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TECHNICAL PROGRESS REPORT

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Washington University

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SUMMARY REPORT ON CYCLOTRON UTILIZATION,
OPERATIONAL ACHIEVEMENTS, AND IMPROVEMENTS
DURING TWELVE MONTHS ENDING MAY 31, 1974

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INTRODUCTION

The Nuclear Chemistry group in the Chemistry Department at Washington University comprises a substantial group of faculty members, post-doctoral research associates, and Ph.D.-candidate graduate students actively conducting research in this field. Their specific interests include studies of fission processes, nuclear reactions, nuclear spectroscopy with particular emphasis on precision gamma-ray measurements and study of very short-lived radionuclides, measurement of exceedingly short lifetimes of excited nuclear states before electromagnetic decay, and investigations of chemical reactions in which the participating atoms have been formed in some preceding nuclear reaction, and hence are moving with substantial velocities (hot atom chemistry). Most of their projects are funded through research contracts with the U. S. Atomic Energy Commission, but some are supported in other ways. The number of faculty involved is five, while the number of graduate students consistently stays in the neighborhood of 15 to 20. Over the past 8 years the research done by these persons has culminated in 13 doctoral theses and 113 published research papers.

Most of this research is carried on in the Washington University Cyclotron Laboratory, located on the University's main campus immediately adjacent to the Nuclear Chemistry Laboratory. The Cyclotron Laboratory houses a 54-inch sector-focused cyclotron, thin-target preparation facilities, a high quality machine shop,

an electronics shop and a variety of research spaces, augmenting those available in the Nuclear Chemistry Laboratory next door and including a centralized data-acquisition station in the cyclotron control room. The Laboratory's staff currently includes seven full-time (or nearly full-time) engineers, technicians, and machinists, plus several persons part-time (secretary, part-time cyclotron operators). This staff maintains and operates the accelerator, assists users in utilizing it for their investigations, designs and constructs a great deal of the specialized operation equipment which is needed, develops and perfects new modes of utilizing the accelerator and its peripheral facilities, and works continuously to improve the accelerator's performance characteristics and its usefulness to its users. The machine shop and its three machinists, in addition to sharing in these normal staff functions, are also available for fabrication of research apparatus (as distinguished from operating equipment) for cyclotron users who lack facilities of their own or who feel that the Cyclotron Laboratory shop offers special advantages in experience and expertise. The engineers of the staff devote considerable time and effort to the design and development of this kind of apparatus, in addition to more directly cyclotron-related functions. This staff is particularly notable for its accumulated experience and skill in meeting the esoteric demands made on them. Five of its seven full-time members have been with the Laboratory for 13 years or more, two of them for more than 20 years.

Funding for the Cyclotron Laboratory's normal activities is provided from four sources:

- (1) the U. S. Atomic Energy Commission, through a Special Research Support Agreement Contract AT(11-1)-1760,
- (2) Washington University, through its contribution to contract AT(11-1)-1760,
- (3) various research users of the Laboratory's facilities, via purchases of cyclotron time (if the research is not supported by the AEC), or of shop time, or by assuming partial or total responsibility for some wages and salaries, and
- (4) sale of cyclotron-produced isotopes to hospitals.

The fraction of the Laboratory's support which is provided jointly by Washington University and the Atomic Energy Commission via contract AT(11-1)-1760 (items 1 and 2 above) is only sufficient to maintain a "basic minimal level of operation." This fraction covers daytime (only) operation for a five-day week (i.e., 35 hours per week, excluding start-up time each morning), plus maintenance and repairs, and would permit only a small effort on development of improvements. It covers some but not all of the staff salaries, minimal purchases of expendable materials and replacement or procurement of equipment, minimum electrical power, plus indirect costs (based on salaries) sufficient for that basic level of operation. It definitely does not cover the additional costs which are incurred when operations are expanded beyond this "basic" level.

Since November, 1967, when contract AT(11-1)-1760 first went into effect, the Cyclotron Laboratory's level of operations have always proceeded at a much higher rate than the "basic

minimal level." Extensive use has been made of both evening and weekend operation, on a regularly-scheduled format; part-time operators have been hired and trained to handle the extended operations; a second machinist (and more recently a third) has been employed both to help with the additional maintenance burden and to increase the shop's capability to serve the users through construction of research apparatus; and the necessary additional electric power and other expenses have been provided. The additional funding to cover expanded operations has been obtained from various sources, as summarized in item (3) above, supplied by users through purchases of cyclotron time and shop time, etc. Whenever the available extra income has been inadequate we have been forced to limit the amount of part-time operator employment, and have instead encouraged researchers to function as their own machine operators during night and weekend runs. This is not a desirable practice, because inexperienced operation unfortunately often leads to excessive maintenance and repairs later. Usually, however, the amount of "outside" income has roughly approximated the need, and, in particular, has been sufficient to employ a second machinist full time for the last several years and to add a third machinist this year. During this period, we have consistently been able to schedule up to 105 hours of cyclotron time per week for our users and for routine maintenance, compared with the 35-hour "basic" capability. Fortunately, the cost for providing additional time is considerably smaller per hour than is required for the "basic" level, which includes large items for salaries and indirect costs.

