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Washington University

St. Louis, Missouri

MASTER

SUMMARY REPORT ON CYCLOTRON UTILIZATION,
OPERATIONAL ACHIEVEMENTS, AND IMPROVEMENTS
DURING TWELVE MONTHS ENDING MAY 31, 1972

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INTRODUCTION

The Chemistry Department of Washington University includes an active contingent of faculty members, post-doctoral research associates, and Ph.D.-candidate graduate students who work on investigations falling roughly into the research field of nuclear chemistry. Included are studies of fission processes, nuclear reactions, nuclear spectroscopy, chemical reaction processes via tracer atoms, oxidation-reduction reactions, etc. Most of these 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 hovers in the neighborhood of 15 to 20. Over the past 6 years the research done by these persons has culminated in 9 doctoral theses and 80 published research papers.

All of this activity centers upon 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, a high-quality machine shop, an electronics shop, and an assortment of research space, augmenting that available in the Nuclear Chemistry Laboratory next door and including a well-equipped, centralized data-acquisition station in the cyclotron control room. The Laboratory's staff currently includes five full-time (or nearly full-time) engineers, technicians, and machinists, plus several persons part-time in various functional capacities. The staff maintains and operates the accelerator, assists users in utilizing

it for their investigations, designs and constructs a great deal of the specialized operating equipment which is needed, develops and perfects new modes of utilizing the accelerator and its peripheral facilities, and seeks continuously to improve the accelerator's performance characteristics and its usefulness for its users. The machine shop and its two machinists, in addition to sharing in these normal staff functions, can also be made 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.

Funding for the Cyclotron Laboratory's normal activities is provided from three 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, and
- (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 responsibility for certain wages or salaries.

That part of the Laboratory's support which is provided by Washington University and the Atomic Energy Commission via contract AT(11-1)-1760 (items 1 and 2 above) is only sufficient to underwrite what we call a "basic minimal level of operation." By this is meant daytime (only) operation for a five-day week (i.e. 35 hours per

week, excluding start-up time each morning), plus maintenance and repairs, plus minimal attention to development of improvements. It covers staff salaries, minimal expenses, minimum electrical power, and indirect costs (based on salaries) sufficient for that basic level of operation. It does not cover additional costs which are incurred if operation beyond the "basic" level is desired.

However, throughout the period since November, 1967, when contract AT(11-1)-1760 first went into effect, the Cyclotron Laboratory's level of operations has always proceeded at a much higher rate than the "basic minimum 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; the second machinist has been employed full time rather than only 1/5 time, not only to help handle the additional maintenance burden, but also to increase the shop's capability to serve the users; and additional power and other expenses have been provided. The extra funding needed for expanded operations has been obtained as the income listed under item (3) above, supplied by users through purchases of cyclotron time and shop time, etc. Whenever the extra income has been insufficient, we have had to limit the amount of part-time operator employment and have encouraged more use of researchers as their own operators during night and weekend runs. This is not wholly desirable, in that inexperienced operation unfortunately often leads to excessive maintenance and difficulties later. By and large, however, the amount of "outside" income has roughly approximated the need, and, in particular, it has been adequate to extend our

employment of the second machinist to full time for several years now. During the same period, we have consistently been able to schedule up to 105 hours of machine time per week for our users and for routine maintenance, compared with the 35-hour "basic" capability. Fortunately, the cost for expanding weekly service is considerably smaller per hour than that required to provide the "basic" level, which includes large salary and indirect cost items.

This Technical Progress Report contains a summary of operations and accomplishments for the Cyclotron Laboratory for the 12 months ending May 31, 1972, at which time preparation of the Report was begun. Reference may be made to similar earlier reports (C00-1760-1, -2, -3, -4) 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 the concrete shielding wall, while Fig. 2 shows the positions of the most important modules in the beam extraction system. Fig. 3 shows an assemblage of auxiliary equipment added during the last several years in the control room, behind the operator's seat at the control console. Fig. 4 pictures the principal data-acquisition station, also in the control room. The remaining figures relate to the section on Improvements.

