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PROPOSAL FOR CONTINUED DEVELOPMENT AND APPLICATION OF SOME FAST NEUTRON DOSIMETRY TECHNIQUES UTILIZING PLASTIC TRACK DETECTORS FOR THERAPY AND HEALTH PHYSICS

Submitted to

U. S. Energy Research & Development Administration

by the

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PROPOSAL FOR CONTINUED DEVELOPMENT AND APPLICATION

OF SOME FAST NEUTRON DOSIMETRY TECHNIQUES

UTILIZING PLASTIC TRACK DETECTORS

FOR THERAPY AND HEALTH PHYSICS

by

M. Sohrabi and K. Z. Morgan
School of Nuclear Engineering
Georgia Institute of Technology

ABSTRACT

Electrochemical etching of fast-neutron-induced recoil particle tracks in polymers indicates it can be used successfully in health physics and therapy. An electrochemical chamber capable of processing large numbers of foils will be designed and combinations of parameters will be investigated for further improvements. Also methods will be explored to find foils having very low background counts or to remove the background. This would make the technique capable of detecting a single neutron track. Directional response needs to be improved and experiments will be carried out to further its reductions. Electrochemical etching behaves in a manner that is expected to lower the energy threshold for neutron detection. Various ion beams from the Georgia Tech Van de Graaff accelerator will be used to investigate this threshold and to further confirm our findings that proton tracks are registered in these foils. Experiments will be carried out to measure neutron contamination in photon beams in accelerators in some local hospitals where other attempts to make these measurements have been unsatisfactory.

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Introduction

Our previous published communications on the use of electrochemical amplification of fast-neutron-induced recoil particle tracks have found worldwide interest as a new approach to the problems of fast neutron dosimetry, in particular, fast neutron personnel dosimetry. The characteristics and advantages of this dosimetry technique as well as a brief description of some interesting and somewhat tantalizing results on the optimization of electrochemical etching parameters are given in the accompanying Progress Report.

While conducting this research and some concomitant studies, we encountered a number of clearly related, new, and interesting ideas which need to be investigated. Further, such investigations would be contiguous with the objectives of our present contract and would enable us to complete and improve this dosimetry approach as a standard dosimetry method with high accuracy for low neutron doses of interest.

Proposed New Research

The proposed new research areas are given briefly as follows:

1. For routine applications the electrochemical etching chamber should have the capacity of etching a large number of foils simultaneously. In our work in progress we are using chambers having a capacity of processing six foils simultaneously to demonstrate

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the feasibility for etching a number of foils. This would make the process very time consuming if a large number of foils were to be etched. Therefore, we are now planning to design a chamber having the capacity of etching a much larger number of foils. Such a chamber is of interest not only to us but also to vendors of film badge services, National Laboratories, and others concerned with large scale dosimetry programs. Improvements will be made also in the design of the chamber to minimize the volume of the etchant in the chamber as well as using fixed electrodes.

2. We should further verify the electrochemical etching parameters governing the etching process. Having about 10 different parameters allows many alternate approaches some of which we believe will lead to additional improvements.

3. For any dosimetry application, background counts will limit the accuracy of the measurements. This is true especially for low neutron doses of interest that are encountered in routine fast neutron personnel dosimetry. In our studies, we used polycarbonate foils obtained from various manufacturers. Some batches showed high background counts, being due for the most part to scratches caused by mishandling the foils in manufacturing, packaging, and shipping, and some high backgrounds were due to cosmic radiation when the foils had been kept in stock for a long time. A batch obtained from one manufacturer had a background track density as high as 500 ± 200 tracks/cm^2. Another batch obtained from one manufacturer had as low as 30 ± 15 tracks/cm^2. Therefore, when low neutron doses are of interest, background could seriously disturb the accuracy of the measurements.

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Attempts will be made to explore many foils obtained from a number of manufacturers and vendors as well as explore methods of removing these background tracks. If the background were removed or the polymer were completely free from these tracks, then any single track caused by cosmic radiation, or other low neutron dose (e.g. around nuclear facilities) could be detected with high accuracy and precision in the measurement.

