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AEC RESEARCH AND DEVELOPMENT REPORT

LABORATORY RECORDS 1954

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THE APPLICATION OF A NEW TYPE ION SOURCE TO THE PRODUCTION OF ENRICHED LITHIUM ISOTOPES

BY

Robert S. Livingston

John S. Luce

John A. Martin

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Subject Category Special

THE APPLICATION OF A NEW TYPE ION SOURCE TO THE PRODUCTION OF ENRICHED LITHIUM ISOTOPES

Robert S Livingston
John S Luce
John A Martin

ELECTROMAGNETIC RESEARCH DIVISION

October 1, 1952

[redacted]

OAK RIDGE NATIONAL LABORATORY
Operated by
Carbide and Carbon Chemicals Company
A Division of Union Carbide and Carbon Corporation
Oak Ridge, Tennessee

Contract No W-7405-eng-26

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ABSTRACT *

Preliminary specifications and cost estimates for a pilot plant using a grid-type ion source for the separation of lithium isotopes was prepared at the request of the ANP Division of ORNL The design is based on an ion source, developed during fundamental studies of an arc plasma, which has an output of one ampere of lithium ions per square inch A pilot plant using 16 Beta vacuum tanks, each equipped with six of these mass spectrograph units, is expected to produce approximately two pounds of 99 97% Li 7 per day at a cost of $3 70 per gram These estimates are based on an incomplete research program and therefore have not yet been demonstrated in a prototype unit Further development work is required to complete the design of production type units and for improving ion collection features Schedules for this development work and for the preparation of the necessary conversion equipment for the pilot plant are included A new name, "Apotron", is proposed for this electromagnetic separation system

*Because of the limited distribution of this report it is not to be included on any abstract list

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INTRODUCTION

In early August 1952 the implications of the ion source performance which was being obtained in one of the projects of the Electromagnetic Research Division were discussed with representatives of the Aircraft Nuclear Propulsion Division Well-defined lithium ion beams of one ampere per square inch had been consistently obtained with an ion source* significantly different from the conventional calutron ion source Although extensive measurements had not been made of the enrichment factors obtainable at this beam intensity, it was clear that the enhancement would be fairly high This conclusion was based on some very crude preliminary separation measurements in which an enrichment of about 100 was obtained, and was further supported by scans at the focal plane which showed complete resolution of the Li 6 and Li 7 peaks at a current density of 500 ma/in^2, Figure 1 The only available data on actual collection under reasonably favorable conditions were obtained by the Stable Isotope Research and Production Division from similar units operated at relatively low current density, about 125 ma/in^2, and yielding an enrichment factor of 310

On the basis of this data the ANP Division requested preliminary cost estimates and feasibility studies for producing a minimum of one pound of Li 7 per day in a portion of a Beta track in Building 9204-3, the estimates to be completed by September 1, 1952 A preliminary draft of the present report was prepared and made available on the date requested

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* If this mass spectrograph is developed for production purposes it is here proposed that the name "Apotron" be used to designate each ion source-collector unit The prefix, "apo-" is from the Greek word meaning "to isolate"