This Technical Progress Report contains a summary of opera-

tions and accomplishments for the Cyclotron Laboratory covering the 12 months ending May 31, 1974 when the preparation of this Report was begun. Reference may be made to similar earlier reports (COO-1760-1, -2, -3, -4, -5, -6), covering operations in the preceding years since November 1, 1967, when contract AT(11-1)-1760 first started. The remainder of the Report has three sections:

- (a) Summary of Cyclotron Use During the Year
- (b) Improvements
- (c) Other Expenses, Other Income.

For reference, several figures have been included. Fig. 1 shows a plan view of the cyclotron vault and the adjacent research apparatus area, separated by a concrete shielding wall, while Fig. 2 shows the positions of several important modules in the beam extraction system. Fig. 3 pictures the principal data-acquisition station, also in the control room. The remaining figures relate to the section on Improvements.

FIGURE 1

Fig. 2

NORMAL BI-WEEKLY SCHEDULE

<u>Day of Week</u>	<u>First Week</u>	<u>Hours</u>	<u>Second Week</u>	<u>Hours</u>
Monday	Maintenance and Improvements	4	Maintenance and Improvements	4
	Sarantites (C)	11	Macias (C)	11
Tuesday	Nuclear Medicine (R)	1	Nuclear Medicine (R)	1
	Welch (C)	2	Welch (C)	2
	Wahl (C), Gaspar (C) deuteron runs to obtain neutrons	7	Wahl (C), Gaspar (C) deuteron runs to obtain neutrons	7
	Cooling off period	1	Cooling off period	1
	Sarantites (C)	4	Sarantites (C)	4
Wednesday	Sarantites (C)	15	Macias (C)	15
Thursday	Sarantites (C)	15	Macias (C)	15
Friday	Nuclear Medicine (R)	1	Nuclear Medicine (R)	1
	Welch (C)	2	Welch (C)	2
	Wahl (C), Gaspar (C) deuteron runs to obtain neutrons	7	Wahl (C), Gaspar (C) deuteron runs to obtain neutrons	7
	Cooling off period	1	Cooling off period	1
	Sarantites (C)	4	Macias (C)	4
Saturday	Sarantites (C)	15	Macias (C)	15
Sunday	Sarantites (C)	15	Macias (C)	15

(C) = Department of Chemistry
(R) = Department of Radiology

SUMMARY OF CYCLOTRON USE DURING THE YEAR

Use of the Washington University cyclotron is characterized by the wide variety of research projects and the highly diverse experimental techniques and procedures that are involved. Prof. Gaspar wants fast neutrons, to produce energetic nuclear reactions in gaseous targets, so that the recoiling atoms become free to take part in relatively isolated succeeding chemical reactions. Prof. Wahl needs slow neutrons to induce fission reactions. Profs. Sarantites and Macias are concerned with charged-particle reactions induced with well-collimated beams delivered to a variety of apparatuses. Prof. Welch is principally concerned with the production of radioisotopes having useful or potentially useful properties in diagnostic tracer work or therapy for medical applications. Prof. Wahl is also interested in on-beam preliminary testing of apparatus designed to search for the possible production of eka-radon in experiments using very massive accelerated particles from the Berkeley Superhilac. Including post-doctoral associates and graduate students, the Laboratory generally is serving about 25 different users working on 10 to 12 different specific projects over a given period. All of these are eager for frequent time on the machine, and would be ill-served by a system giving them a concentration of several days of use but at long intervals. Instead, we have operated for several years on a biweekly schedule, under which all regular users are accommodated with one or more

scheduled periods of use every week (bi-weekly for some). This entails 20 or more shifts each two weeks in the mode of cyclotron operations, sometimes two or three within a single day, frequently requiring a switch from one accelerated particle type to another or at least a change in energy, and usually a switch in the site to which the beam is delivered. Despite the impression of inefficiency in such a procedure, it really works quite effectively, and the operating staff has developed over the years a technique and facility for frequent, rapid changes of operational mode.

The Bi-Weekly Schedule

This schedule (page 6) undergoes revision by negotiation among interested parties at irregular intervals. An attempt has been made to achieve a fair balance of assignment of both prime time and non-prime time to the regular users. Prime time includes the forty daytime hours per week on weekdays from 8:30 a.m. to 4:30 p.m., when the full-time operating staff is on duty and operation of the machine may be expected to proceed most smoothly and expertly. Non-prime time includes seven additional hours in the evenings on weekdays, plus 15 hours each Saturday and Sunday, when operation is managed by part-time operators.

Prime time is almost entirely consumed by Chemistry Department users, more or less equitably divided according to the bi-weekly schedule. The only exceptions are (1) 4 hours weekly for regular maintenance and improvement work by the Laboratory staff and (2) a small weekly assignment to work for the Division of Nuclear Medicine of the School of Medicine, because it requires supervision by full-

time staff members. Non-prime time is entirely used by Chemistry Department users, notably Profs. Sarantites and Macias, who are most likely to be able to use relatively long use periods on single projects. By contrast, the needs of Profs. Wahl, Gaspar, Welch, and the Nuclear Medicine people are best served by very short use periods, usually one or two hours, characterized by very intermittent beam delivery to targets in many instances.

