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TECHNICAL PROGRESS REPORT**CONTRACT AT(11-1)-1760****Washington University****St. Louis, Missouri**

**SUMMARY REPORT ON CYCLOTRON UTILIZATION,
OPERATIONAL ACHIEVEMENTS, AND IMPROVEMENTS
DURING TWELVE MONTHS ENDING MAY 31, 1969**

Submitted to the Atomic Energy Commission

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INTRODUCTION

Contract AT(11-1)-1760 is a Special Research Support Agreement Contract which provides staff salaries, electrical power, equipment and supplies, and shop facilities for the Washington University Cyclotron Laboratory. This maintains a basic minimal level of cyclotron operation for the purposes of chemical research programs requiring the types of accelerated ion beams which the cyclotron can produce.

The "basic minimal level of operation" referred to includes (1) staff services on a daytime basis for a five-day week, (2) necessary maintenance and repairs, (3) minimal improvements of cyclotron operation or in the laboratory itself, either for specific research purposes or to obtain generally better operation.

Washington University pays part of the cost for this level of operation, and the AEC pays the rest via contract AT(11-1)-1760. The original contract took effect November 1, 1967 for one year, and was renewed for a second year which began November 1, 1968. This operations report covers a 12-month period ending May 31, 1969, just prior to the start of preparation of this report. An earlier report (COO-1760-1) covers the preceding seven months, from November 1, 1967 to May 31, 1968.

As detailed here and in the previous operations report, an actual level of operation has been maintained which exceeds the basic minimal level provided by AT(11-1)-1760. This has been accomplished through utilization of graduate students and part-time operators, and with the assistance of additional funds

squeezed from various research contracts and grants. The higher operating level was necessary because the total requests for cyclotron time from chemical researchers and from users in the Department of Physics has exceeded the minimal level by quite a large factor.

The demand for services from the Cyclotron Laboratory shop, either for fabrication and repair of cyclotron components or as a service to specific users of the cyclotron for the manufacture of research equipment, has also exceeded what one machinist (provided by the current AT(11-1)-1760 budget as actually awarded) can do. For one reason, the regular chemistry department shop is not adequate to handle all jobs that it is asked to do. For another, the cyclotron shop's personnel are capable of more than commonly excellent workmanship. For a third, the cyclotron operating staff continues to undertake improvements of the laboratory and of the accelerator itself which add to the shop's burden.

This report is divided into several sections, each devoted to some aspect of the Cyclotron Laboratory's operations during the twelve months ending May 31, 1969. An attempt has been made to break down and analyze the various data presented, to present the clearest possible picture of the laboratory's activities. Figs. 1 and 2 show the layout of the underground cyclotron vault and research room (Fig. 1) and a sketch of the most prominent modules of the cyclotron's beam extraction system (Fig. 2).

Figure 1. Layout of cyclotron vault and research room

Figure 2. Plan view of acceleration chamber

SUMMARY OF CYCLOTRON USE

Scheduled Use

To ensure reasonably equitable distribution of the available time, and to avoid argument and recriminations among competing users, a bi-weekly schedule (shown on p. 4) was in effect throughout practically the entire 12 month period being reviewed. This schedule averaged out to give Chemistry Department users 149.33 hours and Physics Department users 46.67 hours of scheduled time in every two-week cycle. The allotted time falls between 9:00 a.m. and 12:00 midnight, seven days a week, totalling 210 hours every two weeks. In addition to 196 hours of user time, an allowance of 14 hours every two weeks was made for regular maintenance and for cooling-down periods following each deuteron bombardment, to reduce residual radioactivity.

The schedule is made out according to the name of the faculty user or faculty supervisor of each graduate student user. Symbols (C) and (P) indicate Chemistry Department and Physics Department, respectively. Note that every third week a switch of time occurs for the last 8 hours of Friday and again for all 15 hours Saturday, so that 1/3 of the time affected is scheduled to Sarantites and 2/3 to Shull, when averaged over a long time.