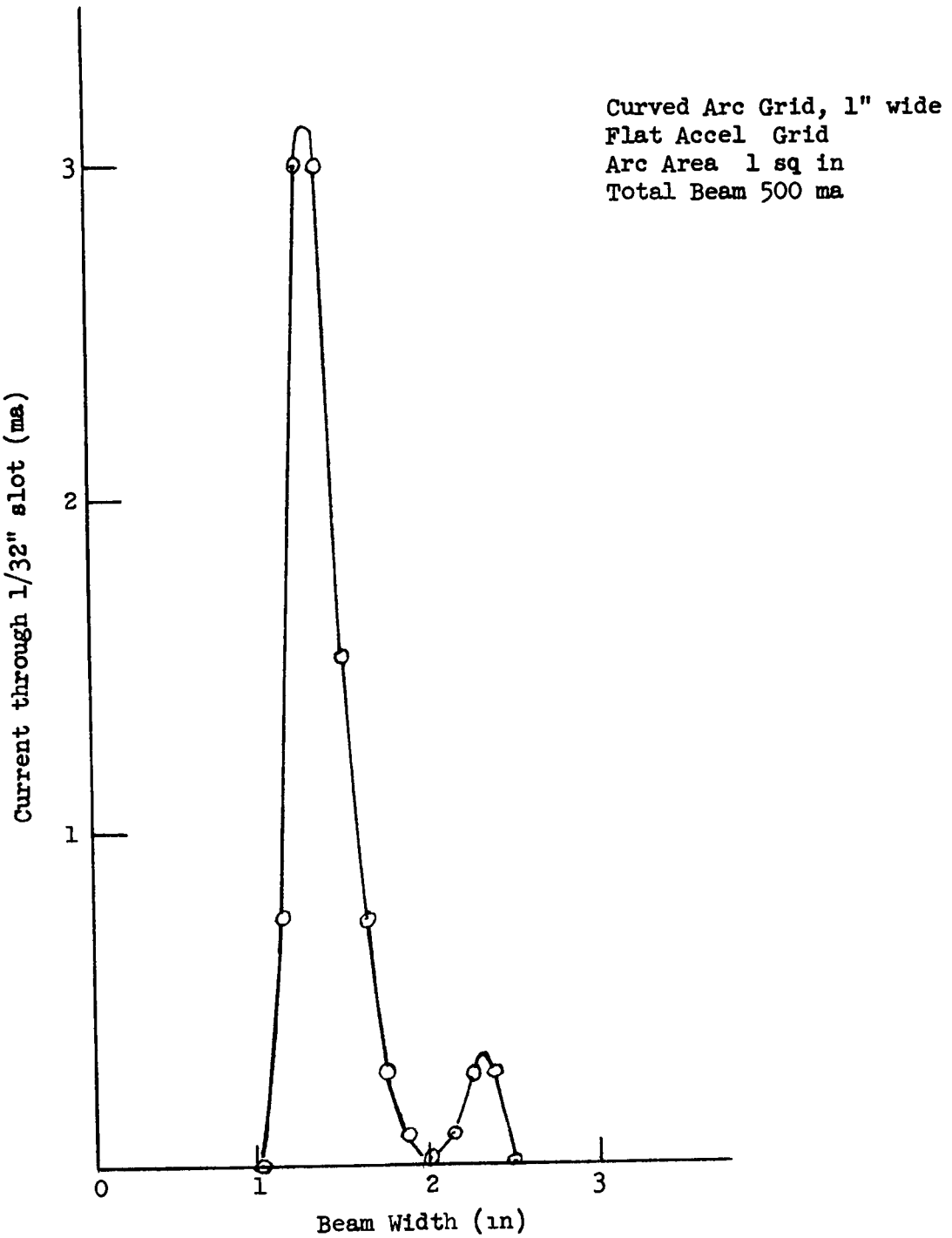


FIGURE 1 CURRENT DENSITY DISTRIBUTION AT BEAM FOCUS

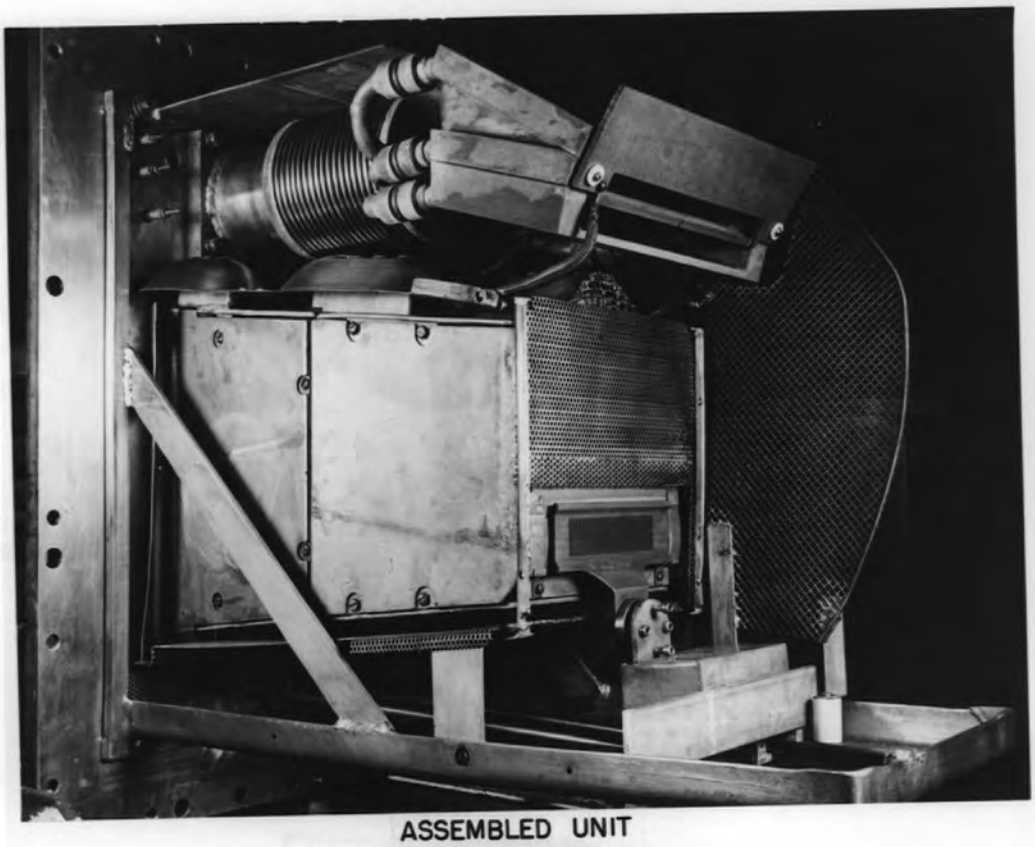
GRID ION SOURCE DEVELOPMENT

The new ion source differs from the conventional calutron type ion source principally in the fact that the requirement of the latter that the ions pass through a narrow focal region has been eliminated In the new source the surface of the arc plasma is stabilized by a grid-type electrode across the broad aperture of the ionization chamber Ions are accelerated by a second electrode of similar design and aligned closely adjacent, Figure 2 A slight convex curvature of the arc electrode provides for focusing of the ion beam at the collector, Figure 3 With this electrode system a broad intense beam originates at the ion source and narrows to a focus only as it arrives at the collector Stabilization of the ion-emitting surface of the arc makes it possible to obtain large ion current densities with relatively low accelerating potentials between the closely spaced electrodes