Summary of Actual Use

Four tables (I, II, III (4 pages) and IV) at the end of this section present numerical data concerning actual use during the twelve months, June 1, 1973 to May 31, 1974. Two different time units appear in these tables:

1. Machine hours. This measures time during which the occupancy of the machine by one user precludes any utilization of it by another user, whether or not the occupant is actually delivering beam to a target, or is instead waiting between bombardments (e.g., for necessary chemical processing to be completed) or because of a temporary breakdown of apparatus or the need to make adjustments. The bi-weekly schedule is expressed in machine hours.
- ii. Beam hours. This essentially measures only the length of time during which beam is delivered to a target. The clock runs only while r.f. power is being supplied to the dee.

In Table I, use is analyzed month by month, both in machine hours and beam hours. The total use of 2757.5 machine hours amounts

to 50.5% of the 5460 assigned machine hours scheduled in the bi-weekly schedule (52 weeks x 7 days x 15 hours). This is a substantial increase over the preceding year (2135 machine hours). Another 4% went into regularly scheduled maintenance periods (all on prime time). Note that beam hours used amount to about 65% of machine hours, somewhat up from last year's 60%.

Table II (same page as Table I) shows how the total 1779.3 beam hours was divided among the various kinds of accelerated particles requested. Use of deuterons (mostly to produce neutrons) held about level with last year, as did the demand for alphas, which are still the most-used. But requests for helions went up substantially, while the increase in proton usage was dramatic, almost tenfold compared to last year, when Prof. Sarantites deliberately held back on new work with proton-induced reactions while digesting and preparing for publication a large backlog of accumulated data from earlier experiments.

Table III breaks down the consumption of machine hours further, first according to prime time (first two pages) and non-prime time (last two pages) and second according to the names of the principal investigators involved. Post-doctoral associates and graduate students are grouped in association with the faculty member with whom they work. The designations (C), and (R) refer to association with the Departments of Chemistry and Radiology, respectively. The total of 2757.5 machine hours divides 1794.5 during prime time and 963.0 during non-prime time. Thus 86% of the scheduled prime time machine hours were actually used (1794.5 out of 2080), while 28% of the scheduled non-prime machine hours were actually used

(963.0 out of 3380). The relevant point, however, is that the availability of non-prime time made possible about 35% of the actual usage of machine time (963.0 out of 2757.5), or, put another way, made possible a more than 50% increase over what could have been done on prime time alone.

Another datum derivable from Table III is the fraction of total machine hours which were used by Chemistry Department researchers (Profs. Wahl, Sarantites, Macias, Gaspar, Welch and their students or post-doctoral associates), mostly on projects which are supported by the AEC via research contracts. Of prime time, chemistry users accounted for 1756.5 out of 1794.5 hours used out of a total 2080 hours scheduled (the remainder mostly went into the scheduled 4 hours weekly for regular cyclotron maintenance -- over 200 hours). Turning to non-prime time, the same chemistry users consumed 933.5 out of 963.0 hours used, the bulk of it by Profs. Macias and Sarantites.

As in prior annual reports, Table IV has been included to illustrate the diverse requests for particle type and different energies, each requiring a different tuning combination of magnetic field and dee frequency, with corresponding alternations in the focusing currents used in the beam quadrupole magnets and steering magnets if external beam is needed.

Table I. Monthly Actual Use

6-1-73 to 5-31-74

<u>Month</u>	<u>Machine Hours</u>	<u>Beam Hours</u>	<u>Maintenance and Improvement Hours</u>
June 1973	245.0	158.7	16.0
July	207.5	123.3	16.0
August	254.4	143.3	16.0
September	281.5	153.8	16.0
October	350.5	257.2	16.0
November	308.0	247.3	16.0
December	124.0	72.3	16.0
January 1974	210.5	135.8	16.0
February	119.5	64.7	16.0
March	269.5	169.8	16.0
April	154.0	80.5	16.0
May	233.0	172.6	16.0
	<hr/>	<hr/>	<hr/>
	2757.5	1779.3	192.0

Table II. Breakdown of Beam Hours by Ion Type

Helium 3	526.6
Alphas	628.6
Deuterons	164.9
Protons	434.5
Carbon 12	24.7
	<hr/>
	1779.3

Table III - Part I

6-1-73 to 5-31-74 Machine Hours. Prime Time (8:30 A.M. - 4:30 P.M. Monday - Friday)

