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Dr 294

DOE/JPL/954888-2

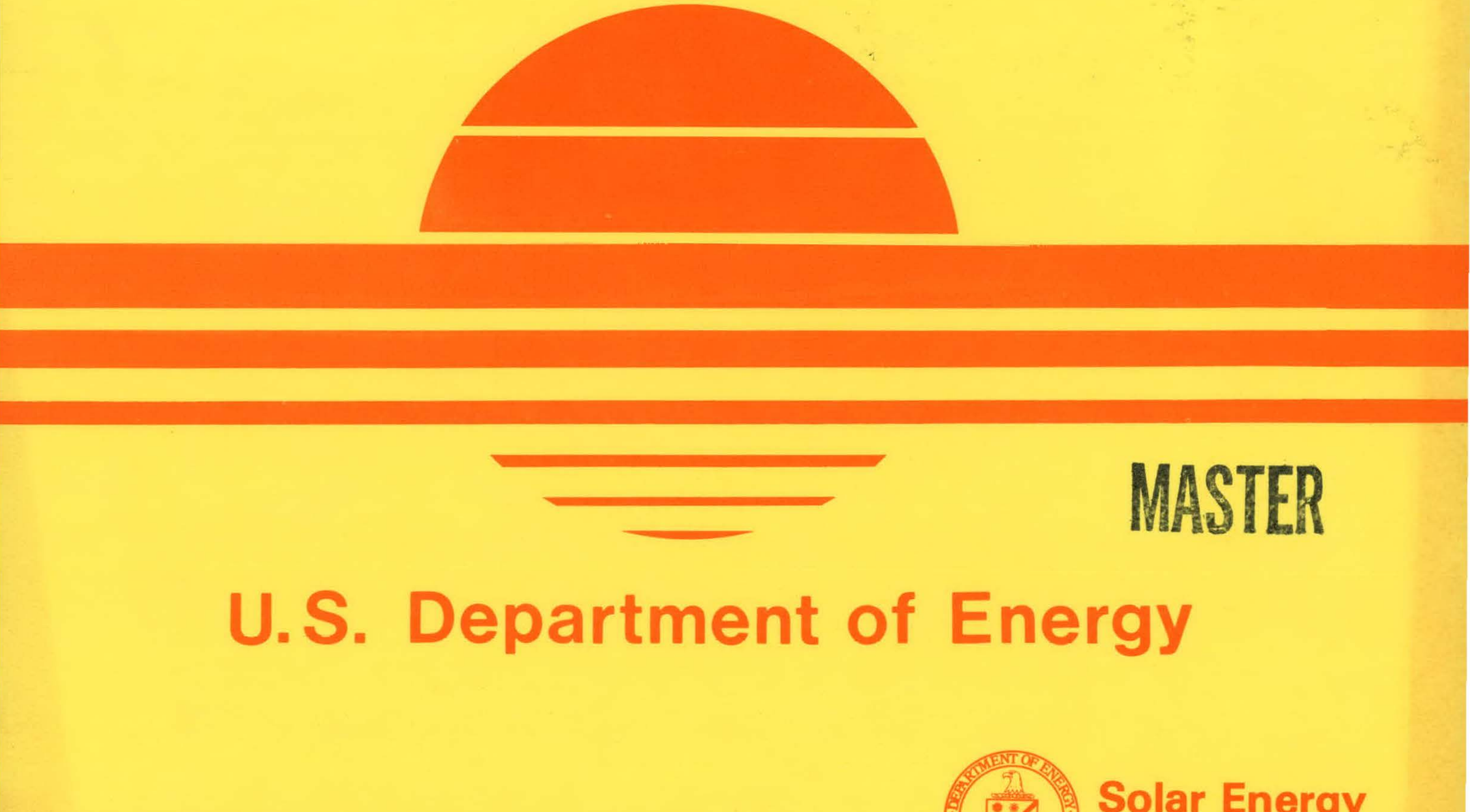
CONTINUOUS CZOCHRALSKI GROWTH

Silicon Sheet Growth Development of the Large Area Silicon Sheet Task of the Low-Cost Silicon Solar Array Project

Second Quarterly Progress Report, January 1—March 31, 1978

Work Performed Under Contract No. NAS-7-100-954888

Kayex Corporation
Rochester, New York



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CONTINUOUS CZOCHRALSKI GROWTH

SILICON SHEET GROWTH DEVELOPMENT OF THE LARGE AREA SILICON SHEET TASK OF THE LOW-COST SILICON SOLAR ARRAY PROJECT

SECOND QUARTERLY PROGRESS REPORT
JANUARY 1 - MARCH 31, 1978
PROGRAM MANAGER: DR. R. L. LANE

KAYEX CORPORATION
1000 MILLSTEAD WAY
ROCHESTER, NEW YORK 14624

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DoE."

ABSTRACT

This project is directed toward the development of equipment and processes to produce single crystal solar silicon by a continuous Czochralski (CZ) method. "Continuous" is defined as the production of at least 100 kilograms of crystal from a single melt container. The approach to be taken is to suitably modify a Hamco CG2000 crystal grower to demonstrate that continuous CZ growth is feasible by the periodic replenishment of the melt container and the removal of grown crystals.

The crystal growth facility is now complete with the exception of the poly weight/recharge system. Installation of this device on the grower will require disassembly of the facility to modify the growth chambers. In the meantime, hot filling experiments are being conducted by attaching poly rod material to the seed lift mechanism.

The work has progressed to the point where a suitable means of melt replenishment has been demonstrated. A poly-crystalline rod of silicon can be lowered into the crucible and melted at rates of over 14 kg/hr. This is considerably faster than the 8-10 kg/hr anticipated.

Using this method of hot filling, a 12" x 9" high crucible was charged with 25 kg of silicon and a zero dislocation, 22 kg crystal 11.4 cm diameter, 87 cm long, was grown. This demonstrates that five crystals grown from a 12 inch crucible can satisfy the continuous CZ criterion. A growth rate of 7.3 cm/hr was achieved corresponding to a continuous throughput of 1.1 kg/hr.

The demonstrated run simulates the first cycle of a five-cycle "continuous" run and therefore can be used as a means to confirm and update the economic model. Estimated power levels and time cycles were confirmed by the run.

An economic model using the SAMICS/IPEG guidelines has shown that the add-on cost of CZ crystal growth can meet the 1982 goals without any technical breakthroughs, but an add-on cost reduction of approximately 50% is necessary to meet the 1986 goal, assuming reasonable slicing yields.

CONTENTS

FIGURES & TABLES

1.0 INTRODUCTION

The approach to continuous crystal growth being used on this project relies on conventional Czochralski growth technology combined with new equipment designs which will allow repeated cycles of crystal growth, and hot melt replenishment, by methods which are suitable for use in a high volume production facility.

A Hamco Model CG2000 crystal grower has been modified with (1) a special pull chamber for storing a supply of poly silicon, and (2) a vacuum-tight isolation valve to permit retrieval of crystals and poly replenishment without contamination. (See Figure 1).

A number of additional modifications to this facility have either been completed or are in process to allow melt replenishment to be performed routinely in a simulated production mode.

It is the purpose of this project to develop equipment and process to achieve low-cost production of single crystal silicon by pulling at least 100 kilograms of crystal from a single melt container.

2.0 PROGRESS

2.1 GROWTH FACILITY CONSTRUCTION AND MODIFICATION

The CG2000 crystal grower with special modifications was made fully operational during the reporting period. Several crystal runs were performed to establish that the unit met all specifications.

2.1.1 POLY WEIGHT/RECHARGE SYSTEM

This device (Figure 2) will permit the charge of poly silicon to be added to the hot crucible in a controlled manner. It will allow a display of the amount of poly left unmelted. If a poly rod is being fed, it will melt back at a predetermined rate and stop at a preset value.

Because of unexpected complexity of design and manufacture, this device is now scheduled for late April and testing and installation are expected to be complete by mid-May.

2.1.2 POLY ATTACHMENT DEVICE

A clamping device to securely hold poly rods of up to 50 kg was designed and built to attach to the cable of the poly weight/recharge device. In order to evaluate it and to proceed with hot-filling experiments, the poly was suspended from the seed lift mechanism for lowering into the crucible.

The first attempt to hot fill was a failure because the cable unexpectedly overheated due to the intense heat of melt-down and failed. The poly attachment device fell into the melt and was destroyed.

Subsequently the device was redesigned with a longer upper piece to allow the cable to be higher up in the furnace away from the heat.

Hot filling with a poly rod has now been demonstrated successfully with the poly attachment device. A poly rod can be melted back to a remaining amount of less than 1 kilogram.

2.1.3 MODIFIED BEAD CHAIN/CABLE MECHANISM

The standard seed lift (pulling) mechanism utilizes a stainless steel bead chain. In order to increase the capacity of the unit to 40 kilograms and to permit accurate weighing of the growing crystal, the device was strengthened and the bead chain was replaced with a polystrand stainless steel cable.

The seed lift mechanism now has produced several high quality crystals with continuous readout of crystal weight and length.

2.1.4 DOPANT FIXTURE

This device is complete (Figure 3), installed on the grower, and has been found to be satisfactory. Dopant can be added in premeasured amounts at any time during melt-down or melt replenishment.