The development work for adapting the grid system for the acceleration of lithium ions was started in September 1951 The initially small experimental program was enlarged as results became more promising, during the first six months of 1952 it was supported at a level of approximately three scientists During this period the optimum magnetic field was determined for the new ion source, flat and curved grids were compared for output and beam focus, and current readings were confirmed calorimetrically There was considerable improvement in focused ion output, Table I * Serious difficulty was initially encountered when attempts were made to collect large ion beams through collector slots Although substantial progress has been made, this problem is still one of the limiting factors in the use of the new ion source

---

* In early November an improved collector design resulted in the focusing of two amperes of lithium ions in the collector pockets from an ion source having 3 in^2 of arc surface In this case the accelerating potential was 18 kv, the magnetic field 4000 oersteds, and the beam radius $\sim$ 5 inches



ASSEMBLED UNIT

GRID ELECTRODES

FIGURE 2 - EXPERIMENTAL GRID UNIT

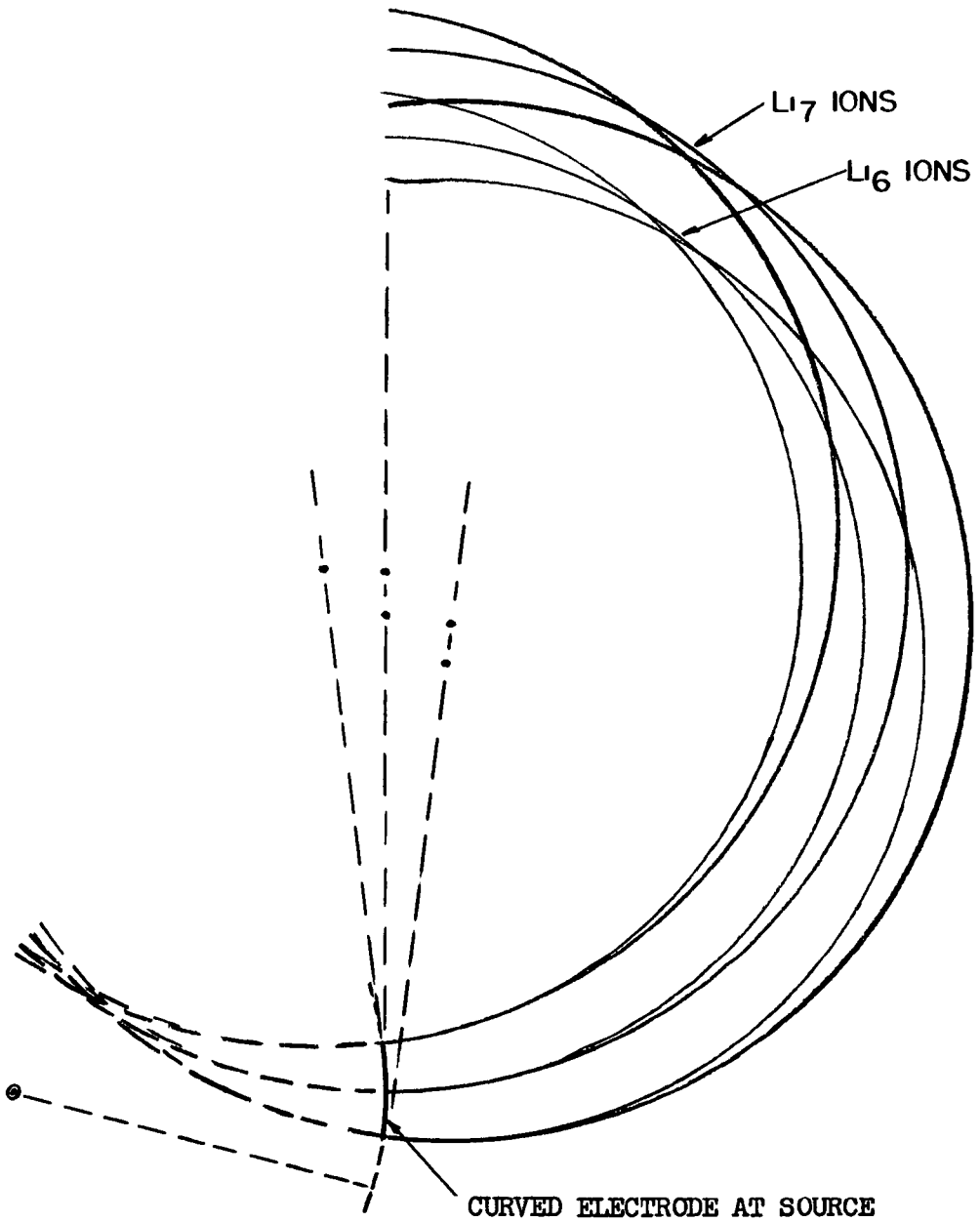


FIGURE 3 ION PATHS FROM CURVED ION SOURCE ELECTRODE

Date of Experiment	Type of Arc Electrode	Area of Grid (in^2)	Ion Current* (ma)			
			Flat-Plate Monitor		Slotted-Plate Monitor	
			Total	per in^2	Total	per in^2
7/10/51	Flat	1	1100	1100	-	-
10/31/51	Flat	1	1500	1500	-	-
12/17/51	Curved	1	900	900	-	-
12/24/52	"	1	-	-	400	400
1/31/52	"	2	-	-	600	300
2/29/52	"	1	-	-	500	500
3/17/52	"	2	1500	750	-	-
4/1/52	"	2	-	-	1100	550
6/17/52	"	1	-	-	800	400
7/10/52	"	4	2500	625	-	-
8/26/52	"	1	-	-	975	975

* The values listed were selected from the official run records based on the criteria that the unit was running steadily for a significant period of time

TABLE I SUMMARY OF OPERATION OF EXPERIMENTAL ION SOURCES

COST ESTIMATES FOR PILOT PLANT

It is proposed that Beta Magnet V and associated facilities in Building 9204-3 be utilized for this pilot plant Since the installation is already in an operable condition, the cost and delay associated with reactivating a building from standby condition would be avoided In order to minimize capital expenditures, it is assumed that existing equipment and facilities will be used wherever possible For a short-term program, operating costs are not seriously affected by this expedient but for an extended operation a more efficient plant design should be considered The capital, operating and production cost estimates are summarized in Table II for the six different cases described below