	<u>1973</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>
Dr. Gaspar (C) D. Holten, R. Hwang B. Mizes		31.5	18.0	16.5	10.0	16.0	18.0	10.0
Dr. Macias (C) H.C. Hseuh, M. Zalutsky		32.0	56.0	54.5	59.5	48.5	34.0	29.5
Dr. Sarantites (C) Dr. Barker, Dr. Urbon Dr. Xenoulis, Dr. Rutledge R. Braga, R. Goldworm		54.5	24.0	53.0	84.5	65.0	70.5	38.0
Dr. Ter-Pogossian (R) Dr. Phelps, Dr. Hoffman		----	----	----	4.0	1.5	----	----
Dr. Wahl (C) Dr. Goth, R. Strickert, G. Erhardt, E. Vine		27.5	26.0	23.0	25.0	35.5	20.0	10.0
Dr. Walker (P) Dr. Zimmerman		1.0	3.5	----	----	----	----	----
Dr. Welch (C) & (R) Dr. Krohn, J. Frost L. Knight		4.5	10.5	10.0	11.5	13.0	18.5	8.5
Nuclear Medicine		10.5	----	----	----	----	----	----
Bio-Medical Computer Lab.		----	----	----	----	----	1.0	----
St. Louis University		1.0	----	----	----	----	----	----
Total		<u>162.5</u>	<u>138.0</u>	<u>157.0</u>	<u>194.5</u>	<u>179.5</u>	<u>162.0</u>	<u>96.0</u>

Table III - Part II

6-1-73 to 5-31-74 Machine Hours. Prime Time (8:30 A.M. - 4:30 P.M. Monday - Friday)

	1974	Jan.	Feb.	March	April	May	Totals
Dr. Gaspar (C) D. Holten, R. Hwang B. Mizes		10.0	14.0	19.0	16.0	14.0	193.0
Dr. Macias (C) H.C. Hseuh, M. Zalutsky		48.0	32.0	24.0	22.0	32.0	472.0
Dr. Sarantites (C) Dr. Barker, Dr. Urbon Dr. Xenoulis, Dr. Rutledge R. Braga, R. Goldworm		50.5	16.5	72.0	48.0	40.0	616.5
Dr. Ter-Pogossian (R) Dr. Phelps, Dr. Hoffman		----	----	4.5	6.5	4.0	20.5
Dr. Wahl (C) Dr. Goth, R. Strickert G. Erhardt, E. Vine		20.0	18.0	25.5	25.0	28.0	283.5
Dr. Walker (P) Dr. Zimmerman		5.0	2.0	1.5	2.0	10.0	25.0
Dr. Welch (C) & (R) Dr. Krohn, J. Prost L. Knight		14.0	14.5	21.5	24.0	21.0	171.5
Nuclear Medicine		----	----	----	----	----	10.5
Bio-Medical Computer Lab.		----	----	----	----	----	1.0
St. Louis University		----	----	----	----	----	1.0
Total		147.5	97.0	168.0	143.5	149.0	1794.5

Table III - Part III

Machine Hours. Non-Prime Time (Evenings, Nights, Weekends)

	<u>1973</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>
Dr. Gaspar (C) D. Holten, R. Hwang B. Mizes		10.5	----	----	----	----	----	----
Dr. Macias (C) H.C. Hseuh, M. Zalutsky		8.0	33.0	43.5	25.5	41.5	45.0	21.5
Dr. Sarantites (C) Dr. Barker, Dr. Urbon Dr. Xenoulis, Dr. Rutledge R. Braga, R. Goldworm		51.0	25.0	48.5	58.5	116.5	98.5	6.0
Dr. Ter-Pogossian (R) Dr. Phelps, Dr. Hoffman		----	----	----	----	----	----	----
Dr. Wahl (C) Dr. Goth, R. Strickert G. Erhardt, E. Vine		----	----	2.0	----	1.0	1.0	----
Dr. Walker (P) Dr. Zimmerman		----	----	----	----	----	----	----
Dr. Welch (C) & (R) Dr. Krohn, J. Frost L. Knight		----	11.5	3.5	3.0	12.0	1.5	0.5
Nuclear Medicine		13.0	----	----	----	----	----	----
Total		82.5	69.5	97.5	87.0	171.0	146.0	28.0
Grand Total		245.0	207.5	254.5	281.5	350.5	308.0	124.0

Table III - Part IV

Machine Hours. Non-Prime Time (Evenings, Nights, Weekends)

	<u>1974</u>	<u>Jan.</u>	<u>Feb.</u>	<u>March</u>	<u>April</u>	<u>May</u>	<u>Totals</u>
Dr. Gaspar (C) D. Holten, R. Hwang B. Mizes		----	----	----	----	----	10.5
Dr. Macias (C) H.C. Hseuh, M. Zalutsky		14.5	5.0	15.0	4.0	32.0	288.5
Dr. Sarantites (C) Dr. Barker, Dr. Urbon Dr. Xenoulis, Dr. Rutledge R. Braga, R. Goldworm		42.0	15.5	82.0	1.5	37.0	587.0
Dr. Ter-Pogossian (R) Dr. Phelps, Dr. Hoffman		----	1.0	1.5	2.0	9.0	13.5
Dr. Wahl (C) Dr. Goth, R. Strickert G. Erhardt, E. Vine		1.0	----	----	----	5.0	10.0
Dr. Walker (P) Dr. Zimmerman		----	----	----	3.0	----	3.0
Dr. Welch (C) & (R) Dr. Krohn, J. Frost L. Knight		0.5	1.0	3.0	----	1.0	37.5
Nuclear Medicine		----	----	----	----	----	13.0
Total		<u>63.0</u>	<u>22.5</u>	<u>101.5</u>	<u>10.5</u>	<u>84.0</u>	<u>963.0</u>
Grand Total		210.5	119.5	269.5	154.0	233.0	2757.5