Figure 1

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 & improvements	4	Maintenance & 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)	7	Wahl (C), Gaspar (C)	7
	deuteron runs to		deuteron runs to	
	obtain neutrons		obtain neutrons	
	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	Sarantites (C)	15
Friday	Nuclear Medicine (R)	1	Nuclear Medicine (R)	1
	Welch (C)	2	Welch (C)	2
	Wahl (C), Gaspar (C)	7	Wahl (C), Gaspar (C)	7
	deuteron runs to		deuteron runs to	
	obtain neutrons		obtain neutrons	
	Cooling off period	1	Cooling off period	1
	Sarantites (C)	5	Hafele (P), Foster (UMSL)	5
Saturday	Sarantites (C)	15	Hafele (P), Foster (UMSL)	15
Sunday	Sarantites (C)	15	Macias (C)	15

(C)=Department of Chemistry

(R)=Department of Radiology

(P)=Department of Physics

(UMSL)=University of Missouri,
St. Louis

SUMMARY OF CYCLOTRON USE DURING THE YEAR

Variable Nature of Research Uses of Cyclotron Time

Contrary to normal practice at many accelerator installations, we attempt to provide each of our frequent cyclotron users with one or more regularly-scheduled time periods each week (bi-weekly for some). More precisely, we attempt to rotate use of the machine among the several faculty members involved, each of whom (usually) has several research students working under him. This results in frequent changes in the nature of cyclotron operation, with concomitant changes of particle-type, particle energy, beam intensity, beam direction, etc. Although this procedure might seem highly inefficient, it proves to be quite workable, on the whole, for the kinds of research we do. Over several years, the laboratory staff has developed deft capabilities as "quick-change" artists.

The basis for this division of time among users is a Normal Bi-Weekly Schedule (preceding page). This schedule, which undergoes revision by negotiation among interested parties at irregular intervals, assigns fixed hours for each researcher during two weeks of 15-hour days, beginning at 8:30 AM each day. The eight hours from 8:30 AM to 4:30 PM are designated as "prime time", especially desirable because this is the period when the regular full-time operating staff is on duty. During non-prime time (the other seven hours per day), operation is by part-time operators. The schedule has been cast so as to divide prime time as equitably as possible among (1) Chemistry Department users, (2) regular weekly maintenance and improvement work by the staff, and (3) brief periods twice weekly for routine production of F^{18} , a medically-useful radioisotope,

for the University's School of Medicine, Department of Nuclear Medicine, and several local hospitals. Non-prime time is principally divided up among Chemistry Department users, but some of it, notably Friday evening and Saturday every other week on the recent current schedule, has been given to non-AEC supported users (from the Physics Departments of Washington University and the University of Missouri at St. Louis, working collaboratively on a scattering problem).

As an interesting side-light, the use of cyclotron time by Dr. Charles Foster of the University of Missouri at St. Louis merits special notice because of the interesting and mutually-profitable arrangement it entails between sister institutions in the St. Louis area. Lacking funds to buy cyclotron time outright, Dr. Foster instigated the establishment of an exchange agreement, whereby his use of our Cyclotron Laboratory is repaid by reactor time for Washington University researchers at the Research Reactor Facility of the University of Missouri at Columbia, Missouri. This barter arrangement has been in effect since November, 1971, and available data seem to show a rough balance. Four Washington University scientists have already made use of the Reactor Facility without charge under this plan. This is an encouraging instance of cooperation among neighboring universities for mutual benefit in these times of tight funding for research.

Variations from the Normal Bi-Weekly Schedule are always possible by mutual arrangement. Some researchers are not always able to use 100% of their assigned time. If agreeable to them, others sometimes move in. Also, there is occasional long-run use

of the machine during the normally unscheduled middle-of-the-night hours. Table I on the next page attempts to summarize actual use as contrasted with scheduled use. The time unit called "machine hours" represents time when the use of the machine is precluded for anyone else by reason of occupancy by the current user, whether he be suffering from temporary breakdowns, waiting between runs for routine chemistry to take place, or actually running beam onto his target.

Note in Table I that actual machine hours used totalled 2977.0 for the twelve-month period, which may be compared with 5460 machine hours scheduled on the Normal Bi-Weekly Schedule (52 weeks x 7 days x 15 hours), of which 2080 hours are scheduled prime time. Note also the fairly regular occurrence that only about 60% of "machine hours" involve actual beam on target. In other words, about 40% of his time a typical researcher is not actually using the beam but is doing other operations or suffering the frustrations of temporary breakdown.

Table II (on the same page as Table I) divides up the actual beam hours for one year according to type of particle being accelerated. Compared to the similar entry in our report of a year ago, there have been no big changes. Use of protons continues to be quite high compared to two years ago, reflecting extensive work by Prof. Sarantites and his students on proton-induced gamma-transitions as a highly-profitable technique for elucidating nuclear energy level schemes.

Table III (covering four pages) goes even further than Table I in breaking down the utilization of the cyclotron by various users.