2.1.5 CRYSTAL/POLY TRANSFER DEVICE

Hot crystals and poly rods must be safely and reliably transferred from and to the growth facility. This design (Figure 4) employs a clamping support for holding the crystal mounted on a commercially available manual lift hoist. Completion of the design is awaiting the delivery of the hoist.

The transfer device is capable of rotating the crystal or poly rod to the horizontal position and placing it on a rack designed for the purpose (Figure 5).

2.1.6 14-INCH HOT ZONE

Because of the long lead time required on graphite, the heater assembly and insulation pack was designed ahead of the program plan. These designs have been released for quotation.

14-inch crucibles have been received and are in the stockroom.

2.2.0 CRYSTAL GROWTH PROCESS DEVELOPMENT

Of primary importance is the reliable and controlled addition of polysilicon to the hot crucible. The feasibility of utilizing polysilicon rods as the supply material has been demonstrated.

A 12-inch crucible was loaded in the usual manner with 18 kilograms of silicon. Because of the packing factor of lump material, 18 kg is the present limit of this crucible, which, when fully melted, leaves about 4 inches of freeboard.

Seven kilograms of silicon were then added to the melt by attaching the poly rod to the seed lift cable, for a total of 25 kilograms. From this melt, a 22 kilogram, 87 cm long, zero-dislocation crystal was grown at a diameter of 11.4 cm. Average growth rate was 7.3 cm/hr. Figure 6 is a plot of crystal weight and length increase during the run.

Power consumption during the run was monitored (Figure 7) and time cycles were recorded. Power usage was found to be the same as that estimated in the economic model. The melt-back rate for the poly rod was 14 kg/hr, considerably faster than that estimated in the model. Cycle time for the hot fill operation, (i.e. loading poly, melt-back, removing poly, stabilization and reseeding) was approximately 1 hour, considerably shorter than anticipated. Throughput for the total run was 1.1 kg/hr.

The conclusions that can be drawn from the process study are:

1. Hot-filling with poly rod feed material is feasible.
2. A crucible can be filled to a larger capacity than with cold fill techniques.
3. The assumptions in the economic model relating to cycle time, power consumption, and growth rate are realistic, and in some areas conservative.
4. Continuous CZ as defined depends now only upon the ability of the crucible to survive the long term exposure to molten silicon and to the ability of the crystal grower to perform without malfunction.

3.0 ECONOMIC MODEL

Previously it was reported(1) that the add-on cost of continuous CZ#1 was \$16.79 per kilogram (See Table 1 for four possible growth methods). This value was arrived at using a model developed at Kayex Corporation and is in 1978 dollars. Subsequently, the SAMICS/IPEG model was applied to the input data which yielded an add-on cost of \$21.69 per m^2 for 1982 and \$19.30 per m^2 for 1986 (1975 dollars).

The model has not been updated to reflect the improved time cycles which were obtained on the recent 25 kg run.

Continuous CZ#2 calls for three 12.5 cm diameter crystals grown from a 14-inch crucible to achieve additional cost savings. Preliminary calculations indicate that the add-on cost can be reduced by this method and the economic analysis of this will be included in a later report.

3.1.0 SAMICS/IPEG ANALYSIS OF CONTINUOUS CZ#1

3.1.1 GROWTH CONDITIONS (See Table 1 under continuous CZ#1).

3.1.2 ASSUMPTIONS

Cycle Time = 74.9 hrs from Table 2

Machine Utilization = 90%

Cycles/yr = (345 days/yr)(24 hr/day)(.90)/74.9 hrs/cycle = 99.5 cycles/yr

Direct Labor - One operator runs three machines. This is equivalent to 4 people/yr continuous operation.

4 people/3 machines = 1-1/3 man x yr/machine

Slicing Yield

1978 = 1.77 kg/m^2 (wafer + kerf = .076 cm)

1982 and 1986 = 1.0 kg/m^2 (wafer + kerf = .043 cm)

(1)Lane, R. "Continuous Czochralski Growth" First Quarterly Progress Report ERDA/JPL 954888-78/1, December, 1977.

CZ GROWTH METHODS

CONDITIONS:	BATCH #1	BATCH #2	CONTINUOUS #1	CONTINUOUS #2
CRUCIBLE SIZE (in)	12 x 9 h	12 x 9 h	12 x 9 h	14 x 10-1/2 h
CRYSTAL DIAMETER (cm)	10	12.5	10	12.5
GROWTH RATE (cm/hr)	10	10	10	10
TOTAL POLY MELTED (kg)	18	18	105	110
TOTAL CRYSTAL PULLED (kg)	14.4	14.4	100	101
PULLED YIELD (%)	80	80	95	92
USABLE AFTER GRINDING (kg)	12.6	12.6	87.5	88.3
GROUND CRYSTAL YIELD (%)	70	70	83	80
NO. CRYSTALS/CRUCIBLE	1	1	5	3

Table 1

CONTINUOUS CZ#1
PROCESS CYCLE TIME

OPERATION	TIME-MINUTES		
Load Poly	45		
Close Furnace	5		
Pump Down	10		
Melt	120		
			180
Hot Fill Cycle			
Position Poly		5	
Lower Poly		5	
Melt Poly		60	
Retract Poly		5*	
Lower Seed		15*	
Sub-Total			70
Stabilize Temperature	40		
Seed Growth	30		
Crown Growth	60		
Straight Growth	525		
Taper End	40		
			695
Recharge Cycle			
Cool Crystal		30	
Remove Crystal		10	
Position Poly		5	
Lower Poly		5	
Melt Poly		120	
Retract Poly*		5*	
Lower Seed*		15*	
Stabilize Temperature		40	
Seed Growth		30	
Crown Growth		60	
Straight Growth		525	
Taper End		40	
Sub-Total	865		
No. of Recharges		4	
Total Recharge Time			3460
Cool Furnace	30**		
Remove Crystal	--**		
Clean, Set Up	60		90
Total Time, min.			4495
Total Time, hr.			74.9
Throughput (Kg/hr)			1.2

* Completed during stabilization of melt temperature
** Part of the recharge cycle

Table 2

3.1.3 INPUT DATA

The input data are in 1978 dollars. The SAMICS/IPEG model has been followed with the exception of treatment of the poly raw material. This has been left out of the calculation in order to arrive at a CZ add-on cost. Ultimately the CZ add-on cost should be combined with the slicing cost, with the assignment of appropriate material plus overhead costs for the poly silicon, to arrive at the "WAFERCO" cost for comparison with the SAMICS goals.

"Miscellaneous" costs of material in the input data primarily relate to graphite usage. Because this is such a large item, the assumptions used in arriving at the amount are included in Table 3. At best, this table is a compilation of educated guesswork. Actual graphite usage could only be determined from the records of a production facility, preferably with a number of crystal growers operating continuously.

1.	Direct Equipment Initial Capital Cost EQPT	$150,000
2.	Direct Manufacturing Floor Space (Type A) SQFT	100
3.	Annual Direct Labor Salaries	
	Production Operator (B3752D)	
	(1.33 PRSN x YRS) ($9,400)(1.08)(1.08)	14,582
	Elect. Technician (B3704D)	
	(0.1 PRSN x YRS) ($11,000)(1.08)(1.08)	1,283
	Inspector (B3720D)	
	(0.1 PRSN x YRS) ($8,250)(1.08)(1.08)	962
	Total DLAB	$ 16,827

4. Directly Used Materials & Supplies

Cycles/Yr = 99.5

Hours/Cycle = 74.9

P Poly (kg/yr)	10,447 kg
Crucibles @$200 ea	$19,900
Seeds $5/cycle	498
Dopant (not costed)	---
Argon*(E1112D) 100 ft^3/cycle-hr @.014/ft^3	11,476
Miscellaneous including graphite usage (See Table 3)	19,264
Total Material, excluding poly MATS-1	$51,138

5. Direct Process Usage of Utilities

Electricity (C1032B)	
(50 kw)($.027 x 1.12)(72.4 hr/cycle) (99.5 cycles/yr) =	$10,806
Cooling Water (C1128D)	
(50 kw)(.00566 x 1.15)(73 hrs/cycle) (99.5 cycles/yr) =	2,361
UTIL	$13,167

6. Annual Production

Poly melted x yield

105 (kg/cycle)(99.5 cycles/yr)(.83) = QUAN 8,706 kg

*Includes 13% inflation rate per SAMICS.