The basic plan for the pilot plant consists of installing six individual mass spectrographs, each with source and collector, in a single vacuum tank, Figure 4 Each ion source would have an effective arc area of approximately 4 5 square inches An average arc current density of 0 44 ampere per square inch is projected for Cases I and II The output for Cases III to VI is based on 0 66 ampere per square inch Three of the cases (I, III, and V) are planned on the basis of 12 tanks, while the remaining three are on the basis of 16 tanks Cases V and VI are included to indicate the effect of power regeneration by deceleration of the ion beam, it is assumed here that the power dissipated in the beam may be reduced 50%

Case II gives the maximum production rate with the greatest element of conservatism One can expect to produce at the annual rate of 720 pounds of Li 7 and 53 pounds of Li 6 The capital cost for this case is estimated at $750,000 and the annual operating cost at $1,241,000 If the cost is shared

Case	I	II	III	IV	V	VI
Conditions						
Current* per arc (amps)	2	2	3	3	3	3
Vacuum tanks (6 arcs each)	12	16	12	16	12	16
Power regeneration (%)	0	0	0	0	50	50
Ion Current* (amps)						
Total	144	192	216	288	216	288
Net**	115	155	175	230	175	230
Production Rates						
Li 6 (gm/day)	49 3	65 8	78 7	104 9	78 7	104 9
Li 7 (gm/day)	676	901	1010	1350	1010	1350
Li 7 (lb/day)	1 49	1 99	2 23	2 98	2 23	2 98
Product Concentration (wt %)						
Li 6 (% Li 6)	93 15	93 15	87 18	87 18	87 18	87 18
Li 7 (% Li 7)	99 97	99 97	99 93	99 93	99 93	99 93
Costs ($)						
Capital	515,000	750,000	630,000	839,000	715,000	958,000
Daily operation	2,610	3,360	3,050	3,940	2,890	3,720
Annual operation	954,000	1,226,000	1,113,000	1,438,000	1,054,000	1,358,000
Unit Cost of Products ($/gm)						
Total cost assigned to Li 6	52 90	51 10	38 80	37 60	36 70	35 50
Total cost assigned to Li 7	3 86	3 73	3 02	2 92	2 86	2 76
One-half cost assigned to Li 6	26 50	25 60	19 40	18 80	18 40	17 70
One-half cost assigned to Li 7	1 93	1 86	1 51	1 46	1 43	1 38