Table I. Monthly Actual Use
6-1-71 to 5-31-72

<u>Month</u>	<u>Machine Hours</u>	<u>Beam Hours</u>	<u>Maintenance and Improvement Hours</u>
June 1971	355.0	207.6	22.5
July	251.0	154.9	22.5
August	245.0	135.7	22.5
September	292.0	189.9	22.5
October	337.0	233.1	15.0
November	242.0	149.9	15.0
December	137.0	66.4	15.0
January 1972	315.0	243.8	15.0
February	170.5	81.3	15.0
March	251.8	175.8	15.0
April	170.5	93.4	15.0
May	210.2	113.1	15.0
	<hr/> 2977.0	<hr/> 1844.9	<hr/> 210.0

Table II. Breakdown of Beam Hours by Ion Type

Helium 3	429.6
Alphas	783.9
Deuterons	203.0
Protons	391.2
Carbon 12	21.9 (+4 ions)
Cyclotron Tune	15.3
	<hr/> 1844.9

The first two pages of Table III show the actual machine hours of prime time according to user and month, while the last two pages do the same for non-prime time. The analysis of prime time use makes clear how much more valued prime time appears to be: total actual use for the year was 1630 machine hours out of 2080 hours of scheduled prime time (78% used). By contrast, 1347 hours of non-prime time was actually used out of 3380 hours of non-prime time on the Normal Bi-Weekly Schedule (40% used).

Another datum derivable from Table III is the fraction of total hours which were used by Chemistry Department researchers (Drs. Wahl, Sarantites, Macias, Gaspar, Welch and their students or associates), most of them on projects receiving AEC support via research contracts. Of prime time, these users consumed 1305 machine hours out of the 1630 that were used (80%), while they consumed 893 of 1347 non-prime machine hours (66%). The other principal expenditure of prime time was for regular cyclotron tuning and maintenance (15%).

As in prior years, Table IV has been included to illustrate the extreme diversity of the demands made by our users. It lists each of the (approximate) energy values required at one time or another during the year for each of five different accelerated particles. Parenthetical data give typical largest currents in the Main Target Chamber (see Fig. 2 for location) for a few of the entries.

Table III - Part I

6-1-71 to 5-31-72 Machine Hours. Prime Time (8:30 AM - 4:30 PM Monday - Friday)

	<u>1971</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>
P. Gaspar (C) D. Holten G. Stewart J. Frost		23	17	3	12	11	----	----
E. Macias (C)		13	16	----	24	29	16	10
M. Phelps (R)		----	----	1	----	----	----	----
D. Sarantites (C) J. Barker B. Atcher N. H. Lu A. Xenoulis B. Braga		85	27	74	65	44	28	----
F. Shull (P)		----	----	----	----	----	----	----
A. Wahl (C) G. Goth G. Erhardt E. Vine M. Fowler R. Strickert		17	26	35	25	37	38	28
R. Walker (P)		2	----	----	----	----	----	----
M. Welch (C) M. Loberg		12	13	6	10	13	17	13
Nuclear Medicine (R)		4	5	5	4	4	5	3
University of Missouri		----	----	----	----	----	----	----
Cyc. Maintenance & Tuning		17	17	16	16	16	31	38
Total		<u>173</u>	<u>121</u>	<u>140</u>	<u>156</u>	<u>154</u>	<u>135</u>	<u>92</u>

Table III - Part II

6-1-71 to 5-31-72 Machine Hours. Prime Time (8:30 AM - 4:30 PM Monday - Friday)

	<u>1972</u>	<u>Jan.</u>	<u>Feb.</u>	<u>March</u>	<u>April</u>	<u>May</u>	<u>Totals</u>
P. Gaspar (C) D. Holten G. Stewart J. Frost		2	----	1.8	5	---	74.8
E. Macias (C)		----	8	15.5	16	---	147.5
M. Phelps (R)		----	----	-----	-----	---	1.0
D. Sarantites (C) J. Barker B. Atcher N. H. Lu A. Xenoulis B. Braga		46	28.5	71.5	36	86	591.0
F. Shull (P)		----	2	-----	-----	---	2.0
A. Wahl (C) G. Goth G. Erhardt E. Vine M. Fowler R. Strickert		24	40.5	29.5	20.5	25.5	346.0
R. Walker (P)		5	2	-----	-----	---	9.0
M. Welch (C) M. Loberg		17	13.5	12.5	10.5	8.7	146.2
Nuclear Medicine (R)		5	4.5	10	8	9	66.5
University of Missouri		----	----	1.5	-----	---	1.5
Cyc. Maintenance & Tuning		29	16	16	16	16	244.0
		<u>128</u>	<u>115</u>	<u>158.3</u>	<u>112</u>	<u>145.2</u>	<u>1629.5</u>