4. Direct interaction of fast neutrons with polymers shows an inherent directional dependence as is the case with many other dosimeters. This directional dependence needs to be reduced to remove any uncertainties in the neutron dose determination for cases where the directions of neutrons might be known. In our paper given in Amsterdam (May, 1975), which is attached to our Progress Report, we reported some improvements by wrapping the foil around a Lucite tube. Satisfactory results were obtained but further work ought to be carried out to optimize the size of the foils and the diameter of the Lucite tube to prevent microscopic fractures in the foil materials. These small cracks in the foils must be avoided because they are amplified also by electrochemical etching and sometimes are difficult to distinguish from neutron induced tracks. In addition, other approaches will be explored and a personnel badge will be constructed.

5. So far, there has been an open question as to whether or not polycarbonate Lexan is insensitive to registration of proton tracks. Only carbon, oxygen, and nitrogen recoils having energy greater than a threshold value produce sufficient damage density

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to be revealed by conventional etching methods. Both theory and experiment seem to provide a neutron threshold energy in this case of about 1 MeV for neutron registration. However, electrochemical etching behaves quite differently from conventional etching. Based on some of our preliminary studies we believe that proton tracks can also be registered in Lexan polycarbonate and that in this case the neutron threshold energy should be lower than 1 MeV for electrochemical etching.

Experiments will be carried out using the Georgia Tech 1 MeV Van de Graaff accelerator. Several types of ions, e.g. protons, carbon, oxygen, etc. will be supplied and used at various energies. This will enable us to determine the energy threshold for track registration of ions, as mentioned above, as well as establish the threshold energy for neutron detection. This information is of great importance not only from the standpoint of practical application but also to resolve some interesting questions of theory.

6. Measurement of fast neutron contamination produced by photoneutron reactions in high energy x-ray beams of medical electron, betatrons, and linear accelerators is of considerable interest and importance to the medical physicist and radiotherapist. Because of the low percent of neutron contamination in the main x-ray beam, a detector having nil response to gamma and x ray is required. The usual method of looking for these neutrons has been activation analysis or fission fragment registration method. However, neither of these methods is quite satisfactory. For example, the fission fragment registration method, due to low threshold for photofission reactions (e.g. >5 MeV) shows sensitivity

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to x rays as well as to neutrons which should be corrected, and activation analysis is less satisfactory in some respects. Therefore, it is of considerable concern that other approaches be found. Our preliminary results have indicated the feasibility of our technique for this application. Therefore, we are proposing to investigate fast neutron contamination of high energy x-ray beams at Emory University Medical Center and Atlanta West Hospital.

As we promised in our original proposal, this continued research is expected also to make a significant contribution to the technology of fast neutron dosimetry, radiation protection, and therapy. In the course of these investigations we have accumulated some necessary equipment which we need for these and future studies. Therefore, in these studies our time will be more efficiently devoted to promote further these research activities.

Duration of the Proposed Research

The proposed research is intended to be completed within a period of 12 months which last from September 1, 1975 to August 31, 1976.

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PROPOSED BUDGET

9/1/75 - 8/31/76

A.	Direct Salaries and Wages	
	1. Principal Investigators:	
	Mehdi Sohrabi* (full time)	$17,000
	Karl Z. Morgan** (½ time academic yr.)	6,000
	2. Machine Shop	600
	TOTAL DIRECT SALARIES AND WAGES	$23,600
	3. Retirement Benefits: 8.77% of applicable salaries and wages	1,491
	TOTAL DIRECT SALARIES, WAGES AND RETIREMENT BENEFITS	$25,091
B.	Materials and Expendable Supplies	2,500
C.	Report and Publication Costs	400
D.	Travel	550
E.	Indirect Costs	11,440
	At a predetermined, fixed rate of 65% of Direct Salaries and Wages as established by the Naval Material Command upon advisory audit by the Defense Contract Audit Agency	
	TOTAL PROJECT COST	$39,981

* Mr. Sohrabi is expected to complete the requirements for the Ph.D. degree in the Summer of 1975. He has 6 years of related experience in addition to the time spent as a graduate student.