* Includes Li 6 and Li 7 ions

** Adjusted for 90% innage and 90% collector retention

TABLE II SUMMARY OF ASSUMPTIONS, PRODUCTION RATES, AND COSTS

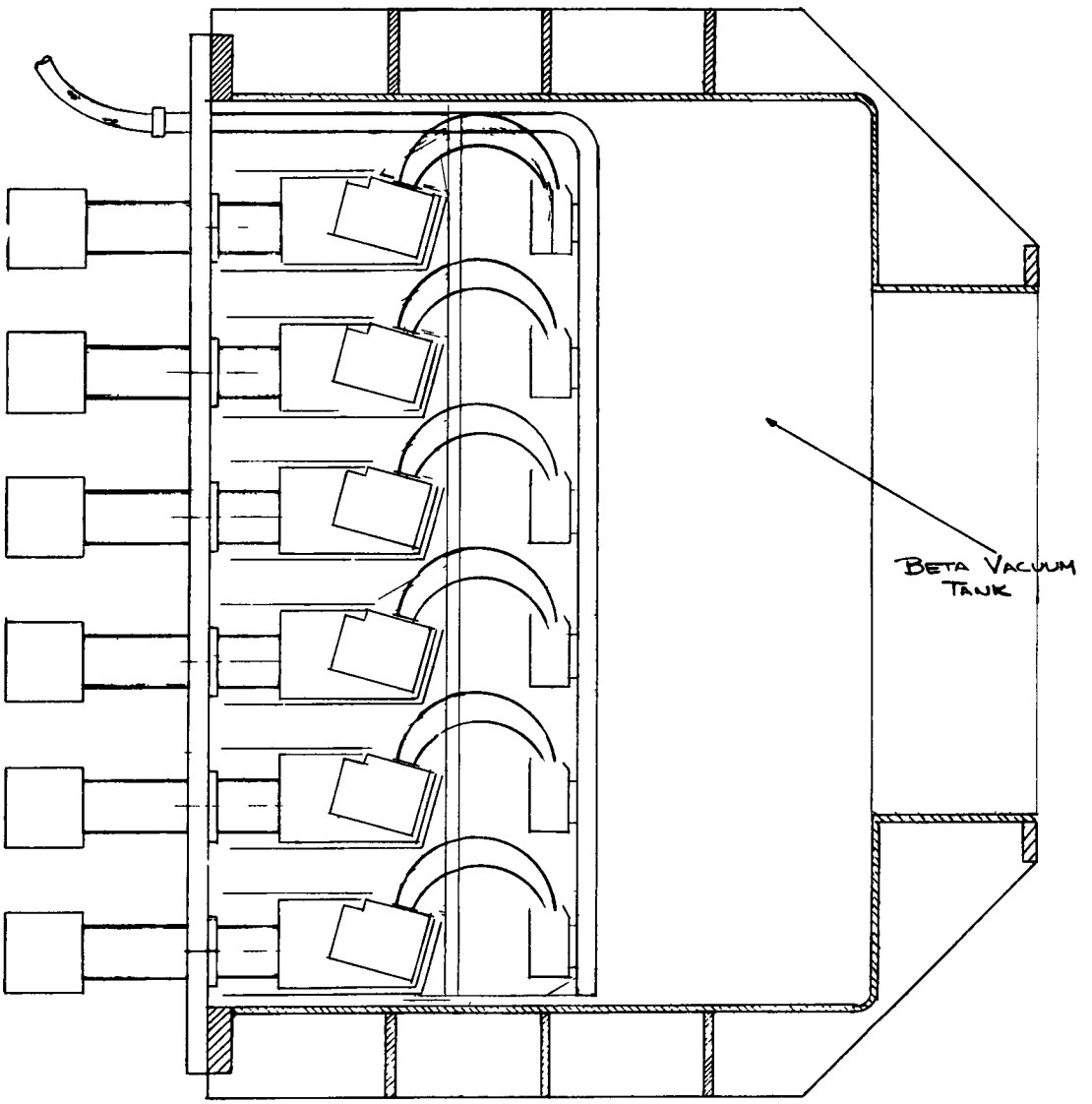


FIGURE 4. PRODUCTION UNIT LAYOUT

equally between Li 6 and Li 7, the unit costs are $25 60 and $1 86 per gram, respectively These costs will be increased to $28 70 and $2 09 if the capital expenditures are written off over a five-year period As is discussed on page 16 of this report, it would take a minimum of approximately seven and one-half months after authorization to put such a pilot plant in operation

The Effect of Different Enrichment Factors

The enrichment factors assumed for the product concentrations in Table II represent the best judgement of qualified personnel who have reviewed existing data to determine values which may be reasonably expected Lower product purity is, of course, possible and higher purity can probably be achieved While not enough basic information is available at the present time to give definite estimates, the general effect of a reduction in product purity would be to permit a more rapid development of plants producing larger currents than those specified in Case II A more thorough analysis will need to await the completion of additional experimental work

SCHEDULES FOR DEVELOPMENT AND OPERATION

The date on which the pilot plant can be put in operation depends on the period of time required for the development, design, and fabrication of the ion sources and the associated collectors Modification and installation of electrical supplies and other facilities can begin when the project is approved and should be completed before the operating units are available The schedule will be determined, of course, on the budget allocations and priorities assigned to the program Since an undetermined additional period would be required for development of power regeneration units, Cases V and VI are omitted from schedule considerations

With Present Development Program

With the funds and staff presently budgeted for this project the design, fabrication, and testing of a prototype six-arc twelve-ampere unit will require approximately 36 weeks The power supplies and other facilities for operating a single test channel are already available The schedule is

Design	4 weeks
Fabrication	16
Assembly	6
Testing	10
	36 weeks

The present program does not, of course, provide for fabrication, installation, and operation of additional units which would be needed for a pilot plant

With Accelerated Development Program

If greater emphasis were placed on the program the development period could be reduced to 17 weeks This would require an increase in available funds and priorities The accelerated schedule would then be