3.1.4 IPEG PRICE CALCULATION

$$\text{Price} = (C_1 \text{*EQPT}) + (C_2 \text{*SQFT}) + (C_3 \text{*DLAB}) + (C_4 \text{*MATS}) + (C_5 \text{*UTIL})/\text{QUAN}$$

in which C_1 = \$0.49/yr per dollar of EQPT

C_2 = \$97/yr per ft^2 of SQFT

C_3 = \$2.1/yr per dollar of DLAB

C_4 = \$1.3/yr per dollar of MATS

C_5 = \$1.3/yr per dollar of UTIL

In 1978 dollars:

CZ add-on Price = \$23.22/kg*

In 1975 dollars:

CZ add-on Price = \$19.30/kg*

*Price does not include poly or its overhead constant

3.1.5 ECONOMIC MODEL DISCUSSION AND CONCLUSIONS

Using the IPEG add-on cost for continuous CZ#1, one can calculate the margin available for slicing for 1978 through 1986 if slicing yields are assumed as follows:

Year	Slice Yield
1978	1.77 kg/m^2
1982	1.0 kg/m^2
1986	1.0 kg/m^2

HAMCO CG2000 HOT ZONE COSTS

CONTINUOUS CZ#1

PART (12" Hot Zone)	COST	NO. CYCLES	COST/CYCLE
A. Graphite			
Heater	$1100	75	$14.67
Heater Support (2)	250	50	5.00
Heater Screws (6)	24	50	.48
Crucible Support, Lower	100	30	3.33
Crucible Support, Upper	225	20	11.25
Insulator, Pedestal	100	50	2.00
Pedestal	130	75	1.73
Heat Shield Assembly	1400	500	2.80
Insulation - Baseplate	80	100	.80
Insulation - Top Ring	50	75	.67
			$42.73
B. Other Hot Zone Parts			
Thermocouple Assembly	220	100	2.20
Quartz Tube (Electrode) (2)	20	75	.27
Quartz Tube (Shaft)	8	75	.11
Sttel Tube (Shaft)	10	75	.13
Heat Shield Support (2)	160	100	1.60
			$ 4.31
C. Other Parts			
Crucible Shaft	600	500	1.20
Lift Cable	20	25	.80
Seed Holder	200	75	2.67
			$ 4.67
Grand Total, per cycle			$51.71/cycle

Estimates based on wear, handling, probability of part failure.

Table 3

Year	IPEG Price Goal - P Wafers	CZ Add-on Cost	Margin Left for Slicing
1978	$381/m^2	$34.16/m^2	$347/m^2
1982	128	19.30	$109
1986	18.2	19.30	($-1.1)

It is apparent that a significant CZ cost reduction is required in order to meet the 1986 goals. A CZ cost reduction of 50% would leave an approximately equal amount for slicing, and would appear to this writer to be achievable.

4.0 PLANS

During the next quarter, an attempt will be made to accomplish true recharging by growing a crystal and refilling the crucible at least twice according to the program plan (Figure 8).

The growth facility will be modified to include the poly weight/recharge system. This is expected to make the recharge process more efficient. This requires major disassembly of the grower for machining and modification of the chambers, but it should be completed and put back in operation in May.

5.0 COSTS

The following costs and man-hours have been expended:

	Last Quarter	This Quarter	Total
Man-hours:	1050	2430	3480
Costs:	$28,235	$103,854	$132,089

Figures 9 and 10 illustrate the time phased progress of costs and man-hours.

6.0 CONCLUSIONS

1. The modified CG2000 is complete with the exception of the poly weight/recharge system. The total facility will be ready in May. The unit has been tested, and several zero-dislocation crystals have been grown.
2. Hot filling by melting back a poly feed rod is feasible, and a melt back rate of 14 kg/hr has been demonstrated.
3. Hot filling provides more efficient use of the vitreous silicon crucible by effectively increasing its capacity. A 12-inch crucible was filled with 25 kg compared with 18 kg when cold filled with lump silicon.
4. A growth rate of 7.2 cm/hr with an 11.5 cm diameter crystal has been demonstrated.
5. The SAMICS/IPEG guidelines have been applied to continuous CZ#1 (12" x 9" high crucible). 1982 goals can be met, but significant cost improvement must be demonstrated to achieve the 1986 goals.

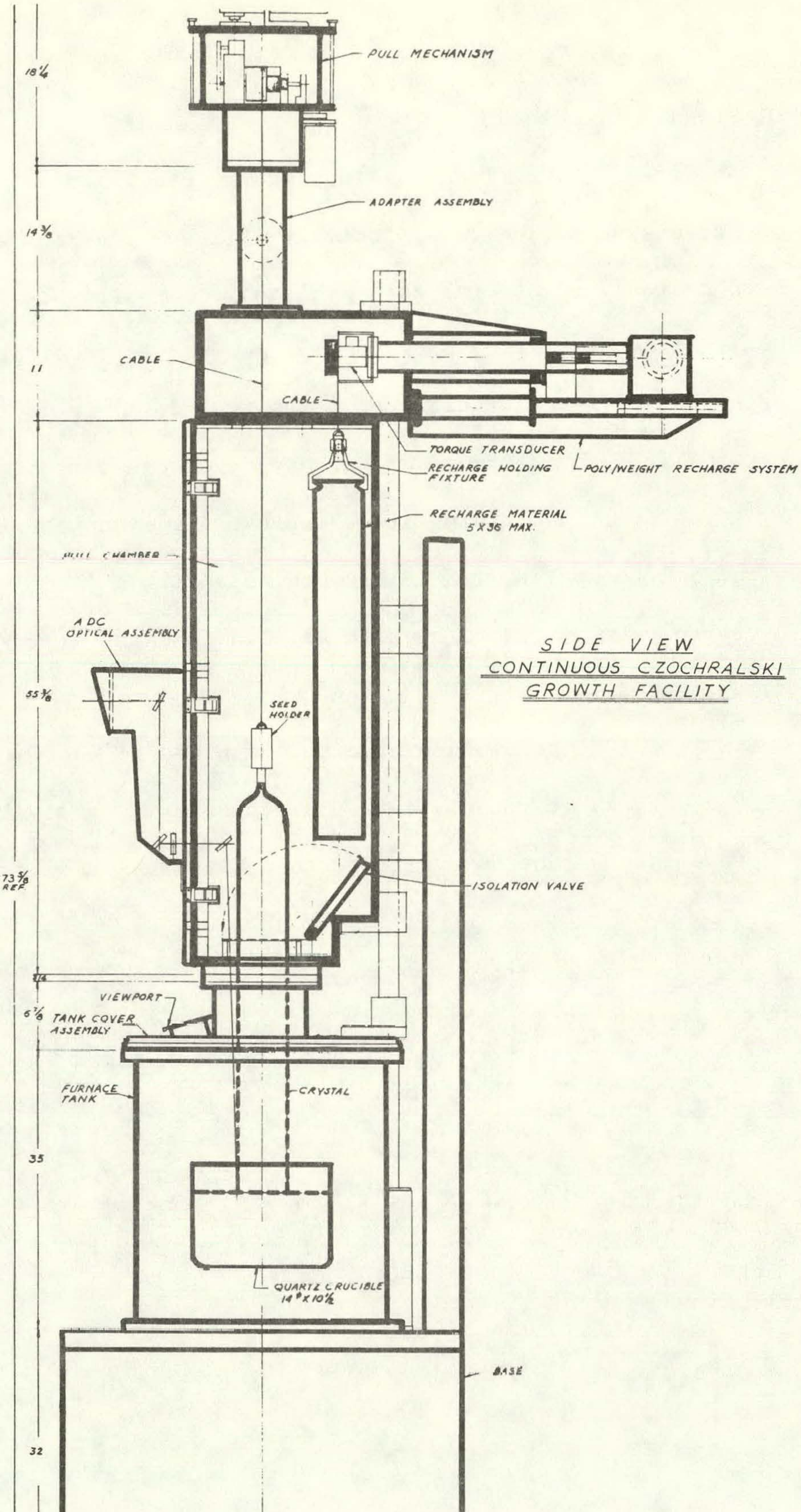
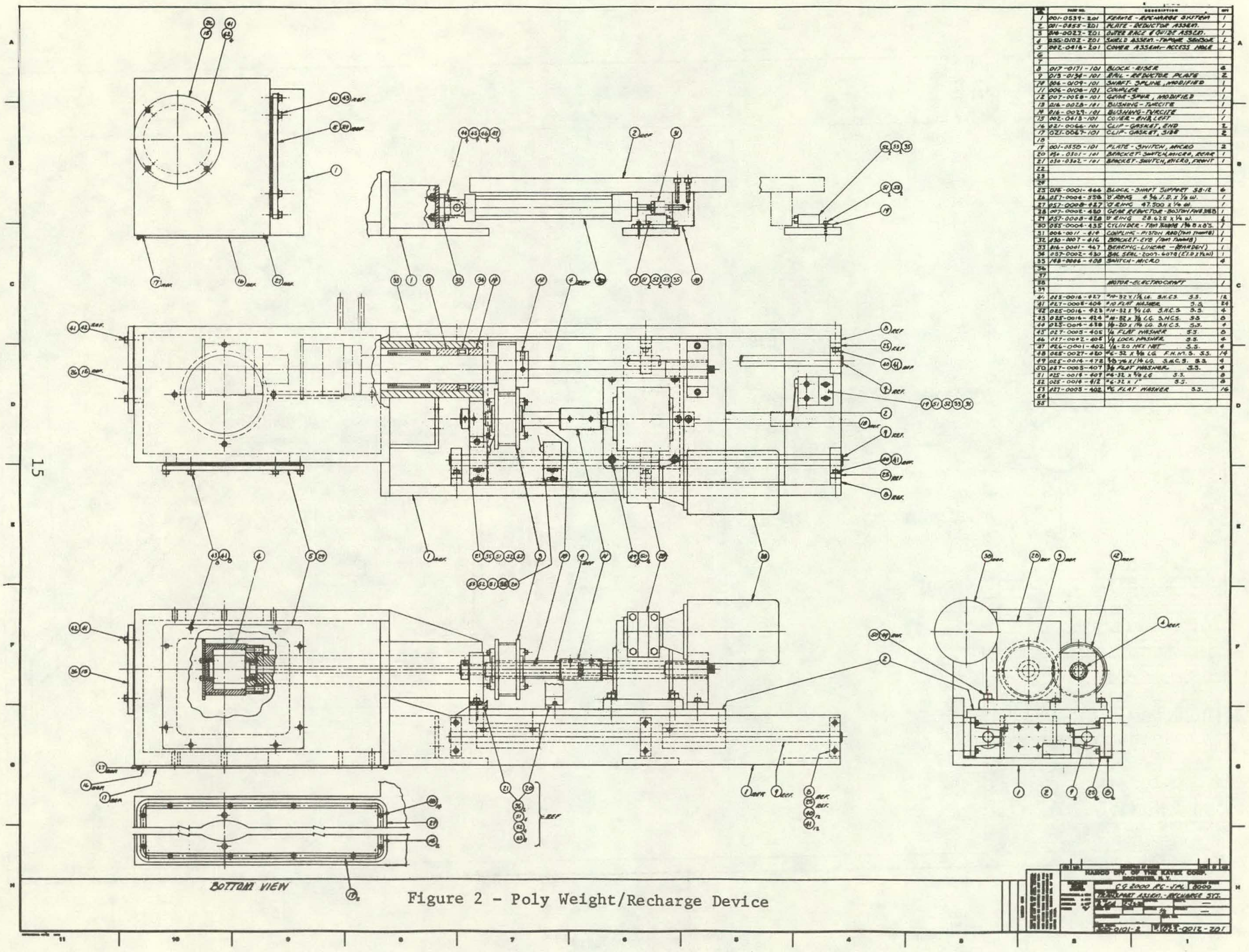
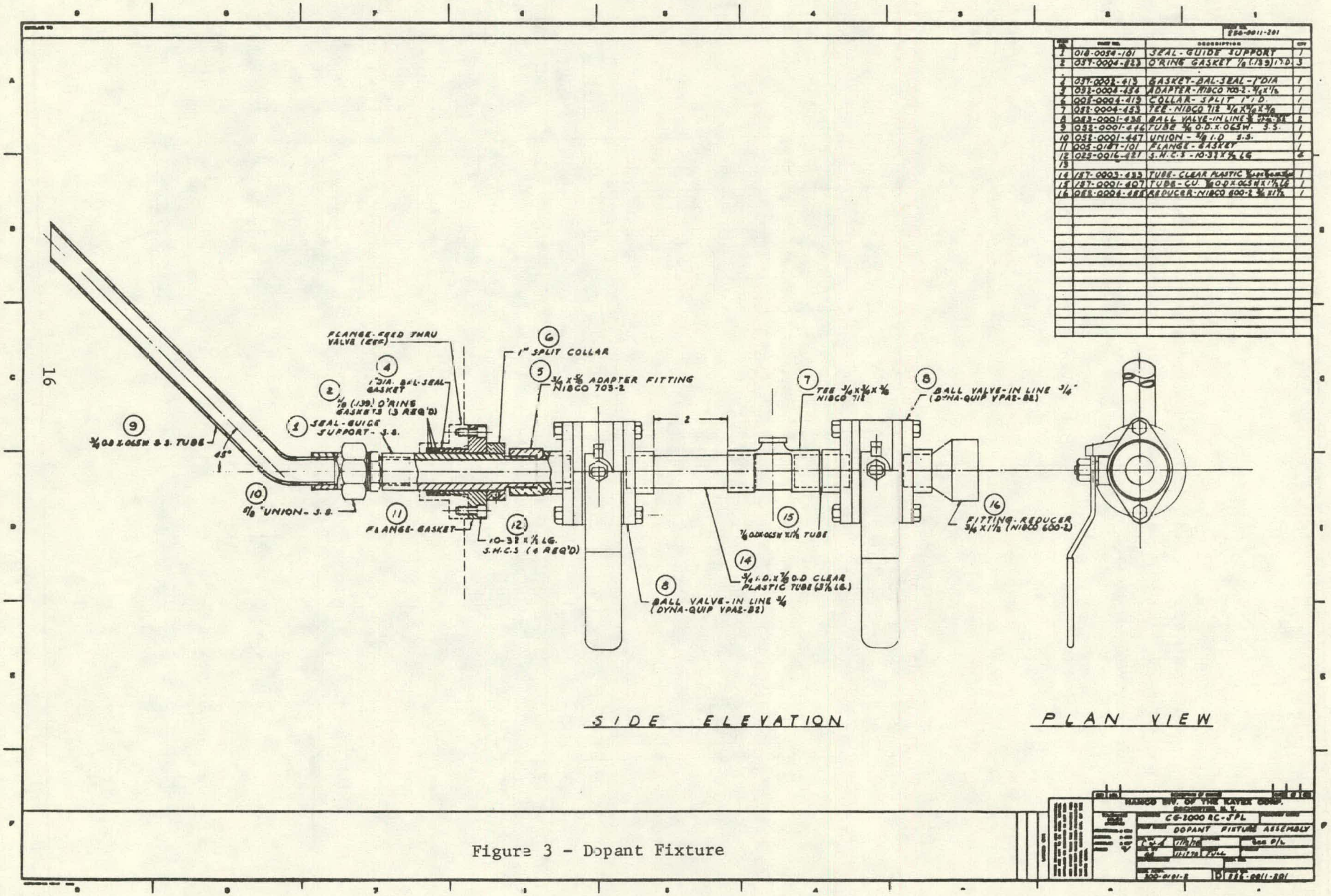