** No overhead charges will be made against K. Z. Morgan who will be employed as a consultant because he has reached age of forced retirement.

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Project Personnel

Karl Ziegler Morgan was born in Enochsville, North Carolina on [redacted]. He received the [redacted] and [redacted] degrees from the [redacted], respectively, and the [redacted] degree [redacted]. From 1934 to 1943 he was chairman of the Physics Department of Lenoir Rhyne College, and during this period did research in cooperation with Duke University in the field of cosmic ray showers, the meson lifetime, etc. in Linville Caverns, on Mt. Mitchell, Beech Mountain, Mt. Evans, etc.

He joined the Metallurgical Laboratory staff at the University of Chicago in the spring of 1943. Here he was one of a group of six persons who developed and established the new science and profession of health physics. During the fall of 1943 he transferred to Oak Ridge National Laboratory where, until the latter part of 1972, he was director of the Health Physics Division which was engaged in research, engineering, and applied problems. Upon leaving Oak Ridge National Laboratory he joined the faculty of the Georgia Institute of Technology as Neely Professor in the School of Nuclear Engineering

In 1956 he was the first president of the Health Physics Society and from 1966 to 1970 was the first president of the International Radiation Protection Association which has about 10,000 members in some 65 countries. He now is President Emeritus of IRPA, an Emeritus member of the Main Commission of ICRP, and a member of NCRP. For 20 years he was chairman of the committees of ICRP and NCRP dealing with maximum permissible internal dose of radioisotopes. He has published over 250 papers dealing with subjects of cosmic rays, radiation protection, instrumentation, internal dose, and

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general health physics. He is editor of the journal HEALTH PHYSICS.

In 1962, K. Z. Morgan and W. Binks (England) were awarded the first gold medals for meritorious work in the field of radiation protection by the Royal Academy of Science of Sweden.

Morgan received the Distinguished Alumni Award and the honorary Doctor of Science Degree from Lenoir Rhyne College, honorary membership in Sigma Pi Sigma from Berea College, and the First Distinguished Service Award of the Western Chapter of the Health Physics Society. He is a member of the Health Physics Society, the International Radiation Protection Association, the American Public Health Association, the American Association for the Advancement of Science, the American Industrial Hygiene Association, the Research Society of America, the Radiation Research Society, the Society of Nuclear Medicine, the American Association of Physicists in Medicine, the American Association of Physics Teachers, an Associate Fellow of the American College of Radiology, a Fellow of the American Physical Society and of the American Nuclear Society, and an Affiliate of the Royal Society of Medicine.

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Major Publications of the Last Five Years