Table IV. Particle Energies

6-1-73 to 5-31-74

<u>alpha</u>	<u>^3He</u>	<u>p</u>	<u>d</u>	<u>$^{12}\text{C}^{4+}$</u>
12.5 MeV	11.0 MeV	3.5 MeV	6.5 MeV	38.0 MeV
15.0 MeV	15.0 MeV	3.7 MeV	8.0 MeV	
18.0 MeV	20.0 MeV	4.15 MeV	8.5 MeV	
20.0 MeV	23.0 MeV	4.3 MeV	10.0 MeV	
21.0 MeV	25.0 MeV	4.5 MeV	13.0 MeV	
22.0 MeV	26.0 MeV	4.6 MeV		
24.0 MeV	28.0 MeV	4.7 MeV		
26.0 MeV	30.0 MeV	4.85 MeV		
27.0 MeV	32.0 MeV	5.0 MeV		
30.0 MeV	34.0 MeV	5.15 MeV		
	35.0 MeV	5.3 MeV		
		6.0 MeV		
		7.3 MeV		
		8.0 MeV		
		10.0 MeV		

IMPROVEMENTS

As in all our previous reports, we attempt here to outline those Laboratory activities of the past year which are in the nature of improvement projects, as opposed to normal operation in connection with experiments. A very substantial fraction of our staff time is devoted to non-operational projects, including design and planning, execution and fabrication, installation and testing. For this review, the kinds of projects have been divided into three categories:

- (a) Projects intended to improve the reliability and convenience of operation of the cyclotron itself.
- (b) Projects aimed at general improvement in the utility of the Laboratory or increasing the versatility of the accelerator for research users, but having no specific user in mind.
- (c) Projects directly associated with the research of some particular user, construction of research apparatus and development of research technology, motivated by the faculty member, research associate, or graduate student whose research is involved. These usually involve extensive highly-skilled machine shop fabrication which might otherwise have been performed in some departmental machine shop.

Some of the brief paragraphs below refer to projects which have been discussed in detail in past reports, and are intended to bring their status up to date and to illustrate the evolutionary character of technical development work. One of the class (c) projects which was begun this year and which occupied a large fraction of staff effort is described in greater detail, to illustrate the high level of ingenuity and sophistication entailed.

To Improve Reliability and Convenience of Cyclotron Operation

1. A second (spare) main magnet rough-regulator chassis is near completion, utilizing modern integrated circuits to replace old amplifiers.
2. One of the fast discriminator circuits in the automatic compensator system failed in service during the past year. The compensator system enables maintenance of steady machine operation, steady beam currents, in the face of heat-induced changes in the radio-frequency dee structures. Quick repair turned out not to be possible, partly because of a 2-month delivery schedule on a tunnel diode. So a second discriminator unit was purchased and installed, and we now have a spare unit on hand in the event of future failures of this kind.
3. An improved "disable" unit, having superior drift characteristics, was also installed in the automatic compensator system. This unit disables (turns off) the drive system for the compensating capacitor plate whenever the dee voltage falls below some predetermined value. This is a particularly useful feature in connection with pulsed operation of the cyclotron for the

study of short-lived radionuclides, in which the cyclotron is periodically turned on for short bombardments, followed by off periods for counting. With the improved system, resumption of the beam for the next "on" period after each off period is more reliable and prompt.

4. During the past year, a lubrication oil leak developed around the sliding seals through which the push-rods move which control the position of the grounding spider for the dee stem. The spider position is changed each time the machine is re-tuned to some new r.f. frequency as part of a switch of energy or particle type. As a result of the leak, the oil in the stem tank vacuum pump became contaminated. To prevent contamination in the event of future seal leaks, an oil trap was built and installed on the stem tank pumping system.
5. A troublesome problem on the ion source gas line manifold was traced to a poorly designed and intermittently-leaking fitting, which has been replaced with a more reliable one of improved design.

To Improve General Research Utility

1. A beam current integrator system having 1.0% accuracy was designed, assembled and installed. This involves a voltage-to-frequency converter circuit obtained commercially, design and construction of a special voltage-follower circuit, and careful design of the impedance-to-ground characteristic of the current collector, to avoid the complication of a competing cooling-water path to ground and make the system direct-

reading in microampere-hours. We were able to make use of counters for frequency measurement which were already on hand.