<u>Day of week</u>	<u>First week</u>	<u>(hours)</u>	<u>Second week</u>	<u>(hours)</u>
Monday	Maintenance	5	Maintenance	5
	Sarantites(C)	10	Sarantites(C)	10
Tuesday	Wahl(C), Gaspar(C)	6	Wahl(C), Gaspar(C)	6
	deuteron runs to		deuteron runs to	
	obtain neutrons		obtain neutrons	
	Cooling off period	1	Cooling off period	1
	Walker(P)	8	Walker(P)	8
Wednesday	Reeder(C)	15	Sarantites(C)	15
Thursday	Sarantites(C)	15	Sarantites(C)	15
Friday	Wahl(C), Gaspar(C)	6	Wahl(C), Gaspar(C)	6
	deuteron runs to		deuteron runs to	
	obtain neutrons		obtain neutrons	
	Cooling off period	1	Cooling off period	1
	Shull*(P)	8	Shull*(P)	8
	(*Note: every third week, Sarantites(C) 8 hours)			
Saturday	Shull*(P)	15	Shull*(P)	15
	(*Note: every third week, Sarantites(C) 15 hours)			
Sunday	Reeder(C)	15	Sarantites(C)	15

Whenever scheduled time was not going to be used, informal arrangements were permitted for trades or replacements by other users.

Actual Use

Control desk instruments keep track of two kinds of time information. One clock runs whenever the power tetrode filament of the cyclotron's r.f. power supply is turned on. For want of a better name, this time is denoted operating hours, since it

usually comes moderately close to measuring actual time consumed. Nevertheless it can be somewhat misleading. For example, maintenance is shown as using up 122.8 operating hours, for such activities as tuning, etc., but the schedule provides 260 hours a year for maintenance. Other maintenance activities tie up the machine for much of this time, without the r.f. supply having to be turned on.

Another useful time datum measures the time during which r.f. power is actually provided to the dees of the cyclotron. This comes pretty close to being the time during which beam is actually being accelerated, although it also includes time spent looking for a beam. This datum is referred to as beam hours in this report.

Operating hours is always longer than beam hours, because the former includes the latter, plus additional time used by the experimenter for set-up work, adjustments, waiting periods for doing chemistry on targets, and repairs when research equipment breaks down.

Table I (pages 7, 8) breaks down the actual operating hours from June 1, 1968 to May 31, 1969, according to month, also according to faculty user or supervisor, and even according to use by individual students of each professor. It also indicated what accelerated ions were commonly requested by each user.

The monthly data on total operating hours are repeated in the following tabulations, along with beam hours data and a summary of actual time spent monthly on maintenance and improvements:

<u>Month</u>	<u>Operating hours</u>	<u>Beam hours</u>	<u>Maintenance and Improvement hours</u>
June '68	169.7	100.8	16
July	203.3	107.5	28
August	201.9	142.7	37
September	312.4	209.6	10
October	397.7	294.2	6
November	305.5	222.9	8
December	320.0	224.5	10
January '69	354.5	254.8	11
February	333.1	249.0	6
March	341.5	254.8	10
April	235.6	175.4	26
May	<u>306.3</u>	<u>224.5</u>	<u>11</u>
	3481.5	2460.7	179

Our records also show what ion was being accelerated during each period of beam use, and the breakdown of beam hours by ion type came out:

Helium 3	1232.9 beam hours
Alphas	1046.5
Deuterons	100.9
Protons	77.0
Carbon 12	3.4 (+4 ions)

Efficiency of Use

"Efficiency of use" is probably a meaningless quantity, defined as the fraction of scheduled time actually used. For 52 weeks, scheduled time according to the schedule on p. 4 totals

TABLE I - PART 1

6-1-68 to 5-31-69 Operating Hours (Tetrode Filament On)

	<u>1968</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>
D. Sarantites(C)		10.6	10.6	----	37.6	10.7	----	10.2
S. Gronemeyer		24.9	----	----	12.4	----	----	----
M. Phelps		17.9	----	----	----	9.7	26.4	61.7
A. Xenoulis		----	43.4	8.4	10.0	76.4	23.0	29.9
N. Lu		----	2.4	----	----	----	----	----
E. Hoffman		----	42.6	34.6	48.1	68.7	41.2	20.0
W. Winn		----	----	----	----	----	----	23.3
A. Wahl(C)		----	----	----	2.8	13.2	10.7	6.4
R. Daenig		17.1	2.6	14.3	22.4	20.9	28.5	15.0
J. Lin		3.7	3.8	2.1	----	2.3	0.2	0.0
M. Fowler		4.4	7.5	2.1	----	3.7	2.6	6.8
R. Strickert		----	6.7	1.7	2.6	----	----	----
P. Reeder(C)		----	----	14.6	58.4	58.4	48.0	48.3
P. Gaspar(C)		2.9	4.3	4.6	----	7.1	4.0	1.7
R. Walker(P)		16.4	----	----	----	----	----	----
J. Kaufhold		7.2	20.7	34.4	15.2	----	----	----
M. Hair		----	----	----	----	13.2	4.9	20.9
M. Seitz		----	----	----	----	----	----	----
F. Shull, J. Hafele(P)								
G. Siegel		45.7	52.0	70.0	90.8	112.6	106.8	71.8
M. Ter Pogossian*		----	----	----	----	----	----	----
Cyclotron Tuning		<u>18.9</u>	<u>6.7</u>	<u>15.1</u>	<u>12.1</u>	<u>0.8</u>	<u>9.2</u>	<u>3.1</u>
		169.7	203.3	201.9	312.4	397.7	305.5	320.0