Table III - Part III

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

	<u>1971</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>
P. Gaspar (C) D. Holten G. Stewart J. Frost		4	3	----	-----	----	----	----
J. Hafele (P)		29	44	23	28	35	22	20
E. Macias (C)		9	12	----	24	33	12	19
M. Phelps (R)		----	----	----	-----	12	----	----
D. Sarantites (C) J. Barker B. Atcher N. H. Lu A. Xenoulis B. Braga		132	61	72	76	95	59	----
A. Wahl (C) G. Goth G. Erhardt E. Vine M. Fowler R. Strickert		----	----	----	-----	----	----	----
R. Walker (P)		----	----	----	-----	----	----	----
M. Welch (C) M. Loberg		----	----	----	-----	----	4	----
C. Foster (UMSL)		----	----	----	-----	----	----	----
Nuclear Medicine		8	10	10	8	8	10	6
		<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
Total		182	130	105	136	183	107	45
Grand Total (Prime + Non-Prime)		355	251	245	292	337	242	137

Table III - Part IV

	Machine Hours, Non-Prime Time (Evenings, Nights, Weekends)						
	1972	Jan.	Feb.	March	April	May	Totals
P. Gaspar (C) D. Holten G. Stewart J. Frost		----	----	-----	-----	---	7.0
J. Hafele (P)		28	28	16.5	-----	---	273.5
E. Macias (C)		----	----	-----	14	---	123.0
M. Phelps (R)		----	----	-----	-----	---	12.0
D. Sarantites (C) J. Barker B. Atcher N. H. Lu A. Xenoulis B. Braga		149	----	51	17.5	---	712.5
A. Wahl (C) G. Goth G. Erhardt E. Vine M. Fowler R. Strickert		----	10	-----	-----	37	47.0
R. Walker (P)		----	4	-----	-----	---	4.0
M. Welch (C) M. Loberg		----	----	-----	-----	---	4.0
C. Foster (UMSL)		----	----	16	19	15.5	50.5
Nuclear Medicine		10	13.5	10	8	12.5	114.0
		-----	-----	-----	-----	-----	
Total		187	55.5	93.5	58.5	65	1347.5
Grand Total (Prime + Non-Prime)		315	170.5	251.8	170.5	210.2	2977.0

Table IV. Particle Energies & Some Maximum Currents in the
Main Target Chamber
6-1-71 to 5-31-72

<u>alpha</u>	<u>^3He</u>	<u>p</u>	<u>d</u>
12 MeV	14 MeV	3.09 MeV	10 MeV (25 μa)
12.17 MeV	15 MeV	3.1 MeV	12 MeV
12.25 MeV	16 MeV	3.5 MeV	13 MeV (30 μa)
12.5 MeV	18 MeV (20 μa)	4 MeV	15 MeV
13 MeV	19 MeV (32 μa)	4.35 MeV (9 μa)	
14 MeV	20 MeV	4.5 MeV	
15 MeV	21 MeV	4.6 MeV	
15.7 MeV	22 MeV (25 μa)	4.7 MeV	
16 MeV	23 MeV	4.8 MeV	
17 MeV	24 MeV	4.9 MeV	
18 MeV	25 MeV	5 MeV	
19 MeV	26 MeV	5.3 MeV	
20 MeV	28 MeV	5.5 MeV	
21 MeV	29 MeV	6 MeV (23 μa)	
22 MeV	30 MeV	6.5 MeV	
23 MeV	32 MeV	8.5 MeV	
24 MeV	35 MeV	10 MeV (20 μa)	
25 MeV			
26 MeV (17 μa)			
27 MeV			
28 MeV			
30 MeV			

$^{12}\text{C}^{4+}$

38 MeV (1 μa)

IMPROVEMENTS

As in past Reports, discussion of improvement projects undertaken during the year has been broken down into three categories:

- (a) Projects intended to improve either the reliability or the convenience of operation of the cyclotron itself.
- (b) Projects aimed at general improvement in the utility of the laboratory or the accelerator for research users, but having no specific user in mind.
- (c) Projects directly associated with the research of some particular user, often shop work which might otherwise have been performed in some departmental shop.