PULL MECHANISM
18¼
ADAPTER ASSEMBLY
14⅜
CABLE
11
CABLE
TORQUE TRANSDUCER
RECHARGE HOLDING FIXTURE
POLY/WEIGHT RECHARGE SYSTEM
RECHARGE MATERIAL
5 X 36 MAX.
PULL CHAMBER
SIDE VIEW
CONTINUOUS CZOCHRALSKI
GROWTH FACILITY
A DC
OPTICAL ASSEMBLY
55⅜
SEED HOLDER
173⅝
REF
ISOLATION VALVE
¼
VIEWPORT
6⅞
TANK COVER
ASSEMBLY
FURNACE
TANK
CRYSTAL
35
QUARTZ CRUCIBLE
14" X 10½
BASE
32

FIGURE 1



	PART NO.	DESCRIPTION	QTY
1	001-0539-201	FRAME - RECHARGE SYSTEM	1
2	001-0555-201	PLATE - REDUCTOR ASSEM.	1
3	016-0027-201	OUTER RACE & GUIDE ASSEM.	1
4	356-0102-201	SHIELD ASSEM. - TORQUE SENSOR	1
5	002-0416-201	COVER ASSEM. - ACCESS HOLE	1
6			
7			
8	017-0171-101	BLOCK - RISER	6
9	013-0134-101	RAIL - REDUCTOR PLATE	2
10	006-0109-101	SHAFT - SPLINE, MODIFIED	1
11	006-0106-101	COUPLER	1
12	007-0058-101	GEAR - SPUR, MODIFIED	1
13	016-0028-101	BUSHING - TURCITE	1
14	016-0029-101	BUSHING - TURCITE	1
15	002-0413-101	COVER - END, LEFT	1
16	021-0066-101	CLIP - GASKET, END	2
17	021-0067-101	CLIP - GASKET, SIDE	2
18			
19	001-0550-101	PLATE - SWITCH, MICRO	2
20	030-0301-101	BRACKET - SWITCH, MICRO, REAR	1
21	030-0302-101	BRACKET - SWITCH, MICRO, FRONT	1
22			
23			
24			
25	016-0001-466	BLOCK - SHAFT SUPPORT SB-12	6
26	057-0004-558	'O' RING 4 3/4 I.D. x 1/8 W.	1
27	057-0008-427	'O' RING 47.500 x 1/8 W.	1
28	007-0002-480	GEAR REDUCTOR - BOSTON FWB 388	1
29	057-0008-428	'O' RING 28.625 x 1/4 W.	1
30	055-0004-435	CYLINDER - TOM THUMB 1 1/16 B x 8 S.	1
31	006-0011-414	COUPLING - PISTON ROD (TOM THUMB)	1
32	030-0007-416	BRACKET - EYE (TOM THUMB)	1
33	016-0001-467	BEARING - LINEAR - (BARDEN)	1
34	057-0002-430	BAL SEAL - 2007-6078 (E.I.D x 1/8 W)	1
35	148-0006-408	SWITCH - MICRO	4
36			
37			
38		MOTOR - ELECTROCRAFT	1
39			
40	025-0016-427	#10-32 x 1 1/2 LG. S.H.C.S. S.S.	12
41	027-0005-404	#10 FLAT WASHER S.S.	24
42	025-0016-423	#10-32 x 3/4 LG. S.H.C.S. S.S.	4
43	025-0016-424	#10-32 x 7/8 LG. S.H.C.S. S.S.	8
44	025-0014-430	1/4-20 x 1 1/4 LG. S.H.C.S. S.S.	4
45	027-0005-405	1/4 FLAT WASHER S.S.	8
46	027-0002-405	1/4 LOCK WASHER S.S.	4
47	026-0001-402	1/4-20 HEX NUT S.S.	4
48	025-0027-480	#6-32 x 3/8 LG. F.H.M.S. S.S.	14
49	025-0014-472	3/8-16 x 1 1/4 LG. S.H.C.S. S.S.	4
50	027-0005-407	3/8 FLAT WASHER S.S.	4
51	025-0014-409	#6-32 x 1/2 LG S.S.	8
52	025-0014-412	#6-32 x 1" S.S.	8
53	027-0005-402	#6 FLAT WASHER S.S.	16
54			
55			