1. "Common Sources of Human Exposure to Ionizing Radiation in the United States," American Engineer, July 1968.
2. "Ionizing Radiation: Benefits Versus Risks," Annual Meeting of the Health Physics Society, June 16-20, 1968, Denver, Colorado; and published in HEALTH PHYSICS, Vol. 17, No. 4.
3. "Assumptions Made by the Internal Dose Committee of the International Commission on Radiological Protection," Sixth Annual Meeting of the Gesellschaft fur Nuclearmedizin, Wiesbaden, Germany, September 26-28, 1968; Published in Proceedings, 1969.
4. "Redirecting Health Physics Studies to Areas of Greatest Interest," First European Congress of the International Radiation Protection Association, Menton, France, October 9-11, 1968; Published in Proceedings, 1968.
5. "The Need for Standardization Procedures in the Application of Ionizing Radiation to Medical and Dental Patients," Seminar sponsored by the National Center for Radiological Health, Rockville, Maryland, November 15, 1968, Seminar Paper 003.
6. "The Proper Working Level of Radon and Its Daughter Products in the Uranium Mines of the United States," Hearing on Radiation Standards for Mines, Washington, D. C., November 20, 1968; Congressional Record, 1968.
7. "Supplemental Statement on the Proper Working Level of Radon and Its Daughter Products in the Uranium Mines of the USA," Supplement to Testimony presented on November 20, 1968, Washington, D. C.; Congressional Record, 1968.
8. "Future Opportunities in Health Physics," Health Physics Society Midyear Topical Symposium, Los Angeles, California, January 29-31, 1969.
9. "Risks from Diagnostic X-Rays," Yale Scientific, Vol. XLII, No. 5, February 1969; Reprinted from Yale Scientific in the Journal of the American Radiography Technologists, Vol. XIV, No. 4, Winter 1969.
10. "Radiation Standards for Reactor Siting," Testimony presented before the Joint Committee on Atomic Energy at its Hearings on Environmental Effects of Producing Electrical Power, Phase 2, January 1970; Congressional Record.
11. "Energy Pollution of the Environment," Midyear Symposium of the Health Physics Society, Louisville, Kentucky, January 28, 1970; Proceedings published in USPHS-BRH Series.
12. "A Time of Challenge to the Health Physicist," Presidential Address presented before the Second International Congress on Radiation Protection, May 8, 1970, Brighton, England; Health Physics, Vol. 20, May 1971, pp. 491-498.
13. "My Opinion--You Can Drastically Cut X-Ray Exposure Below Today's Levels," Consultant, March/April 1970.
14. "History of the Health Physics Society," published as part of the RSNA Symposium on the Critical History of American Radiology (Nov. 1970).
15. "History of the International Radiation Protection Association," published in Proceedings of the RSNA Symposium on the Critical History of American Radiology, November 1970.
16. "Criteria for the Control of Radioactive Effluents," IAEA Symposium on Environmental Aspects of Nuclear Power Stations, UN Building, New York, August 1970, Proceedings published, this paper is IAEA-SM-146/10; synopsis published also in Environmental Studies, 1971.

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17. "Maximum Permissible Levels of Exposure to Ionizing Radiation," International Summer School on Radiation Protection, Boris Kidric Institute of Nuclear Sciences, Cavtat, Yugoslavia, September 20-30, 1970; Proceedings published in 1971 under title of "Radiation Dosimetry."
18. "President's Report to the General Assembly of IRPA," Brighton, England, May 1970, Health Physics, Vol. 20, No. 5, 1971.
19. "History of Radiation Protection," Symposium Commemorating the 75th Anniversary of the Discovery of X-Rays, Milwaukee, November 13-14, 1970; Materials Evaluation, Vol. XXIX, No. 3, March 1971.
20. "Why the 1968 Act for Radiation Control for Health and Safety Is Required," Radiology, Vol. 99, No. 3, pages 569-588, June 1971.
21. "Excessive Medical Diagnostic Exposure," Third Annual National Conf. on Radiation Control, Scottsdale, Arizona, May 3, 1971; Published in Proceedings.
22. "Health Physics and the Environment," International Symposium on Rapid Methods for Measurement of Radioactivity in the Environment, Neuherberg, Federal Republic of Germany (Proceedings published by IAEA).
23. "Adequacy of Present Radiation Standards," presented at the Environmental and Ecological Forum, Silver Spring, Maryland, January 20, 1971; Proceedings of Forum published in 1972.
24. "Proper Use of Information on Organ and Body Burdens of Radioactive Material," presented at the IAEA/WHO Symposium on the Assessment of Radioactive Organ and Body Burdens, Stockholm, Sweden, November 22-26, 1971, IAEA/SM/150-50; Proceedings of Symposium published by IAEA.
25. "Health Physics Measures to Implement New USAEC Regulations Relating to Radiation Exposure of the General Public," Budapest, May 1971; Proceedings published.
26. "The Need to Reduce Medical Exposure in the United States," outline of testimony presented before the Health and Welfare Subcommittee of the Senate Committee on Labor and Public Welfare on Senate Bill S.3327, May 15, 1972, Washington, D. C.; published in Congressional Record, 1972.
27. "Environmental Impact of Natural and Man-Made Ionizing and Non-Ionizing Radiations," Second Health Physics Summer School, Herceg Novi, Yugoslavia, August 1973; Proceedings published 1974.
28. "The Need for Radiation Protection," Radiologic Technology, 44, no. 6, 385-395, 1973.
29. "Possible Consequences of Excessive Medical Exposure in the United States," Given before the Fachverband für Strahlenschutz at the Bern, Switzerland meeting, March 21, 1973 and published in the Fachverband Proceedings 1973.
30. "Transportation of Radioactive Material by Passenger Aircraft," committee report to the Joint Committee on Atomic Energy of Congress, Congressional Record, Sept. 17, 1974.
31. "Biological Effects of Ionizing Radiation," published in Proceedings of Short Course, Sept. 9, 1974.
32. "Reducing Medical Exposure to Ionizing Radiation," J. Amer. Industrial Hygiene Assn., 36, 5, 358 (May 1975).
33. "Appropriateness of Regulations for Air Shipment of Radioactive Materials," Miami Beach, Fla., Sept. 23, 1974, International Conf. on Shipping of Radioactive Material, Proceedings to be published (1975).
34. "Health Physics--Past, Present and Future," Published in Proceedings of First Asian Congress of the International Radiation Protection Association, Dec., 1974.