Design	3 weeks
Fabrication	6
Assembly	4
Testing	4
	17 weeks

Construction Schedule

Power supplies, vacuum equipment, and other facilities now in use at Magnet V would require very little modification to accommodate one six-arc channel Considerable time would be required, however, to provide for 12- or 16-channel operation These modifications could begin as soon as the project is approved and with reasonable priority could be completed on the following schedule

	Cases I & II	Cases III & IV
2 channels	12 weeks	16 weeks
12 channels	16 weeks	20 weeks
16 channels	20 weeks	28 weeks

Minimum Schedule for Operation after Accelerated Development

It is estimated that after the design of the production units has been established it will require 15 weeks to fabricate the required number of units and to put 16 channels in operation With the accelerated development the total schedule would be

Weeks after Authorization	Production Units	Facilities
1	Design started	Installation started
3	Design completed	
9	First unit fabricated	
13	First unit ready for tests	2 channels ready
17	Final design established	
18	1 channel in operation	12 channels ready
22	3 channels in operation	16 channels ready
23	4 channels in operation	
27	8 channels in operation	
30	12 channels in operation	
32	16 channels in operation	

RESEARCH AND DEVELOPMENT

With the successful operation of the experimental equipment on a laboratory scale, two additional aspects of the program should be considered

1 The development program necessary to make a satisfactory production machine

2 An analysis of the long-range potentialities of the separation method, a consideration of reasonable research and development goals for a program of continued investigation and improvement

Development Program

Component Life Equipment which will provide steady operation over long periods is essential for a production plant Certain components of the present equipment such as the filament, the defining slot, and the arc electrode, can unquestionably be improved with respect to lifetime

The present filament would probably have to be changed once every 24 hours While the present cost estimates have included this requirement, it would be very desirable to extend the filament life As yet, no development work has been done on this type of problem because of the greater necessity for obtaining reliable basic information A new type of rotatable indirectly-heated cathode has been conceived but not tested, Figure 5

The present defining slot suffers deterioration due to the large amount of electrical energy it must dissipate It is known from previous experience that a modification such as illustrated in Figure 6 will improve the slot by permitting it to run cooler and making it less likely to be blocked by deposited material

Deposits of undesirable material, principally copper compounds, frequently appear on the arc electrode It is likely that a reduction in the amount of copper in the heater castings and the periodic use of additional chlorine gas would contribute to a solution of this problem