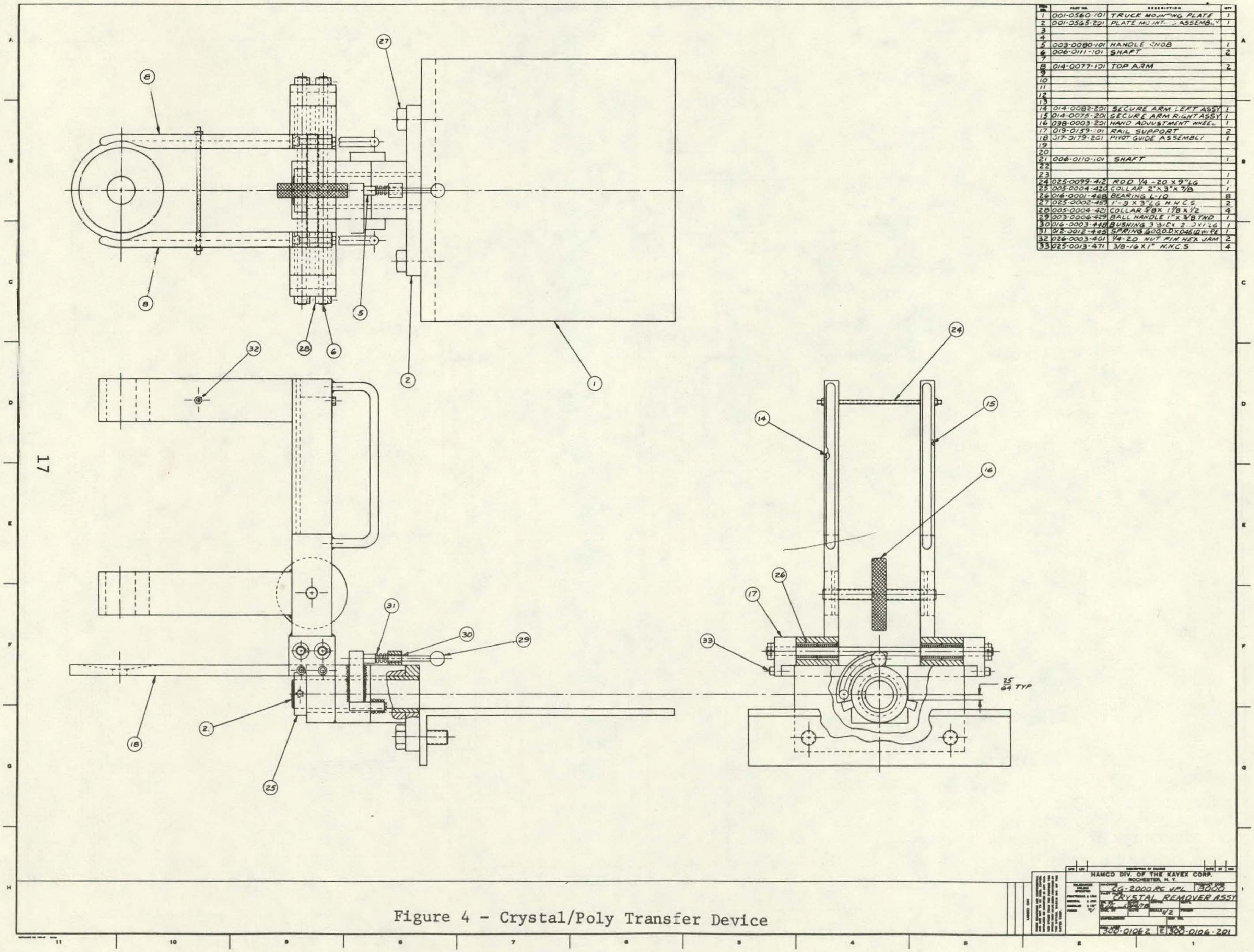
Figure 2 - Poly Weight/Recharge Device



256-0011-201

1	018-0054-101	SEAL-GUIDE SUPPORT	1
2	037-0004-823	O'RING GASKET 1/8 (.139) 1 I.D.	3
4	037-0002-413	GASKET-BAL-SEAL-1"DIA	1
5	052-0004-454	ADAPTER-NIBCO 703-2. 3/4 X 5/8	1
6	005-0004-419	COLLAR- SPLIT 1" I.D.	1
7	052-0004-453	TEE-NIBCO 712 3/4 X 3/4 X 3/4	1
8	053-0001-435	BALL VALVE-IN LINE 3/4 [illegible]	2
9	052-0001-446	TUBE 3/4 O.D. X .065W. S.S.	1
10	052-0001-447	UNION - 5/8 I.D S.S.	1
11	005-0187-101	FLANGE-GASKET	1
12	025-0016-421	S.H.C.S -10-32 X 1/2 LG	6
13			
14	157-0003-433	TUBE-CLEAR PLASTIC [illegible]	1
15	157-0001-407	TUBE-CU. 7/8 O.D X .065W X 1 1/8 LG	1
16	052-0004-455	REDUCER-NIBCO 600-2 3/4 X 1 1/8	1

Figure 3 - Dopant Fixture



ITEM NO.	PART NO.	DESCRIPTION	QTY
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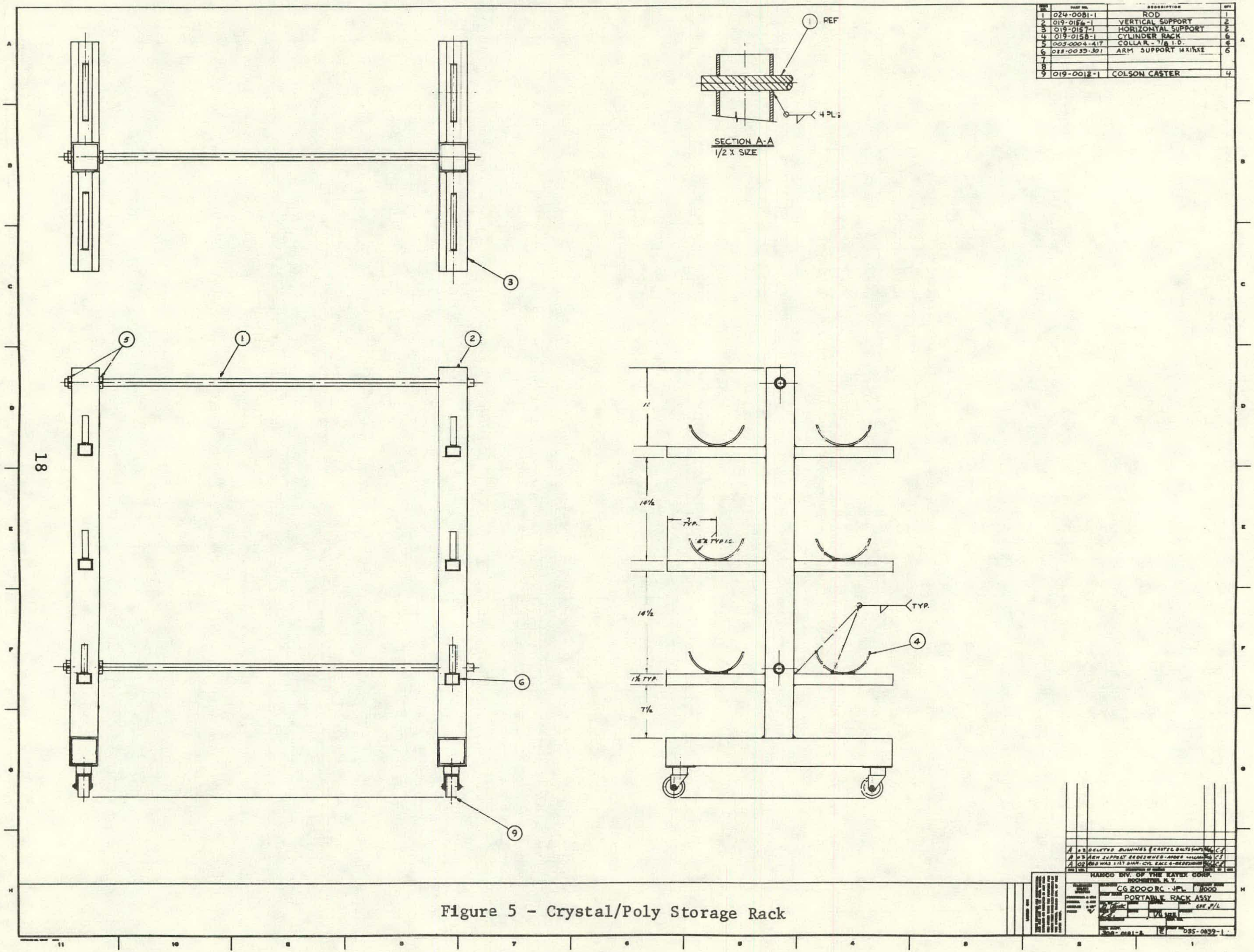
2	001-0565-201	PLATE MOUNTING ASSEMBLY	1
3			
4			
5	003-0080-101	HANDLE KNOB	1
6	006-0111-101	SHAFT	2
7			
8	014-0077-101	TOP ARM	2
9			
10			
11			
12			
13			
14	014-0082-201	SECURE ARM LEFT ASSY	1
15	014-0075-201	SECURE ARM RIGHT ASSY	1
16	038-0003-201	HAND ADJUSTMENT WHEEL	1
17	019-0159-101	RAIL SUPPORT	2
18	017-0179-201	PIVOT GUIDE ASSEMBLY	1
19			
20			
21	006-0110-101	SHAFT	1
22			
23			1
24	025-0099-412	ROD 1/4 -20 X 9" LG	1
25	005-0004-420	COLLAR 2" X 3" X 7/8	1
26	016-0001-468	BEARING L-10	8
27	025-0002-459	1"-8 X 3" LG H.H.C.S.	2
28	005-0004-421	COLLAR 5/8 X 1 1/8 X 1/2	4
29	003-0006-429	BALL HANDLE 1" X 3/8 THD	1
30	016-0003-448	BUSHING 3 3/8 ID X 2.0 X 1 LG	1
31	012-0012-445	SPRING .600 O.D. X .045 DIA WIRE	1
32	026-0003-401	1/4-20 NUT FIN HEX JAM	2
33	025-0013-471	3/8-16 X 1" H.H.C.S.	4