To Improve Reliability and Convenience of Operation

1. A new He^3 gas recovery system was designed, constructed, and put into service. This project was stimulated by a failure of an oil seal in the original recovery system, which has been in operation for six years. During the two weeks that the system was out of service, we were able to continue He^3 ion acceleration at not too excessive cost for gas by feeding the ion source with a 3:1 mixture of He^4 and He^3 . Although the expensive He^3 gas was lost through normal pumping without recovery, its net cost was reduced to only about \$15 per hour by this technique. Meanwhile, the recovery system was repaired and returned to operation. But, chronic troubles with leaking valves and with failures of the modified Welch pump, which is an integral component of the system (modified to be leak-proof for the He^3 gas which it circulates), prompted construction

of a new system. The new recovery cart (Fig. 5) incorporates small ball valves, a commercially-available vacuum pump guaranteed to be He^3 tight, and a number of other features suggested by our six years of experience with the original design.

2. A system was developed and installed for detection and prevention of short-circuits to ground in the main magnet winding. This improvement was stimulated by the occurrence of a ground fault across a maple insulator within the cooling oil tank which encloses the winding, apparently caused by an arc which charred the wood. Repair of such faults is difficult and inconvenient because of the oil and the inaccessibility of the maple separators. For prevention of such faults in the future, a vacuum drying system has been installed to remove moisture and prevent its accumulation in the magnet oil. At about ten minute intervals, a portion of the cooling oil is automatically withdrawn from the coil tank, to be exposed to a partial vacuum for ten minutes to pump off moisture, and is then returned to the tank at the same time a new portion is being withdrawn for treatment. Detection of ground faults has been provided through installation of a sensitive relay in the magnet circuit, which will turn off the magnet if the ground current reaches about 1.0 ampere. This prevents operation of the magnet when a leakage path appears, thus inhibiting charring of the hard-to-get-at maple insulators, and forcing an investigation of the difficulty before it becomes worse. Since installation, the detection system has already proved its value at least once.

3. A digital readout was installed near the control desk (Fig. 3, on top of the oscilloscope) which continuously informs the operator about the dee frequency. On several occasions, considerable time has been wasted searching for a beam because of human error in setting the desired frequency of the driver which controls the r.f. supply for the dee. Now the frequency value is continuously visible to the operator. This moreover acts as a monitor to indicate any drift of frequency of the driver.
4. Some improvements were incorporated in the arrangements for focusing and steering the external beam from the cyclotron. Vernier controls were installed on the power supplies for the 4-cm focusing quadrupole magnets (see Fig. 2) which will permit more sensitive adjustments of beam focus. Also, the four-jaw slit assembly built last year, featuring independent adjustability for all four jaws, has been further improved through installation of remotely-controlled motor drives (Fig. 6).

To Improve General Research Utility

1. Progress has been made in development of a system intended to deliver every fourth RF beam pulse to a research chamber, to aid in study of short-lived radioisotopes. As described in last year's Report, the idea is to use electrostatic deflection electrodes in an external beam tube to sweep the beam up and down across a small aperture at a frequency which is $1/8$ of the dee frequency. The section of beam tube containing the deflecting electrodes and a defining baffle has been built

(Fig. 7), and a place prepared for its installation in the beam line (just downstream from the magnet yoke, approximately at the word "beam" in Fig. 2). The several modules for the electrode voltage supply system are now complete, including (a) a frequency-dividing circuit to obtain $1/8$ of the dee frequency precisely, (b) a phase-shift network, to achieve proper timing of the sweeping voltage with respect to the beam pulses, and (c) an intermediate amplifier, suitable for driving the final sweeping oscillator. The final step-up in sweeping voltage is obtained by a resonant circuit (Fig. 8) operating at $1/8$ of the dee frequency, consisting of a variable inductance and capacitance in parallel with the sweeping electrodes. Bench-testing of the circuitry has gone as far as it can go, and further testing of the system awaits some suitable break in cyclotron operations to permit its installation and trial. Also on hand is a high-power square-wave pulser circuit obtained commercially, intended for use in a modification of the system in which bunches of from 10 to 1000 pulses are delivered on target, alternated with dead periods of maybe five to ten times the duration.

2. The high voltage ion source, constructed last year as an improved source of multiply-charged heavy ions (e.g. C^{4+}), received preliminary tests under vacuum in a vacuum tank normally used as part of our thin target preparation system. The axial magnetic field to simulate the cyclotron field was provided by an old steering magnet, modified for the purpose. Under these conditions, approximate gas flow rates and striking voltages

were determined, after which it was installed in the cyclotron. It was connected to a 5000-volt, one-ampere supply through a current-limiting resistance, then was operated for a number of hours with varying voltages, currents, and gas flow rates and with helium, methane, and carbon dioxide gases. A solenoid-actuated bypass had to be installed around the gas-flow regulating valve, to obtain temporary high flow rates for striking the arc. It was found that the arc strikes at lower voltage and more reliably in He than in CH_4 or CO_2 . Hence a procedure has been adopted, when C ions are to be produced, of striking the arc with helium. Then when the arc has stabilized, the gas is switched to CO_2 or CH_4 . The ion source was then tested for 6 hours using helium and producing an 8-microampere alpha beam. In this test, the thick (1/8 inch) tantulum cathodes, which are heated by ion bombardment, wore approximately half-way through. Beams of C^{4+} ions ranging from 0.1 to 1.0 microampere have also been achieved a number of times with the new ion source, and the operating staff is now fairly familiar with the techniques of achieving beam with it. A recent test with a 38 MeV C^{4+} beam gave a burn-through cathode life of about 10 hours. Currently a regulator for the power supply is being designed.