TABLE I - PART 2

6-1-68 to 5-31-69 Operating Hours (Tetrode Filament On)

	1969	Jan.	Feb.	March	April	May	Total	Prof. Total	Particles
D. Sarantites(C)		5.5	37.0	27.1	11.0	18.8	179.1		α , p, d
S. Gronemeyer		----	----	----	----	----	37.3		^3He
M. Phelps		14.7	32.7	21.5	26.2	29.3	240.1		α , ^3He
A. Xenoulis		69.2	56.9	67.9	25.0	----	410.1		^3He , α
N. Lu		----	----	----	----	----	2.4		α
E. Hoffman		79.6	18.7	28.9	16.6	63.1	462.1		α , ^3He , p
W. Winn		----	----	12.6	----	----	35.9	1367.0	α
A. Wahl(C)		----	----	----	----	----	33.1		d, α
R. Daenig		----	----	----	----	----	120.8		d
J. Lin		6.3	5.5	7.7	2.2	5.8	40.5		d, α
M. Fowler		7.3	1.5	19.5	4.7	6.4	66.5		α , d
R. Strickert		----	----	----	----	----	11.0	271.9	d, α
P. Reeder(C)		50.0	30.9	----	15.6	10.3	334.5	334.5	^3He , α
P. Gaspar(C)		----	-----	1.1	4.2	3.8	33.7	33.7	d
R. Walker(P)		----	----	----	----	----	16.4		α
J. Kaufhold		----	----	----	----	----	77.5		α
M. Hair		17.1	19.6	28.5	23.8	----	128.0		α , p, d
M. Seitz		1.8	16.2	----	----	10.9	28.9	250.8	α , p
F. Shull, J. Hafele(P)									
G. Siegel		103.0	99.4	119.0	60.1	144.3	1075.5	1075.5	^3He , α , p
M. Ter Pogossian*		----	11.8*	2.3*	4.9*	6.3*	25.3*	25.3*	p, ^3He
Cyclotron Tuning		----	2.9	5.4	41.3	7.3	122.8	122.8	
		354.5	333.1	341.5	235.6	306.3		3481.5	

*Exploratory tests of a specific isotope-producing reaction, for Dr. Ter Pogossian of the university's Mallinckrodt Institute of Radiology.

$52 \times 105 = 5460$ clock hours. This resulted in 3481.5 operating hours and 2460.7 beam hours, as summarized on p. 6.

In terms of operating hours the overall average efficiency of use comes out to be $3481.5 / 5460 = 64\%$. In terms of beam hours, the average works out to be $2460.7 / 5460 = 45\%$. Considering the diverse nature of the experiments carried out by our users and also the high frequency with which user shifts occur, requiring different particles and energies, we feel that these percentages are very favorable evidence of the good utilization of the Cyclotron Laboratory.

Considerable variation occurs among efficiencies of use posted by various research groups using the cyclotron, categorized according to supervising professor:

<u>Professor</u>	<u>Assigned time per 52 weeks</u>	<u>Operating hours for 52 weeks</u>	<u>Efficiency of use</u>
Sarantites(C)	2478.67	1367.0	55%
Wahl, Gaspar(C)	624.0	305.6	49%
Reeder(C)	780.0	334.5	43%
Walker(P)	416.0	250.8	60%
Shull, Hafele(P)	<u>797.33</u>	<u>1075.5</u>	135%
	5096.0	3333.4	
Maintenance,			
Ter-Pogossian*	<u>364.0</u>	<u>148.1</u>	
(*see note, p.8)			
Total	5460.0	3481.5	64%

It is not difficult to discover which group is most willing and eager to take over someone's scheduled time if it is not going to be used for some reason.

OPERATIONAL ACHIEVEMENTS

- a. Alpha-particles have been accelerated at energies of 12, 12.17, 12.5, 13, 15, 16, 18, 20, 22, 23, 24, 26, and 30 MeV at various times during the period covered by this report. Some improvement has been obtained in maximum beam current to the main target chamber (see Fig. 2), which is where targets are positioned when maximum yield of some specific radioactivity is intended.