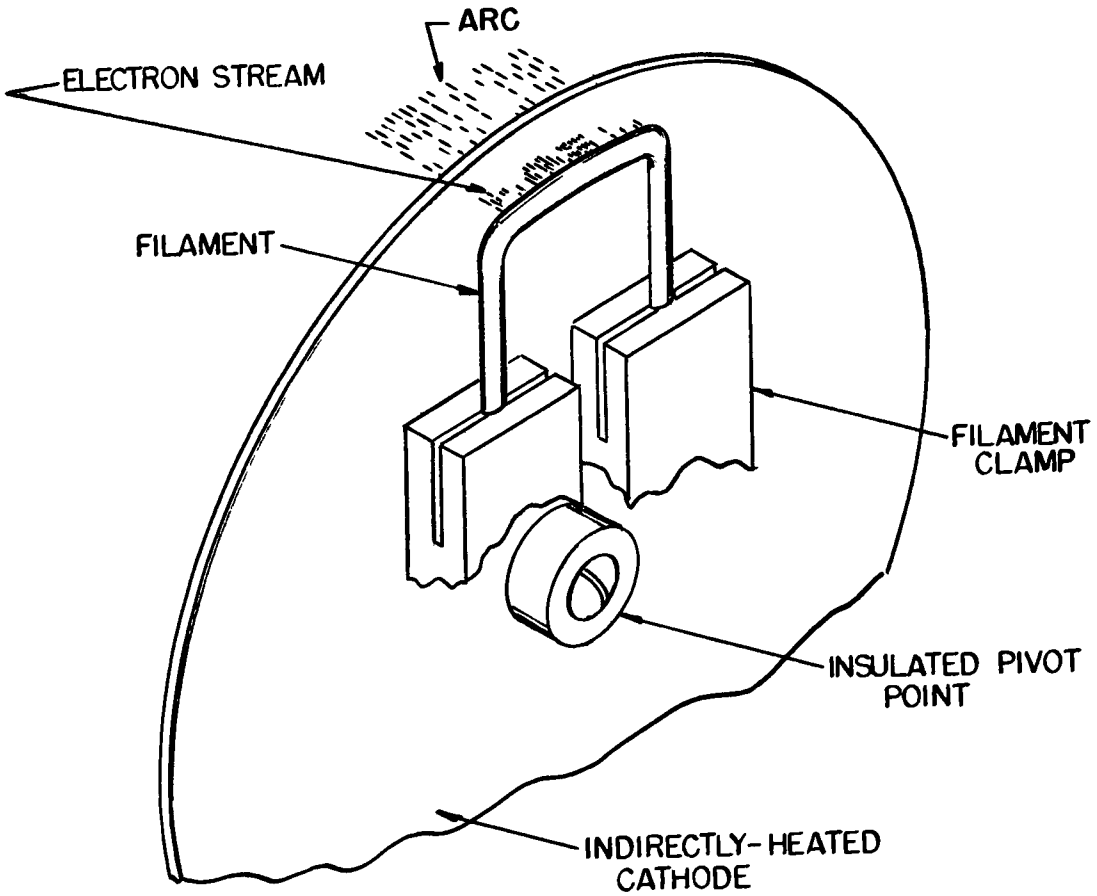


FIGURE 5 ROTATABLE INDIRECTLY-HEATED CATHODE

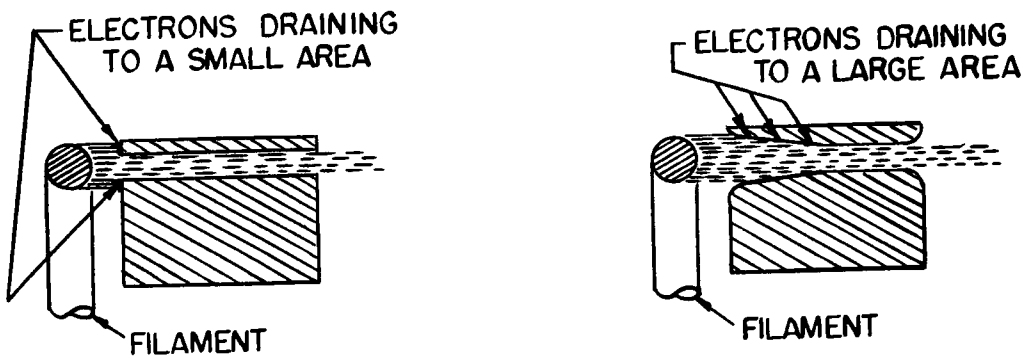


FIGURE 6 SHAPE OF DEFINING SLOT

Paralleled Power Supplies In the Beta installation it is impossible to have a separate power supply for each source without great cost It would be necessary to devote some time to perfecting operation with the supplies paralleled

Improved Focus The very high current densities at the collector present a limitation in the quality of focus which can be achieved at high output Satisfactory solutions have already been found for current densities up to 500 ma/in^2 Two or three times this current density has been obtained, however, and on flat collector electrodes the quality of focus is excellent The use of flat target plates inside the collector pockets, the effect of insulated anodes and the external circuit associated with them, and the addition of biased side screens, injected electrons, and various added gases and solids all need to be carefully studied to determine how much further the current densities can be raised without loss of focus

Long Range Potentials

The costs and production rates presented in the foregoing pages of this report are a conservative interpretation of what the existing basic information implies for a short range production program This report might be misleading if it did not include an appraisal of the longer range possibilities of the process

The cost breakdown for Case IV, which gives the largest production rate, is

Labor and overhead	32%
Beam power	25
Electrical supplies	19
Miscellaneous power	4
Unit supplies	14
Miscellaneous	6

From this breakdown it can be seen that labor, beam power, and electrical supplies contribute 76 percent of the production costs It is logical, therefore, to consider what cost reduction might be expected with greater output per arc, with power regeneration, and with more efficient rectifiers

Greater Output per Ion Source If other factors are held constant, there is a definite relationship between output per ion source and labor, that is, if the output per ion source is doubled the labor costs are cut in half If outputs as high as 1 5 amperes per square inch, obtained experimentally, were achieved for an ion source of 10 square inches, it would give an output of 15 amperes per arc A more conservative goal then might be 10 amperes per ion source in an Alpha tank While an Alpha building is on the average more expensive to operate than a Beta building, unit costs would actually be cheaper, since more and longer ion sources (at least 12) could be installed in one channel The only foreseeable difficulty associated with this larger number of ion sources would be in pumping speed of the vacuum system Large improvements in the Alpha vacuum systems can be made In view of these assumptions, reducing labor and overhead from 32 to 12 percent of the present estimates should not be difficult if sufficient time is allowed for research A saving of 20 percent in process costs might thus be achieved

Power Regeneration It is believed by those who have studied it carefully that power regeneration to the extent of at least 50 percent could be realized in a reasonable time In addition, the present electrical supplies are only about 72 percent efficient Regulated supplies of 85 percent efficiency are obtainable If it is assumed that power costs could be cut slightly more than one-half, then a saving of an additional 15 percent could be made

Improved Rectifiers The dc power supplies suggested in the various cases presented in this report were chosen since they are already available (usually as surplus) and could be utilized quickly They are, however, considerably more expensive to maintain and less efficient in operation The development of a mercury arc dc power supply should have a high priority since its maintenance would not be greater than 5 percent of the operating costs A savings of 15 percent could be achieved here

Conclusion on Long Range Potentials

Further development of this process for the separation of lithium isotopes should result in greatly increased throughput and in a reduction of costs to less than 50 percent of the lowest figures quoted in this report While these cost reductions and throughputs do not represent ultimate limits of the process, they do give an idea of the practical levels of operation which might be expected The time required to reach these goals would depend upon the effort and priorities allocated to the project The largest output and lowest cost could be attained in an Alpha magnet but very significant improvements can also be made with an installation in a Beta magnet