3. The 45° beam tube was finally activated (Fig. 9) to provide a research station with beams of somewhat higher energy resolution than obtained on the other tubes. This involved installation of a beam tube vacuum valve and the transfer of the 4-inch quadrupole magnet pair, with its associated plumbing

and wiring, from its former position on the 0° tube. Beam tweaker magnets were installed downstream from the quadrupoles for positioning beam on target. Finally, the rotatable Pb shielding house for gamma-decay studies, formerly also on the 0° tube, was relocated at the 45° research station. Currently this station is principally used to study angular dependence of gammas emitted in reactions such as (α, p) or $(p, n\gamma)$, using high resolution detectors and without coincidence techniques, and to examine coincidence of gammas with gammas from various reactions, including angular dependence, if desired.

4. The 15° beam tube has been converted to use by Prof. Sarantites and his students for nuclear spectroscopy. The mass spectrometer formerly using this station has been removed, and the 15° tube was re-aligned beyond the switching magnet, using a laser beam as the reference axis. This station is being used principally for reactions such as $(\alpha, p\gamma)$ or $(\alpha, \alpha'\gamma)$, by looking for coincidences between the gammas and the outgoing charged particle.
5. The vacated 0° line has been fitted with a beam tube vacuum valve and a pump-out, to provide a research station close to the shielding wall, for sporadic use by those requiring an external beam who can get along with less focusing and beam control than is available on the other tubes. The 30° tube continues to serve the 43-inch scattering chamber. Dr. Sarantites uses the big chamber mostly for particle spectra with angular dependence, also for some particle-particle coincidence work.

6. An adapter for the Main Target Chamber (see Fig. 2) was constructed. Using this, targets having vertical dimensions up to 3.0 inches high can now be inserted for charged-particle irradiation.
7. After a hiatus of several years, during which it saw little use, the thin target evaporation chamber was overhauled and reactivated in response to renewed demand.

In Aid of Specific Research Experiments

A considerable portion of shop time and engineering effort by the staff goes into projects falling into this category. Although most of these are mentioned only briefly below, a rather more detailed description of one of them has been prepared for this Report, as offering a typical example of the high level of ingenuity and sophistication involved. It seems appropriate here, however, to comment upon the changing nature of the demands made on the Laboratory machine shop during the past two years. Increasingly our users are finding it necessary to petition for "free" shop work on research apparatus, to compensate for diminished research contract funds to cover such work. Our shop staff (two men, only 1.2 paid from AT(11-1)-1760) has a great deal of work always on hand having to do with the cyclotron itself; it is not large enough to handle this normal work and do justice to the growing needs of our regular users. One of our most pressing needs is for more machinist help, at least half-time (and preferably full time) for a third man in the shop.

1. One of the more elaborate design and fabrication jobs carried out this year was a beta recoil apparatus for Prof. Wahl. Its purpose is to study a variety of rather short-lived fission products, typically in the neighborhood of one-second half-life, but perhaps as low as 10^{-1} sec and as high as 10 sec. Its operation involves two basic steps: (1) deposit of fission product atoms on one foil, and (2) recoil of the atom off of the first foil and onto a second, resulting from beta-decay of the atomic nucleus while the atom is still on the first foil. The short-lived process being studied is the beta emission. To enable half-life measurements, the first foil moves continuously past the second; thus recoils of short-lived beta emitters are deposited on the near end of the second foil, while longer-lived recoils deposit progressively farther along on the second foil.