2. A special beam-tube target-holder was designed and built, which is cooled by liquid nitrogen. It is intended for increasing the life of volatile or semi-volatile target materials, or to enhance the retention of reaction products in targets where the product of interest is gaseous in character.
3. The data acquisition electronics were rearranged in the control room area for greater convenience, efficiency, and versatility. The new arrangement is pictured in Fig. 3, which may be compared with Fig. 3 of last year's Report. The total number of columns of rack-mounted equipment has increased from three to five, plus the computer and oscilloscope. More and more, our research users are coming to incorporate the data system in their work. The cost of such systems dictates concentrating our capability in one system rather than dividing it between two systems in different buildings (see next item).
4. Planning is underway on a proposal to rearrange and reconstruct the part of the Laboratory immediately adjacent to the cyclotron control console and all the associated cyclotron operational circuitry both behind and in front of the console (the cyclotron control area referred to earlier). The proposed modifications would become necessary if we are successful in obtaining funds with which to modernize and expand our data acquisition system. Proposals are being made at the present time, seeking support for improving the data system. If successful, the expanded system would (1) permit two different groups working

on different projects to have access to the system at the same time, one in process of doing an experiment, the other getting ready for their turn on the cyclotron, and (2) increase the sophistication of experiments by making three-parameter and four-parameter experiments possible, where now we are limited to two-parameter experiments. Moreover, our current system is beginning to become obsolete in some respects and to suffer from rather frequent difficulties requiring excessive maintenance and trouble-shooting. The existing data acquisition system occupies and fills the other half of the room housing the cyclotron control area. There is literally no space remaining for desirable improvements and expansion of the data system, for utilization by others users besides Prof. Sarantites and Macias (notably Prof. Wahl and his students, working with neutron-induced reactions while conducting radiochemical studies of fission processes). At present an inadequate and isolated chemistry room and a toilet and locker room are located directly behind the data system and control areas. The space they occupy represents the only available room for expansion of the data system area. It would also accommodate a good fast chemistry facility with hood, having direct electrical connections to the data system and excellent communication with the cyclotron control area, yet retaining the characteristics of proper separate ventilation and quick, easy access required in a fast chemistry room.

It is proposed to move the toilet and locker room and the more conventional chemistry room to new locations on the second floor

above the machine shop, where they would occupy space which is not now heavily used. Tentative plans for the design and reconstruction work have been put into the hands of the campus architect, and university funds are being sought with which to implement this project if the data system proposals are successful. Construction will not in any way depend upon support from the AEC, but is reported here for informational purposes.

5. End terminations and plumbing were completed for the large (3-inch) pneumatic rabbit line connecting the cyclotron vault and the radiochemistry building next door. The large size matches the size of the so-called "neutron cave" facility built into the cyclotron, in which Dr. Wahl carries on slow-neutron bombardments using neutrons produced internally by the Be (d,n) reaction which are moderated to thermal energies by internal blocks of polyethylene moderator material.
6. Development of our capability to accelerate $^{12}\text{C}^{4+}$ ions has continued. A beam of 50 nanoamperes at 38 MeV was focused on target through the 45° beam tube into the research area beyond the shielding wall, and some trial reaction spectra were studied. This was done using the regulated heavy-ion source assembly, on which development work was reported last year. Since Prof. Sarantites and others have indicated their intentions of using this capability somewhat extensively, a complete spare heavy-ion source is being assembled in the shop.
7. A beam-sweeping system described in past Reports as under development to aid in the study of short-lived radionuclides was extensively tested, and a paper describing it was published.

("A Simple Fast Sweeping System for Extracted Cyclotron Beams", J.T. Hood, R.A. Goldworm, E.S. Macias, and D.G. Sarantites, Nucl. Inst. and Methods 118). This system enables a pulsed mode of operation, in which beam-on and beam-off periods are alternated, suitable for the measurement of lifetimes in the range from 0.5 to 5000 microseconds.

In Aid of Specific Research Experiments

1. Still further evolutionary modifications have been made for Prof. Wahl in the rotating beta recoil apparatus which we first described in a Report two years ago, with additional modifications last year intended to enhance the collection efficiency with which fission recoils deposit on the rotatable collector. Those changes did not succeed as well as hoped, and, in addition, the Teflon seals began to leak after being under compression for a while. Heaters have been built into the chamber walls, which for some not obvious reason appear to enable the Teflon seals to remain effective. The faraday cone assembly has been changed to give closer spacing between the uranium foil and the collector, to increase collection efficiency. The catcher foils have been provided with altered clamping arrangements to expose more surface. The motor drive system has been improved. A logic system was designed and is under construction, which will provide incremental rotation at various duty cycles. All this required 222 man-hours of shop work this year.
2. The helium jet transfer system reported as being built last

year for Prof. Macias has worked very successfully, and has been the subject for several improvements during the past year. A more powerful motor drive system has been installed to overcome occasional slippage occurring in the original version, and this in turn required the construction of a new power supply for the drive motor translator module. A second counter window was added exactly opposite the original one, to permit coincidence studies, and is reported to have worked beautifully on its recent first trial. A rather unsuccessful attempt was also made to adapt the transfer apparatus to another kind of work, the pickup and transfer of specific fission products. A quick-change foil system was designed and built for this purpose, in which recoiling tellurium atoms were to react with carbon monoxide gas to form a volatile compound, which was to be swept through tubing to a deposition chamber incorporating the quick-change foil system. Although activity was indeed transferred, the efficiency was quite low, probably because the tellurium carbonyl molecule is not too stable. The shop time required totalled 100 man-hours.