ACKNOWLEDGEMENTS

A L Boch, H B Bainbridge, G F Leichsenring, M B Marshall, and L E Parsons assisted substantially in assembling and preparing information for this report A major responsibility in editing the report was carried out by F T Howard The entire development of the project has been under the tireless personal supervision of E D Shipley

APPENDIX A SUMMARY OF DAILY OPERATING COSTS

Case	I	II	III	IV	V	VI
Labor	$ 565	$ 693	$ 565	$ 693	$ 565	$ 693
Overhead	480	589	480	589	480	589
Materials and Supplies	809	1,079	978	1,304	1,181	1,574
Electrical Power	610	802	853	1,126	488	640
Steam and Water	100	130	100	130	100	130
Process Feed*	49	65	73	98	73	98
Total Operating Cost	$2,613	$3,358	$3,049	$3,940	$2,887	$3,724

* LiCl at $1 25/lb, 25% process efficiency, and no recycle

APPENDIX B PERSONNEL REQUIREMENTS

	12 Channel Operation 21 shifts/wk	16 Channel Operation 21 shifts/wk
General Supervision	1	1
Operations		
Foreman	4	4
Unit Operators	12	16
Track Operators	4	4
Shift Relief	5	5
Electricians	6	9
Chemical Operators	3	4
Maintenance and Assembly		
Assemblers	4	5
Major Repair	1	2
Vacuum Testing	1	1
Track Maintenance	1	1
Miscellaneous	2	2
Total Personnel	44	54
Labor Cost at $390/mo	$565	$693
Overhead at 85%	$480	$589

APPENDIX C DAILY COST OF ELECTRICAL POWER, MATERIALS & SUPPLIES

Case	I	II	III	IV	V	VI
Electrical Power						
High Voltage	$ 486	$ 648	$ 729	$ 972	$ 364	$ 486
Magnet	24	24	24	24	24	24
Arcs, Pumps, Misc	100	130	100	130	100	130
Total	610	802	853	1,126	488	640
Materials and Supplies						
Graphite Electrodes	120	160	120	160	120	160
Filaments	108	144	108	144	108	144
Unit Parts	180	240	180	240	180	240
Electrical Supplies	401	535	570	760	773	1,030
Total	$809	$1,079	$978	$1,304	$1,181	$1,574

APPENDIX D SUMMARY OF CAPITAL EXPENDITURES

Case	I	II	III	IV	V	VI
Electrical Conversion	$266,000	$406,000	$370,000	$487,000	$412,000	$545,000
Spectrograph Units	167,000	232,000	167,000	232,000	203,000	282,000
Miscellaneous	35,400	43,900	35,400	43,900	35,400	43,900
Contingency	46,800	68,200	57,200	76,300	65,000	87,100
Total	$515,200	$750,100	$629,600	$839,200	$715,400	$958,000

APPENDIX E ESTIMATE FOR ELECTRICAL CONVERSION

Case	I	II	III	IV	V	VI
Labor and New Material	$185,000	$285,000	$255,000	$329,000	$297,000	$395,000
Salvage Material (on hand)	34,000	46,000	45,000	60,000	55,000	74,000
Control Consoles	18,000	24,000	18,000	24,000	18,000	24,000
Additional Power Facilities*	0	16,000	18,000	32,000	0	0
Miscellaneous	19,000	25,000	24,000	32,000	30,000	40,000
Engineering	10,000	10,000	10,000	10,000	12,000	12,000
Total	$266,000	$406,000	$370,000	$487,000	$412,000	$545,000

* Present installed capacity is adequate for Cases I, V, and VI

APPENDIX F COST BREAKDOWN - SPECTROGRAPH UNITS

	6-Arc Assembly without Power Regeneration (Cases I,II,III, & IV)	6-Arc Assembly with Power Regeneration (Cases V & VI)
Fabrication Costs		
Faceplate	$ 575	$ 575
Junction Boxes	138	138
Cage	-	1,030
Collectors	1,130	1,130
Support Frame	253	253
Ion Sources	3,240	3,380
Total	$5,336	$6,506
Assembling Cost	$1,200	$1,450
Total Cost per Assembly	$6,536	$7,956
Engineering (Total)	$3,400	$4,000
Total Cost of 25 Units (12 Vacuum Tanks)	$167,000	$203,000
Total Cost of 35 Units (16 Vacuum Tanks)	$232,000	$282,000

APPENDIX G MISCELLANEOUS MODIFICATIONS

Case	I	II	III	IV	V	VI
Vacuum Tank Conversion	$ 1,400	$ 1,900	$ 1,400	$ 1,900	$ 1,400	$ 1,900
Tank Front Modification	24,000	32,000	24,000	32,000	24,000	32,000
Tank Water Supply	4,000	4,000	4,000	4,000	4,000	4,000
Unit Cleaning and Product Chemistry	5,000	5,000	5,000	5,000	5,000	5,000
Engineering	1,000	1,000	1,000	1,000	1,000	1,000
Total	$35,400	$43,900	$35,400	$43,900	$35,400	$43,900