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35. "Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements," in press and to be published in J. of Amer. Industrial Hygiene Assn. (probably July 1975).
36. "Effects of Radiation on Man," Proceedings of Short Course on Energy and the Environment--Cost-Benefit Analysis to be published by Pergamon Press (1975).
37. Chapters on "Ionizing Radiation Exposure" and on "Exposure to Non-Ionizing Radiation" in text, Environmental Problems in Medicine, Ed. W. D. McKee; publisher, Chas. C. Thomas, 1974.
38. "Recent Developments in Fast Neutron Personnel Dosimetry Using Track Etch Methods," Proc. 3rd European Cong. IRPA, Paper 14, Amsterdam, The Netherlands (May 1975), with Mehdi Sohrabi.

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BIOGRAPHICAL SKETCH

SOHRABI, MEHDI -- [redacted]

Education

[redacted]

Employment History

National Iranian Oil Co., Trainee in Mechanics	1965
Army of Iran, 2nd Lieutenant	1966-1967
Tehran University Nuclear Ctr., in charge of reactor Health Phys	1967-1970
Officer's College, Instructor	1968
Oak Ridge National Laboratory, Alien Researcher	1970-1971
Georgia Institute of Technology, Graduate Assistant	1972-Present

Experience Summary: While working at the Tehran University Nuclear Center, Sohrabi was responsible for personnel monitoring, calibration of instruments, shielding inspections of radiology departments of the hospitals, and dosimetry research. Since the Tehran Univ. Research Reactor, a 5 MW swimming pool type reactor, became critical, he was in charge of reactor health phys. Meanwhile, he was involved in teaching college physics, mechanics, and health physics at the Univ. of Tehran and other colleges. He attended many programs such as Applications of Radioisotopes in Medicine, Agriculture, and Industry--Handling of Radiation Accidents--Dosimetry Intercomparison held by the International Atomic Energy Agency. He has been active in establishing the Iranian Radiation Protection Association and has been a member since its inception.

In August 1970, under the sponsorship of the IAEA and the National Academy of Sciences, Sohrabi was sent to the DOSAR, Health Physics Div. at ORNL where, under the direction of Drs. Karl Z. Morgan, John A. Auxier, and Klaus Becker, he did some solid state dosimetry research. Since 1972 he has been pursuing a Ph.D. degree in Nuclear Engineering with a specialty in Health Physics. Meanwhile he has been studying, teaching, demonstrating laboratory experiments, and doing research. He is a member of the Iranian Radiation Protection Association, Health Physics Society, and the Society of Sigma Xi.

Reports, Publications and Papers

1. "Electrodeposition of U-238 and its application in fast neutron dosimetry by fission fragment registration in silver activated phosphate glasses," M.S. Thesis, Tehran University Nuclear Center, 1969.
2. "Some studies on the application of track etching in personnel fast neutron dosimetry," M.S. Thesis, University of Tennessee, ORNL-TM-3605, 1971.
3. "Fast neutron personnel monitoring by fission fragment registration from Np-237," Nucl. Inst. Methods, 104, 409 (1972).
4. "Fading characteristics of various films and solid state dosimeters in a warm and humid climate," Paper 58, 17th Annual Meeting, Health Physics Soc., Las Vegas, 1972.
5. "Literature review of the proposed research; Fast neutron microdosimetry by plastic track detectors inside heterogeneous phantoms," in partial fulfillment of the Ph.D. degree, Ga. Institute of Technology, 1973.