3. The lighter ion search apparatus (LISA, Dr. Goth and Dr. Whal) whose design and construction were reported last year has undergone substantial modification to improve overall detector efficiency, which proved to be only about 0.1% in a background run at the Berkeley Superhilac, using a argon bombardment of a ytterbium target. The test was partially successful, however, in that it demonstrated that radon isotopes (and their

daughter polonium isotopes) could indeed be produced and the associated alpha decay detected. The low efficiency was attributed to (a) ineffective transfer of sweeping gas from the target to the counting chamber, partly because of the periodic nature of the sweeping, partly because of injudicious selection of relative volumes of the transfer tubing and the target chamber, so that only about 30% of the gas ever reached the counting chamber, and (b) small solid angle for the alpha counter in the counting chamber.

Two modifications have been introduced in an attempt to improve efficiency, and a new background test at the Superhilac is planned for the near future. The first stems from the discovery that substantial numbers of alpha recoils can be collected from very large low-pressure volumes (best at pressures between 250 and 1000 microns) on charged metal plates. Further, the charged plate can be a solid state alpha counter whose surface is held at negative potential, so that the counter solid angle becomes 50% (instead of about 5% as formerly). For example, 20% of all recoils from the alpha decay of radon can be collected on a 1.0 cm^2 plate at - 300 volts from a volume of 62 liters. The second improvement was the substitution of semicontinuous sweeping for periodic sweeping. The technique now employed somewhat resembles the helium jet transfer method used by Dr. Macias, but has to function at much lower pressure to obtain efficient collection. The sweeping gas (again helium) passes through small bore tubing to the large collection chamber (Fig. 4), building the pressure

there in about five minutes up to about 1000 microns, at which time it is necessary to pause briefly (1.5 minute) to pump the collection chamber down to 250 microns to keep it within the pressure range for most efficient collection. Total shop time for the LISA project this year was 662 man-hours.

4. At the instigation of Prof. Sarantitis, a large segment of staff time and shop time (479 man-hours) this year has gone into the design and fabrication of a recoil-distance lifetime measurements system (RDLMS), intended to enable the study of short-lived nuclides with lifetimes in the range from 10^{-9} to 10^{-12} second, which is appropriate for the measurement of electromagnetic lifetimes of excited nuclear states before photon emission. The design used here is closely patterned after that described by Alexander and Bell of the Chalk River Laboratories (Nuclear Instruments and Methods, 81, (1970) pp. 22-26). An overall view of the assembled system is shown in Fig. 5 and several views of important subassemblies in Figs. 6 to 8. The basic technique is that of time-of-flight measurement for excited recoiling nuclei, which move at constant known speed over a measured (and variable) distance. This distance is the small gap between a target foil and a parallel catcher foil, on which the recoils stop. The speed of crossing the gap is known from the energetics of the reaction in which the recoiling nuclei are produced in the particular excited state in question. Gamma rays emitted in the forward direction while crossing the gap suffer a Doppler shift (increase in frequency and energy), but gammas emitted after the recoiling

nucleus has come to rest on the catcher foil do not. Thus a Ge(Li) detector just downstream or slightly to one side of downstream will detect gamma rays from the same kind of transition at two slightly different energies. The result is one sharp peak due to unshifted gamma rays and a second much broader peak at slightly higher energy, due to the Doppler-shifted gamma rays. The second peak is broad because the relative directions of the recoiling nucleus and of the gamma ray it emits in flight vary considerably. The relevant measured quantity is the ratio of the intensity of the unshifted peak to the total intensity, the sum of the shifted and unshifted peak areas. The minimum spacing between the target and catcher foils has to be about 5×10^{-4} cm, corresponding to a recoil speed about 3% the speed of light and a transition lifetime of about 5×10^{-13} sec, which is an effective lower limit on the capability of the technique, being roughly the time required for a moving recoil to come to rest after hitting the catcher. The separation distance has to be variable, up to about half a millimeter, and must be easily and accurately measureable. Measurement of this distance is based on a measurement directly of the capacitance of the system and requires that the two foils be unwrinkled and highly parallel.

Fig. 6 shows perhaps the best interior view of the apparatus, with its housing (Fig. 7) and its cooling baffle (Fig. 8) removed. The beam enters the apparatus shown in Fig. 6 from the right. The first block is the target mounting block into which a small cylindrical bushing is inserted from the right;

the target foil is held taut over the end of the bushing, and protrudes leftward beyond the target block about a quarter of an inch. The second block is an electrical guard ring for the target, to eliminate edge effects when measuring capacitance. The guard ring surrounds the target-bearing bushing protruding from the target block, with the target surface flush with the left surface of the guard ring. The third metal block is the catcher mounting block, with the catcher foil held taut over a protruding bushing by a Teflon ring. The first two blocks are a mechanical unit, held in fixed position. The catcher block is mounted on a complex of adjustment mechanisms, including a sliding stage for changing the target-to-catcher separation and goniometer for obtaining parallelism of the target and catcher foils. The sliding stage is moved by the micrometer screw at the right, working against an opposing spring. Electrical connections that are visible are used for measuring the capacitance. In our version, the catcher foil is thin and permits the beam to pass through to a Faraday cup, if desired.