The actual arrangement is pictured in Figs. 10 and 11, showing, respectively, a disassembled and an assembled version of the apparatus. When assembled, the entire assembly can be inserted into the 3-inch diameter neutron cave inside the cyclotron acceleration chamber, where our slow neutron bombardments are carried out (see Fig. 2 for location). Referring to the disassembled view in Fig. 10, the block on the left carries a deposit of U^{235} on its recessed inner surface, while the flattened hollow cone next to it is an insulating separator, which encloses a nitrogen-filled space of 3 cm. between the U^{235} and the rotor (shown near the bottom of Fig. X). With a substantial potential difference between the U^{235} and thin metal

foils mounted in the recesses on the periphery of the rotor, slow neutron induced fission products are drawn through the nitrogen to be deposited on the rotor foils. Turning now to the right side of Fig. 10, the curved electrode is used to mount the second foil fixed on its inner surface; the rotor foils move past the fixed foil with a spacing of about 1/4 inch. The Teflon "squirrel cage" shown in position on the rotor (a spare is shown above the chamber) acts as a moving gasket, separating the nitrogen-filled region in front of the U^{235} from the evacuated region around the fixed curved second foil. Thus the rotating foils receive deposited fission products in an atmosphere of nitrogen, which slows the energetic atoms to modest speed for good deposition; but then each rotor foil goes past the second foil with only a quarter-inch of evacuated space between them, so that there is no gas interference with the beta-recoils crossing this gap while having only very modest energies. Provision is made for a potential difference also between the two foils to aid in deposition of the beta recoils.

The rotor is capable of rotation speeds between 0.1 and 10 rev/sec. After the apparatus has undergone a suitable period of exposure to slow neutrons, the fixed foil has to be subjected to simultaneous counting of radiation from various parts of its surface, to determine the relative amounts of deposition as a function of position. From the measured rotation rates, the lifetimes of the beta-emitters can hopefully be deduced. The apparatus has survived design tests of a mechanical nature and is soon to receive first trials in normal operation. Its

design required about five man-days, more or less, and its fabrication approximately 380 man-hours in the machine shop.

2. An even more complicated irradiation assembly than that described above is currently being built and tested here, to be used by Prof. Wahl and Dr. Goth at the Berkeley Super Hilac accelerator (Figs. 12-15). Its purpose is to look for super-heavy-rare-gas atoms ($Z=118$, $A\approx 300$, eka-radon) which may be formed during the interaction of one very heavy nucleus with another (e.g. a Xe or U projectile colliding with a U target nucleus). The eka-radon's rare gas character permits its rapid separation from other super-heavy isotopes, which presumably would also occur frequently, by the emanation technique. The reaction products are stopped in a layer of a metal stearate, the emanation layer (Fig. 12), but only the rare gas type can easily get out again. It is expected that the yield of eka-radon will be further amplified through its production as the result of a rapid chain of alpha-decays of other, heavier reaction products which have been stopped in the emanation layer. The hoped-for method of detection would be by observation of fission fragments in a plastic or mica film, since the chain of decays for the super-heavy reaction products is expected to terminate with a fission process.

The complexity of this apparatus is increased by attempting, in the same exposure, to observe fissions of any isotope whatsoever (not just eka-radon) which occur in flight within the apparatus. This will become the more interesting if it turns out that the hoped-for eka-radon fissions are not detected as

described above. Some measure of the design and construction problem here can be gained from two numbers: as of May 31, 1972, with the work perhaps 80% complete, it has already used up about 10 days of detail design time and about 520 man-hours of shop time.

3. Associated with item 2. above, an electrostatic sparking plate was constructed for Prof. Wahl, to be used in locating fission fragment damage tracks in plastic films.
4. Two small reaction chambers and associated detector mounts and collimators were designed and fabricated for Prof. Sarantites. One accommodates an annular particle detector for in-beam coincidences of particles with gammas, which are observed with a Ge (Li) detector, while the other (Fig. 16) fulfills the special requirements for somewhat similar in-beam coincidence studies when the incident projectile is an alpha particle of more than 24 MeV. Another project for Prof. Sarantites was the construction of a vacuum-lock valve arrangement (Fig. 17), for handling targets which deteriorate in air. The target is stored in an argon atmosphere inside the valve, from which it can be passed through a locking system into the vacuum chamber where it is to be irradiated, with retrieval in reverse.
5. A variety of sample holders and detector shields were manufactured for Prof. Macias, for use with his angular correlation table.
6. The neutron howitzer inherited last year from the School of

Engineering, which contains five one-curie plutonium-beryllium neutron sources, was modified to accept targetry for Prof. Gaspar, who made extensive use of the 10^4 n/cm²/sec neutron flux which it provides.