The following numbers give maximum beam currents at various energies:

13 MeV	-	10 microamperes
15 "	-	7 "
18 "	-	10 "
23 "	-	12.5 "
26 "	-	13 "
30 "	-	3 "

- b. Helium-3 ions have been accelerated to energies of 9.5, 11, 11.5, 12, 13, 15, 18, 20, 25, 28, 29, 30, 32, and 35 MeV. Maximum currents delivered to the main target chamber were as follows at selected energies:

13 MeV	-	6.3 microamperes
18 "	-	5.0 "
20 "	-	7.0 "
29 "	-	7.5 "
30 "	-	6.4 "
35 "	-	2.2 "

These numbers represent some improvement over earlier achievements, more as the result of experience in tuning than because

of any profound change of technique.

- c. A maximum current of 26 microamperes of 13 MeV deuterons was achieved in the main target chamber. This has been used to produce higher fluxes of fast neutrons for Prof. Gaspar, compared with our earlier technique using the internal beam instead of the deflected beam. We continue to do all experiments requiring thermalized neutrons by using the internal deuteron beam to produce the neutrons (from a beryllium target).
- d. Maximum current of protons has been improved to 6 microamperes at 10 MeV measured again in the main target chamber.
- e. In addition to the improvement of beam currents at the main target chamber, corresponding improvement has also been achieved in providing larger focussed and collimated beams onto targets in the adjacent research room. For example, up to 1.0 microampere through a 0.25 inch square aperture has been delivered to the big 43-inch scattering chamber there. Currents as high as 3 to 4 microamperes have been delivered to apparatus on the "straight through" or 0° beam tube in the research room.

Summarizing, we have been generally pleased with our success in upping the beam intensities which we can provide to experimenters who need high intensities, notably those who are studying reaction and scattering problems with rather small differential cross sections and low counting rates.

IMPROVEMENTS

The cyclotron laboratory staff, including the shop and machinists as well as the technicians and engineers, have worked on a wide variety of projects during the year which were intended to improve the laboratory or its usefulness in some respect. These are summarized now in four categories:

- (i) Projects aimed at improving either the reliability or the convenience of operation, especially to reduce the probability of prolonged shut down for repairs to the accelerator.
- (ii) Projects aimed at a general improvement in the utility of the laboratory or the accelerator for research users, but having no specific user in mind.
- (iii) Projects directly associated with the research of some particular user, usually shop work which might otherwise have been performed in some departmental shop.
- (iv) Projects aimed at improved safety for staff, operators, and casuals.

To Improve Reliability and Convenience of Operation

- 1. Shaped electrode extensions were added to the internal deflector assembly to overcome periodic insulator breakdown. Since installation, ten months of operation without failure due to such breakdown have resulted.
- 2. A complete spare rotating beryllium probe was built and is now in use alternately with the original one. This probe is used

for the production of neutrons from the internal deuteron beam. The availability of the spare gives us a "cooling off" period for a "used up" probe head, which is extremely radioactive, before we have to tackle the job of removing the old head and installing a new one on the probe. The neutron work can go right on with the alternate probe during the cool-down and exchange of heads. These are switched about every two months.

3. The cyclotron vault 15-ton air conditioner compressor was replaced. The old unit failed.
4. A spare r.f. shorting spider was constructed to insure against a long shut down in the event that the fingers of the present spider fail and it would have to be replaced. The spider is the moveable electrical connection between the dee stem and the conducting walls of the dee stem tank. Its position determines the length of the co-axial line and thus also the resonant frequency of the r.f. system. The present spider has been in use for $3\frac{1}{2}$ years. The interest by Drs. Hafele and Reeder in higher energy He-3 ions causes the greatest r.f. currents in the dee stem (highest frequencies) and threatens the greatest danger to the rather delicate silver finger contacts used in the spider.
5. A closed circuit TV system was installed which provides continuous monitoring of the central region of the cyclotron by the operator at the control desk. It has proven extremely valuable in enabling quick diagnosis of beam fall-off due to

erosion of the puller electrode, deterioration of the ion source chimney, and so forth. It recently provided the answer to a beam intensity droop caused by warping of the lower dee liner, causing it to protrude up into the path of the beam.

6. We are now in process of constructing a new dee and dee stem of improved design, but having the same dimensions as the present unit. This gives us a spare part in the event of a failure, and will allow us to determine if the new design features should also be applied to a larger diameter stem planned for future design and construction. We have recently been troubled by bad electrical contacts between different pieces of the dee stem. These develop when high r.f. frequencies are used. The new design is intended to remedy this difficulty.