Figure 4 - Crystal/Poly Transfer Device



ITEM NO.	PART NO.	DESCRIPTION	QTY
1	024-0081-1	ROD	1
2	019-0156-1	VERTICAL SUPPORT	2
3	019-0157-1	HORIZONTAL SUPPORT	2
4	019-0158-1	CYLINDER RACK	6
5	005-0004-417	COLLAR - 7/8 I.D.	4
6	035-0039-301	ARM SUPPORT 14 X 1½ X 2	6
7			
8			
9	019-0012-1	COLSON CASTER	4

Figure 5 - Crystal/Poly Storage Rack

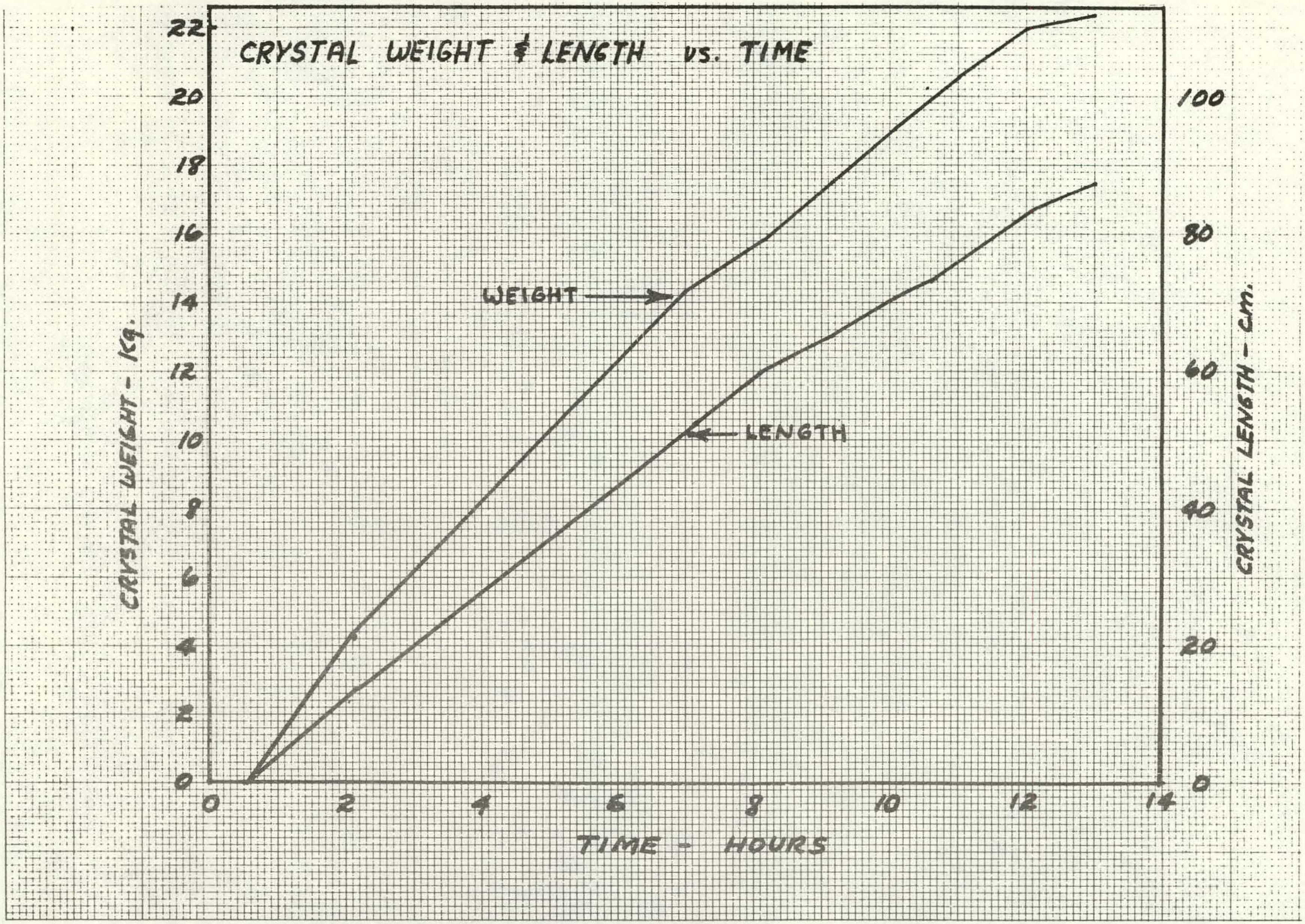

CRYSTAL WEIGHT & LENGTH vs. TIME
WEIGHT
LENGTH
CRYSTAL WEIGHT - Kg.
CRYSTAL LENGTH - cm.
TIME - HOURS
22
20
18
16
14
12
10
8
6
4
2
0
100
80
60
40
20
0
0
2
4
6
8
10
12
14

