determination of sources of optical inhomogeneities in glass.

Publications:

1. Becknell, D., Marsh, R., Allie, W., "Use of Anion Exchange Resin Loaded Paper in the Determination of Mercury in Water by Neutron Activation Analysis," Anal. Chem., 43, 1230 (1971).

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., the Environmental Research Group, Inc., and BASF Wyandotte Corporation.

The Environmental Research Group, Inc. (ERG), has used the facilities of the Phoenix Memorial Laboratory and the Ford Nuclear Reactor to pursue a basic environmental study for six major utility companies currently building nuclear power plants on Lake Michigan.

This study involves measurement of some 35 trace elements in the basic members of the food chain in Lake Michigan. Reconcentration factors for these elements are being calculated and predictions will be made as to the pathways and concentrations that radioactive isotopes will follow if they are released into Lake Michigan. The staff of ERG presented the following papers and publications as a direct result of this study.

Publications:

1. "The Mercury Threat: Questions to Consider," Limnos, 3, 2, 11, (Summer 1970).
2. "Selenium and Mercury Distribution in Lake Michigan Invertebrates." Presented at the Geological Society of America Annual Meeting, November 11-13, 1970, Milwaukee, Wisconsin.
3. "Selenium, the Unknown Pollutant," Limnos, 3, No. 4, 7, (Winter 1970).
4. "Non-Destructive Neutron Activation Analysis of Environmental Samples." Presented at the 161st. American Chemical Society Meeting, Los Angeles, Calif., (April, 1971).

The BASF Wyandotte Corporation has used the facilities of the Michigan Memorial-Phoenix Project to test for and determine arsenic and chlorine in its products. This has been done both for trouble shooting and to set specifications on these products.

VI. CONCLUSION

During 1970-1971, as in previous years, the operation of the Ford Nuclear Reactor has provided major assistance to a wide variety of research and educational programs at the University of Michigan, programs at other universities, and 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 U. S. Atomic Energy Commission through the University Research Reactor Assistance Program has been instrumental in maintaining this continuous operation of the reactor facility.