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Reports, Publications and Papers (Cont.)

6. "Electrochemical Amplification of Recoil Particle Tracks in Polymers and Its Application in Fast Neutron Personnel Dosimetry," Health Physics, 27, 598 (1974).
7. "Recent Developments in Fast Neutron Personnel Dosimetry Using Track Etch Methods," Proc. 3rd European Cong. IRPA, Paper 14, Amsterdam, The Netherlands (May, 1975) with Karl Z. Morgan. See also Trans. Am. Nuc. Soc. Student Conf, p. 24 (1975). (This paper was awarded as the best paper of the Health Physics Session at the American Nuclear Society Student Conference.)
8. "Electrochemical Amplification of Fast-Neutron-Induced Recoil Particle Tracks in Polymers for Therapy and Radiation Protection," Ph.D. Dissertation (1975), in preparation.

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Support Facilities at Georgia Tech

The facilities most closely related to teaching and research in the nuclear engineering programs at Georgia Tech are located in the Cherry L. Emerson Building and the Frank H. Neely Nuclear Research Center.

Cherry L. Emerson Building

The School of Nuclear Engineering occupies about 24,000 square feet in the Emerson Building. This space contains ample classrooms, student laboratories and offices, as well as a periodical library, staff machine shop, electronics shop, seminar room, computation lab and a large, two-story bay with a ten ton crane. The latter space houses the nuclear engineering laboratory. The counting rooms and other laboratories have been well equipped with conventional radiation detection instruments (including several multichannel analyzers) in sufficient numbers to accommodate laboratory sections of 12-15 graduate students.

Specialized equipment available in the Emerson Building to nuclear engineering students includes:

an AGN-201 training reactor

a natural uranium-light water subcritical assembly

100 μgram Cf-252 source

Korad K-15 pulsed ruby laser

three EAI Model TR-20 analog computers

a 12,000 curie Cs-137 gamma source

a one MeV Van de Graaff positive particle accelerator with beam analysis system

50 and 250 KVP X-ray machines

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several gas chromatographs

eleven radioisotope fume hoods and three glove boxes

vacuum deposition system

The training reactor is located in the nuclear engineering laboratory. It is used in laboratory exercises and for special student problems and theses. The GTRR continues to be available for all pedagogical experiments and research which require its higher flux.

Nuclear Research Center

The Frank H. Neely Nuclear Research Center, valued at $4,500,00, was completed in 1964. The Georgia Tech Research Reactor (GTRR) which serves as the key component of the Center is a heterogeneous, heavy-water moderated and cooled type, fueled with enriched uranium. It is similar in design to the Argonne Research Reactor, CP-5, which has demonstrated excellent research capability and dependable service. The GTRR has been designed to develop a sustained power output of five megawatts with a corresponding thermal neutron flux of about 10^{14} neutrons/cm^2. The reactor has a variety of experimental facilities (such as beam tubes, through-tubes, pneumatic tubes, fast flux facility, biomedical facility, thermal column, and gamma facility) to provide for a wide range of experiments. The GTRR currently operates at a power of one megawatt two or three shifts per day. It currently is undergoing modification to increase power to the full, rated level of 5 megawatts.

The reactor and associated systems are housed in a steel containment building eighty feet in diameter and sixty-five feet in height. The adjoining 24,000 square foot, two-story, air-conditioned laboratory and office building contains laboratories for radiochemistry, health physics, materials preparation, nuclear spectroscopy, low-level counting, radiobiology, electronics, as well as a machine shop and a large animal quarters.