Figure 6

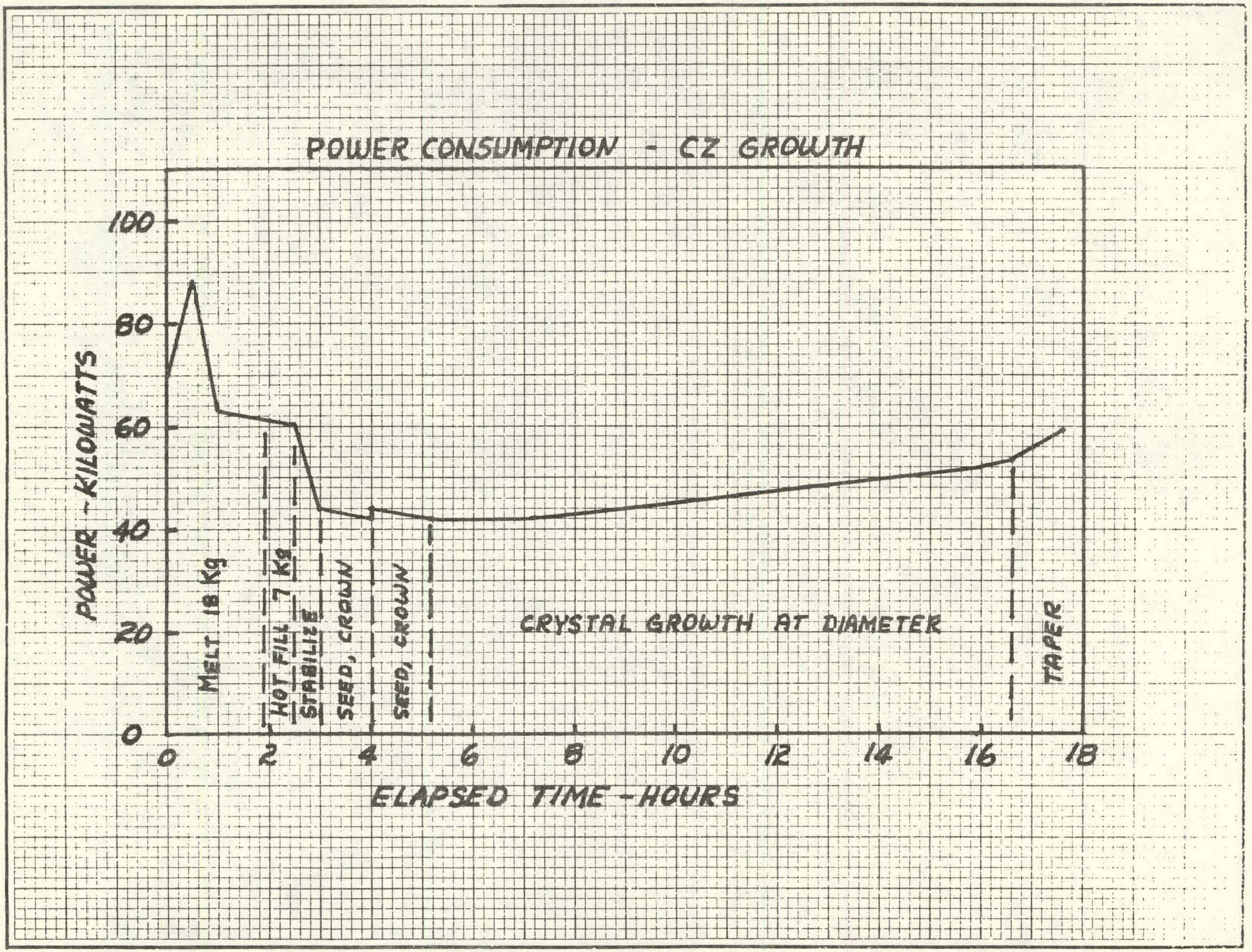

POWER CONSUMPTION - CZ GROWTH
POWER - KILOWATTS
0
20
40
60
80
100
ELAPSED TIME - HOURS
0
2
4
6
8
10
12
14
16
18
MELT 18 Kg
HOT FILL 7 Kg
STABILIZE
SEED, CROWN
SEED, CROWN
CRYSTAL GROWTH AT DIAMETER
TAPER

Figure 7

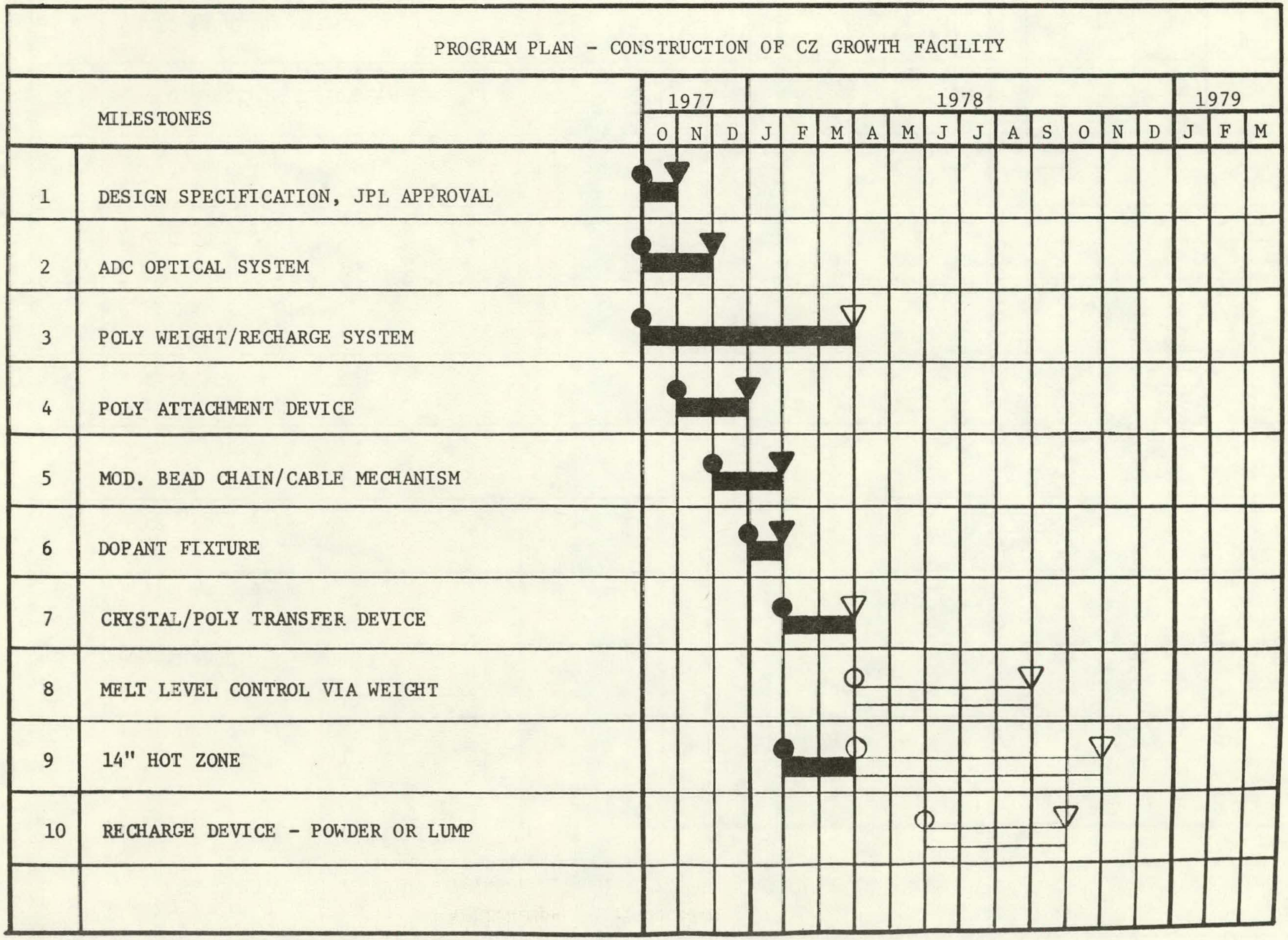

PROGRAM PLAN - CONSTRUCTION OF CZ GROWTH FACILITY
MILESTONES
1977
1978
1979
O N D J F M A M J J A S O N D J F M
1 DESIGN SPECIFICATION, JPL APPROVAL
2 ADC OPTICAL SYSTEM
3 POLY WEIGHT/RECHARGE SYSTEM
4 POLY ATTACHMENT DEVICE
5 MOD. BEAD CHAIN/CABLE MECHANISM
6 DOPANT FIXTURE
7 CRYSTAL/POLY TRANSFER DEVICE
8 MELT LEVEL CONTROL VIA WEIGHT
9 14" HOT ZONE
10 RECHARGE DEVICE - POWDER OR LUMP