To Improve General Research Utility

1. A water-cooled target holder was designed and constructed, which moves through the beam in the main target chamber with a vertical reciprocating motion at constant speed. This distributes the bombardment exposure over more target area. It now has 155 hours of recorded exposure.
2. A new "rabbit hutch" for charged-particle bombardments was completed and has had many hours of use. This is the compartment into which pneumatic "rabbits", carrying targets from the radiochemistry laboratory in the next building to the main target chamber, are delivered, positioned properly,

and bombarded.

3. A four-segment insulator collimator with a 1/4-inch square aperture was designed, built, and installed in the 30° tube about two inches upstream from the target of the 43-inch scattering chamber. When it is in place, it aids in the steering and alignment and focusing of the beam at that point prior to an experiment.
4. The existing evaporation chamber and system were cleaned and activated for use by Dr. Sarantites and others for target preparation.
5. A beryllium target was constructed which can be inserted in the deflected beam by interchanging it with the beam valve. About one inch downstream, a cave in the main target chamber allows placement of a target for fast neutrons in line with the incident deuteron beam and behind the beryllium. At this location, the fast neutron flux is about 5 times that achieved with the previous arrangements. Formerly a beryllium probe was placed in the internal beam rather than in the deflected beam. The neutron target had then to be placed downstream and vertically lower than the probe head.

Projects in Aid of Specific Research Experiments

1. A pulsed rotation "table" was designed and built for use by Dr. Reeder in the small scattering chamber in connection with pulsed-beam experiments. The table alternately places a target in the beam, then replaces it with a hole while presenting the target instead to a radiation detector.

2. A quick-change source holder was designed and constructed for use by Dr. Sarantites in his beta ray spectrometer apparatus.
3. The lid of the 43-inch scattering chamber was modified for Dr. Sarantites, to accommodate a refrigerated solid-state detector, with its Dewar.
4. A close-geometry target and collimator assembly was designed and built for Dr. Sarantites, for use on the 0° tube in the research room.
5. An "in cave" detection system for measuring slow neutron flux was installed for Dr. Wahl. This incorporates recorder read-out.
6. At the present time, an "on beam" mass spectrometer system is being activated and tested for Dr. Reeder prior to installation.
7. Numerous smaller jobs were also undertaken, which belong in this category.

To Improve Safety

1. A "radiation area" fence was installed around the area directly over the cyclotron vault and adjacent to the cooling tower, to prevent casual exposure to radiation leaking upward through the cooling tower from the underground research room and cyclotron vault below.
2. Safety bars were installed around the front and rear perimeters of the door into the cyclotron vault. Depressing any of these stops the door.
3. Visual and audible radiation warning systems in the cyclotron vault and in the research room were completed.

OTHER EXPENSES

The funds provided by Washington University and by the AEC as specified under contract AT(11-1)-1760 are barely adequate to maintain the basic level of operation, let alone the higher level of operation actually achieved. It has been necessary to find other sources of funds, which has been partially possible, and to ask the University for a larger contribution to operating costs than scheduled under the terms of contract AT(11-1)-1760 as finally awarded.

In this section of the report we have outlined the principal items of additional expense and the principal sources of additional funds, for the 12 months ending May 31, 1969.

<u>Additional Actual Expenditures</u>	<u>Cost or Estimated Cost, 12 months</u>
i. Half-time of a second machinist. Includes annuity and social security, plus indirect costs at 54%.	\$ 7,140
ii. Night and week end operators, part-time. Cost includes some social security and indirect costs at 54%.	\$ 7,160
iii. Draftsman. Has worked 238.60 hours at \$2.00 per hour. Student, no social security. Includes 54% indirect costs.	\$ 735
iv. Additional electrical power. Total power used in 12 month period amounted to \$9083. Of this, \$4491 was paid from AT(11-1)-1760.	\$ 4,592

v.	Special materials, notably beryllium probe heads.	\$ 1,723
		<hr/>
		\$21,350

Additional Sources of Income

1.	Dr. M. Ter-Pogossian, Mallinckrodt Institute of Radiology, for shop services. He pays the full-time salary, annuity, social security and indirect costs for a second machinist. Half of this man's work is for Dr. Ter-Pogossian and half for the Cyclotron Laboratory. Therefore he con- tributed half of \$14,279.	\$ 7,140
ii.	Cyclotron time purchases by research users from research funds:	\$ 5,750
	Prof. Wahl(C) \$ 750	
	Prof. Walker(P) \$5000	
iii.	Specific purchases of materials, from chemistry research contracts, of which \$1680 was by Prof. Wahl(C) and Prof. Gaspar(C) for 4 Be-probe heads.	\$ 1,723
iv.	Contribution to cost of part-time operators, from various chemistry research contracts.	\$ 6,530
		<hr/>
		\$21,143