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Equipment at the Frank H. Neely Nuclear Research Center includes:

5 megawatt, heavy-water research reactor

three neutron diffractometers

time-of-flight neutron spectrometer

experimental set-up for pile oscillator measurements

50,000 curie hot cell with master-slave manipulators

20' x 6' x 18' deep storage pool joined to hot cell by transfer chute

neutron generator--200 keV TMC Activatron Model 211, (d,n) reaction with tritium producing 14 MeV neutron peak intensity of 2×10^{14} n/sec

gamma facility--spent fuel element storage in pool provides gamma rates to 10^6 R/hr depending on sample geometry

100,000 curie cobalt irradiation source

intermediate level radiochemistry laboratory (18' x 26') with radioisotope hoods, shielded glove boxes

facilities for treatment, storage, and handling of solid and liquid radioactive wastes, including retention tanks of 8,000 gallon capacity

Model 33 teletype terminal providing remote computer access on and off campus

PDP-8 computer system

PDP-12 computer

The data acquisition system consists of two data processors (PDP-8, PDP-8/I), with appropriate peripheral devices for use in sophisticated experiments requiring on-line analysis and control, as well as data collection. One of the processors is located within the reactor containment building and is intended for use by experimenters with a minimum of setup time. A rather sophisticated interface for accepting both digital and analog signals is operational. There is a communications link to the other processor, located in the laboratory portion of the Center, which acts as a data collection center for several experiments and a secondary processor. Both processors function (with lower priority) as a data reduction and preprocessing facility, and as such are generally available for use 24 hours a day. The PDP-12 computer is also available to this project if required.

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Computer Facilities

The Rich Electronic Computer Center is housed in a modern reinforced concrete and brick building. Especially designed to accommodate computer facilities, the plant contains approximately 6,000 square feet of space used for equipment and offices.

Two computers with associated card and tape-handling capabilities are presently in operation at the Computer Center. These are:

1. Burroughs B-5500 with 32,000 48-bit words for core memory and 3.6 million 48-bit words of disc memory. High speed card readers and line printers are also provided. This machine also has multiplexing capability.

2. In 1975, a Control Data Corporation CYBER 70 Model 74-28 replaced Univac-1108 Shared Processor system. Also a Control Data Corporation 6400 replaced an IBM 360/30. Both computer systems are dedicated to the support of education and research.

The Computer Center maintains an extensive library of frequently used computer programs. In addition to the programs available for immediate use in the library, the Center participates in program-sharing plans with other computer users, which effectively increases the extent and scope of its own library.

Library

The Price Gilbert Memorial Library is a centralized scientific, technical, and management collection of 679,000 volumes plus six hundred thousand microtext and other bibliographic units. Outstanding collections in the fields of science and engineering have been developed to support graduate study and research. It is housed in adjoining structures totaling 240,000 square feet of space. It can house over one million volumes and can seat two thousand users. The library's United States Patent specification collection is the only one in the Southeastern area. In 1962, the library was designated one of twelve Federal Scientific Report Centers and its collection of reports from the Atomic Energy Commission, the Department of Defense, the National Aero-

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nautics and Space Administration, and the Clearinghouse for Scientific and Technical Information now totals over 490,000 titles. Extensive files of standards issued by American associations and societies and a complete file of U. S. Military Standards and Specifications and of British Standards are maintained. The Library is also a depository for United States government publications issued by the Government Printing Office, and for maps issued by the Army Map Service. Available on microfilm are more than 6,000 company catalogs providing information on industrial components.

Other Facilities

Georgia Tech has many other facilities closely allied with the nuclear engineering program including, for example, various facilities operated by Divisions of the Engineering Experiment Station. Among these are specialized laboratories utilizing X-ray equipment, optical and electron microscopes, emission and absorption spectroscopes, analog computers, microwave systems, cryostats and many other research devices. In addition, close cooperation exists between the School of Nuclear Engineering and other Schools of the Engineering College and the School of Physics.

In addition to the facilities available on the Georgia Tech campus, Oak Ridge National Laboratory, which is located about three hours driving time from Atlanta, has radiation sources of our interest and, under a subcontract No. 3921, we have easy access to these facilities. In particular, the Health Physics Research Reactor, which is a bare, unmoderated reactor facility having a neutron leakage spectrum of 1.5 MeV average energy, is available to us. This facility and the DOSAR low-energy neutron generator are considered as two sources of neutrons in addition to those at Georgia Tech.

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