OTHER EXPENSES, OTHER INCOME

It was pointed out in the Introduction of the Report that the funding of Cyclotron Laboratory operations by the AEC and Washington University via contract AT(11-1)-1760 is sufficient only to provide the "basic minimum level" of operations. The following section summarizes information about additional expenses and additional income to cover them, needed in order to extend operations to include evenings and weekends, and, most particularly, to increase our machine shop staff. The first chart below tabulates the extra expenses, and compares them to amounts available from AT(11-1)-1760 for comparable items under the "basic minimum level". Note that the contract year does not end until October 31, 1972, so that numbers given for actual expenses involve some estimates for the period June through October. Numbers have been rounded off, and are given in thousands of dollars (K\$).

<u>Item</u>	<u>Budgeted in</u> <u>AT(11-1)-1760</u>	<u>Total actually</u> <u>spent (est.)</u>	<u>Excess spent</u> <u>over budget (est.)</u>
Salaries, wages, and indirect costs based on salaries, plus fringe benefits	112.4 K\$	137.2 K\$	24.8 K\$
Supplies, materials, services	9.5 K\$	10.1 K\$	0.6 K\$
Equipment	5.0 K\$	8.6 K\$	3.6 K\$
Power	5.0 K\$	7.0 K\$	2.0 K\$
	<hr/>	<hr/>	<hr/>
	131.9 K\$	162.9 K\$	31.0 K\$

The 24.8 K\$ of extra salary-related costs breaks down approximately as follows:

5/6 of a second machinist, including salary, overhead, and fringe benefits	16.4 K\$
several months of a part-time third machinist, salary, overhead, fringe	2.0 K\$
extra part-time help, as operators, draftsmen, general labor, wages	6.4 K\$
	<hr/>
	24.8 K\$

The outside income by which the extra costs of 31.0 K\$ are supposed to be covered include the following:

From Dr. Wahl, 13.3% of the second machinist, salary, overhead, fringe, from research grants	2.6 K\$
From Dr. Ter-Pogossian, Department of Radiology, 50% of second machinist, from a research grant	9.8 K\$
Sale of F ¹⁸ for medical purposes	13.0 K\$
Sale of irradiation time to non-AEC users, in- cluding Drs. Wahl, Welch, Walker, Hafele	4.4 K\$
Sale of hourly shop time	1.2 K\$
	<hr/>
	31.0 K\$

The last three entries above are estimated, since they are projected ahead to the end of the contract period on October 31, 1972. Failure to achieve the estimated incomes from irradiation and hourly shop work would require us to cut back in some way near the end of the contract year.

Effective May 1, 1972, there was a change in status for Mr. John T. Hood, who has been the Associate Director of this Cyclotron Laboratory for many years and who has now been promoted to a new position as Operations Director, Washington University Cyclotrons.

This development was instigated at the request of Prof. M. Ter-Pogossian of the Department of Radiology of the Washington University School of Medicine, who is in charge of the 5 MeV cyclotron at the medical school. Due to changes in the operating staff of that machine, Dr. Ter-Pogossian requested consideration of a new position for Mr. Hood, giving him responsibility for maintaining operations at both machines, which have separate staffs otherwise. Mr. Hood will be responsible for hiring and training staff members for the medical school installation, and for overseeing their work, especially with advice and assistance when difficulty arises. Under the new arrangement, Mr. Hood will devote 90% of his time to the campus Cyclotron Laboratory and 10% to the medical school machine. His office and principal place of business will continue, as before, to be at the campus Cyclotron Laboratory.

OSC. CPG, CAPRS,

$$V = \frac{Be}{2\pi m v}$$

2 mil IRON Foil
100 Mamp-hours of
10 MeV protons Beam $\leq 10\mu$

Fig. 3. Control Room Area Showing External Beam Slit Meters, Beam Current Integrator, Automatic Compensator, Frequency Readout, etc.

Fig. 4
Analyzer Area

Figure 5

Fig. 6
Remotely Positionable, 4 Jaw Slits

Fig. 7
Beam Deflecting Tube

Fig. 8
1/8 Frequency Resonant Circuit

Fig. 9
45° Tube Showing Quadrupoles, Tweakers,
Annular Detector Chamber, & Lead House

Figure 10

Figure 11

Fig. 12. Hilac Detector Sandwich. First compartment is shown empty. Clockwise, others shown in successive stages of being filled. Emanation layer fills holes of expanded metal insert in second compartment.

Fig. 13

View of Portion of Hilac Assembly
Showing Rear of Detector Sandwich

Fig. 14

View of Portion of Hilac Assembly Showing
Viewing Section, Vacuum Valve, Shutter, Target Block

Fig. 15

View of Portion of Hilac Assembly
Showing Shutter in Place

Fig. 16

Tee Chamber and Cold Finger
for Cooling Ge(Li) Detector

Fig. 17

Vacuum Lock for Handling Targets
Without Exposure to Air