In Fig. 5, where the apparatus is shown assembled, a beam collimation tube is shown attached to the housing, with electrical connections to insulated apertures used for obtaining good beam alignment, and the cooling tube assembly is mounted atop the housing. The cooling tube surrounds the target-catcher system with surfaces at liquid nitrogen temperature to obtain better pumping speeds for vapors near the target and thus reduce contamination of the target. This apparatus has received

preliminary tests on beam. The touchy problem of attaining good parallelism of target and catcher has been solved by using laser beam reflections.

It cannot be emphasized too much how important is the role of the Laboratory staff in design, development, fabrication, and testing of both experimental apparatus, as illustrated in the type (c) examples above, and operational equipment, as illustrated in the type (a) and (b) examples. The problems to be solved are highly specialized, esoteric ones, and the quality and sophistication of workmanship, the ingenuity and precision of design, and the dependence upon experience can't be over emphasized. We are fortunate in now being able to maintain three machinists in our shop, with two of their salaries being paid by users, in return for part of their services. Their remaining time is thus available to aid in the never-ending task of keeping the cyclotron functional and improving its performance characteristics and versatility of application. We believe that excellent scientific work is being done in this Cyclotron Laboratory by our research users, and that a large share of the credit for this achievement is due to the talents, skills, and industry of the Laboratory staff members.

OTHER EXPENSES, OTHER INCOME

In the Introduction, the point was made that the total annual cost of Cyclotron Laboratory operations exceeds the budget amount for Contract AT(11-1)-1760. The AEC and Washington University, through their joint contributions to the contract budget amount, underwrite the basic minimum operational level, daytime only on weekdays. The contract budget we are currently operating under covers salaries for a basic crew of two engineers, one cyclotron technician, and one machinist full time, plus part-time salaries for the principal investigator, an electronics technician, a secretary, and hourly-paid cyclotron operators. It also covers basic expenditures for expendable supplies and materials and for minimal equipment purchases, plus minimum electric power, services, and salary-related fringe benefits and indirect costs. It does not cover salaries and related costs for two other machinists and additional hourly workers, or extra electric power for evening and weekend operation.

In the first table below, a summary is given of the additional expenditures made or planned for the current contract year, November 1, 1973 to October 31, 1974, over and above what is provided for in the contract budget. The total amounts actually spent and compared with the contract budget amounts for each item, and the excess expenditures calculated for each. Note that the numbers listed as actual total expenditures and excess expenditures are estimates, since about four months of the contract year still

remain at the time this is being written. Numbers have been rounded off, and are given in thousands of dollars (K\$).

<u>Item</u>	<u>Budgeted in AT(11-1)-1760</u>	<u>Total actually spent (est.)</u>	<u>Excess spent over budget (est.)</u>
Salaries, wages, and indirect costs based on salaries, plus fringe benefits	126.2 K\$	169.3 K\$	43.1 K\$
Supplies, materials services	9.5 K\$	11.5 K\$	2.0 K\$
Equipment	5.0 K\$	8.5 K\$	3.5 K\$
Power	5.0 K\$	6.1 K\$	1.1 K\$
	<hr/> 145.7 K\$	<hr/> 195.4 K\$	<hr/> 49.7 K\$

The extra salary-related costs are broken down further in the second table:

second machinist, salary, overhead fringe benefits, twelve months	21.3 K\$
third machinist, salary, overhead fringe benefits, eleven months (hired Dec. 5, 1973)	19.6 K\$
extra operators, hourly	1.6 K\$
other hourly labor	0.6 K\$
	<hr/> 43.1 K\$

The third table outlines the sources of income received (or still hoped for) with which to cover the 49.7 K\$ of additional expenditures listed in the preceding two tables.

From Prof. Ter-Pogossian, Department of Radiology, 100% of salary, fringe, and overhead, 12 months for second machinist, 11 months for third machinist, from research grants	40.9 K\$
Irradiation time for non-AEC users, including Profs. Wahl, Welch, Walker	5.8 K\$
Sale of hourly shop time	0.5 K\$
Sale of F ¹⁸ for medical purposes	2.5 K\$
	<hr/>
	49.7 K\$

The last three entries above are estimated, since they have been projected ahead to the end of the contract period on October 31, 1974. Should the income from irradiations and hourly shop work fall short of these numbers, we would have to adjust our extra expenditures downward near the end of the contract year.

Fig. 3: Data Acquisition System in the Cyclotron Control Room

Fig. 4: LISA Collec-
tion Chamber

Fig. 5: Recoil Dis-
tance Lifetimes
Measurement System
Assembled

Fig. 6: Recoil Dis-
tance Lifetimes
Measurement System Tar-
get and Catcher

Fig. 7: Recoil Dis-
tance Lifetimes
Measurement System
Entrance Collimator

Fig. 8: Recoil Dis-
tance Lifetimes
Measurement System LN
Cold Trap