Figure 8-a

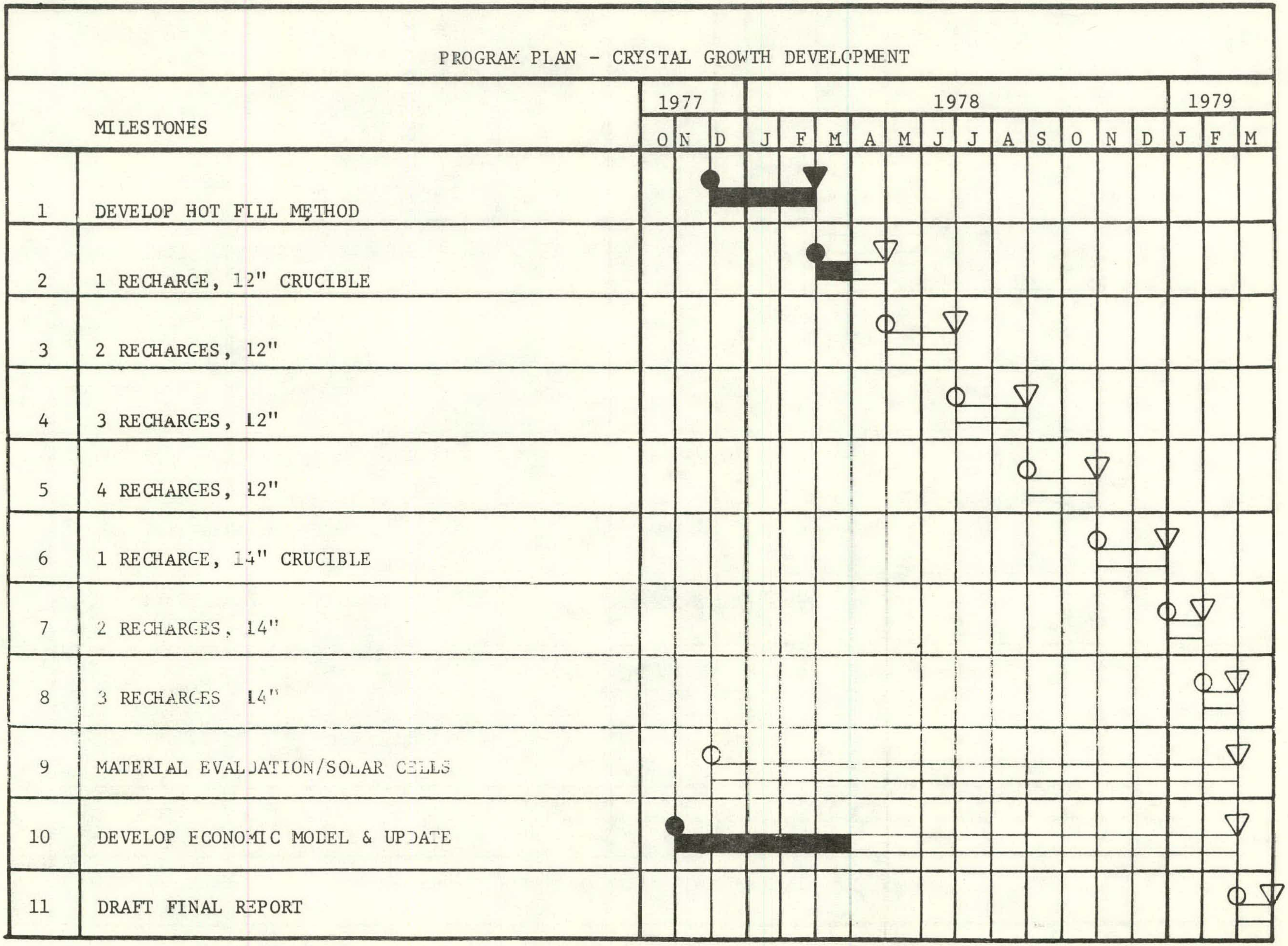

PROGRAM PLAN - CRYSTAL GROWTH DEVELOPMENT
MILESTONES
1977
1978
1979
O N D J F M A M J J A S O N D J F M
1 DEVELOP HOT FILL METHOD
2 1 RECHARGE, 12" CRUCIBLE
3 2 RECHARGES, 12"
4 3 RECHARGES, 12"
5 4 RECHARGES, 12"
6 1 RECHARGE, 14" CRUCIBLE
7 2 RECHARGES, 14"
8 3 RECHARGES 14"
9 MATERIAL EVALUATION/SOLAR CELLS
10 DEVELOP ECONOMIC MODEL & UPDATE
11 DRAFT FINAL REPORT

Figure 8-b

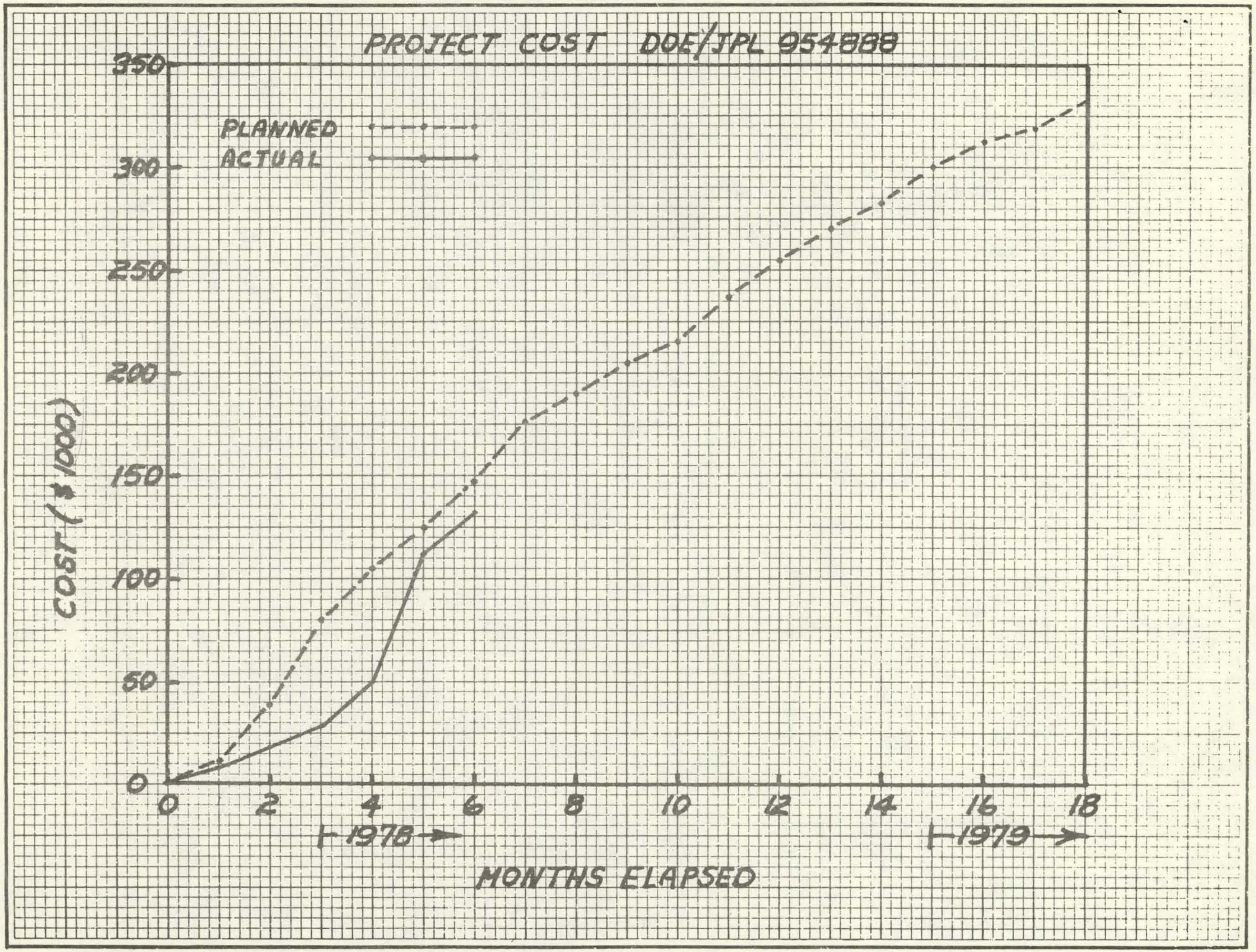

PROJECT COST DOE/JPL 954888
PLANNED
ACTUAL
COST ($1000)
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
1978
1979
MONTHS ELAPSED

Figure 9

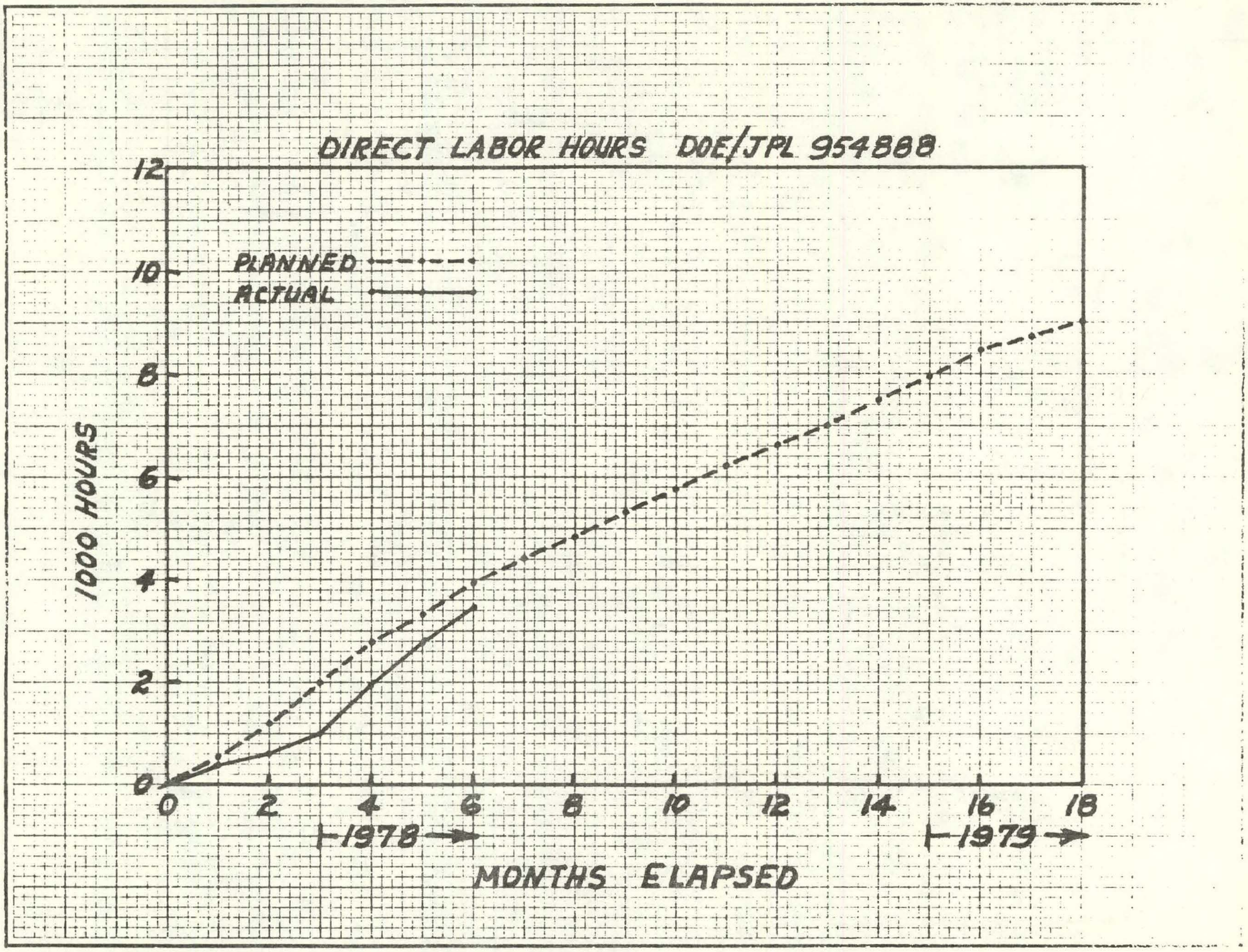


Figure 10

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