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LOW COST CZOCHRALSKI CRYSTAL GROWING TECHNOLOGY

NEAR TERM IMPLEMENTATION
OF THE
FLAT PLATE PHOTOVOLTAIC COST REDUCTION
OF THE
LOW COST SOLAR ARRAY PROJECT

FIFTH QUARTERLY PROGRESS REPORT
APRIL 1 - JUNE 30, 1980

PROGRAM MANAGER: R. L. LANE
PRINCIPAL INVESTIGATOR: E. G. ROBERTS

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.

DISCLAIMER

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ABSTRACT

During this reporting period, the primary activity has been to develop microprocessor control of the crystal growth process and to develop and demonstrate the accelerated crystal growth program.

Accelerated recharging of the quartz crucible by the RF melting of polycrystalline silicon feed rods was deemphasized by JPL primarily due to the unavailability of suitable quality feed rods at an effective economical price.

The development of the cold crucible program as an alternative method of crucible recharging was continued, but at a lower priority.

During the entire quarter, the crystal puller was made available to the microprocessor development group so that an effective demonstration could be scheduled during the first week of May. Software programming problems delayed this demonstration.

Work continued on the accelerated crystal growth program. Crystal growth runs were made utilizing the water cooled work coil previously used in the RF polycrystalline silicon rod melting program. Accelerated growth rates were demonstrated but an oxide build-up on the cold surface of the work coil, resulting in heavy flaking and consequent falling of oxide into the melt, resulted in our abandoning this approach and redesigning, evaluating, and demonstrating an alternative heat sink arrangement.

All necessary parts were received for the cold crucible premelter and the system was assembled and interfaced to the multiturn high voltage RF power supply. During commissioning of the high voltage remote switching station, a continued arcing problem occurred within the "tickler" (feedback) coil. This problem was identified and corrected. A series of bench type melting trials was undertaken to establish the feasibility of the approach. A port capable of

interfacing the cold crucible to the crystal grower was fabricated into the furnace tank for subsequent recharging experiments.

All parts required to convert the crystal grower from utilizing 12 inch parts to using 14 inch parts were received. The crystal grower was converted to 14 inch parts during May.

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FIGURES AND TABLES

I. INTRODUCTION

The purpose of the program is to demonstrate the growth of up to 150 kilograms of 6" diameter single crystal silicon ingot from one crucible by the Czochralski (CZ) method.

The method being developed relies upon conventional CZ technology combined with new equipment and process designs and concepts. These concepts alternate cycles of crystal growth and hot melt replenishment and are designed to be ultimately suitable for use in a high volume production facility.

A Hamco Model CG2000 RC crystal grower was installed for the project. Modifications were made to allow the storage of a polycrystalline silicon rod within the chamber which is utilized in the crucible recharging cycle. A vacuum tight isolation valve allows retrieval of grown crystals and crucible melt replenishment without contamination.

Additional modifications designed into the system provided for melting either polycrystalline silicon rods or polycrystalline silicon chunks by the use of RF induction heating. The capability exists in the design to melt rods directly into the crucible by the use of an induction heated copper work coil. Power to the work coil is fed from a 50 kg RF generator via a remote switching system to a Hamco designed and fabricated RF feedthru system. The feedthru was designed to be sited in one of the spectator viewports and to couple directly onto the work coil. It was utilized initially to melt rod, and then was vertically adjusted to act as a heat sink for accelerated crystal growth. However, due to process problems related to oxide formation and flaking occurring on the cold surface of the RF coil when it was utilized in the heat sink mode, an alternative heat sink assembly was designed and fabricated. The principle of the heat sink arrangement is that it will absorb the energy released by the heat of fusion during crystal growth and therefore increase the throughput.

A secondary accelerated melt program is undergoing development using polycrystalline silicon chunks as feedstock. These chunks will be melted and fed into the growth crucible by the utilization of a cold crucible premelter. Silicon chunk feedstock will be fed into the cold crucible arrangement by means of a controlled feed mechanism which preheats the silicon with a resistance heater. Melting takes place in the cold crucible by utilizing the induction heating multiturn work coil surrounding the cold crucible. The cold crucible is inclined slightly so that the levitated silicon melt will transverse the length of the silver boat and so transfer molten silicon directly into the CG2000 RC crystal grower quartz crucible. The total system interfaces with the puller through a port in the furnace tank wall. The system is designed such that the transfer tube assembly system can be retraced after discharge of the molten silicon, so that it does not interfere with normal crystal growth.

The CG2000 RC crystal grower will be controlled with a microprocessor based control system. This system will be programmable to the required sequencing and control requirements.

The program, therefore, deals primarily with process improvements which will lower the costs of the meltdown and the crystal growth steps. Additionally, it deals with improved automation for the process to reduce labor costs and increase yields.

2.0 PROGRESS

During this quarterly period, primary effort has been aimed towards completion of the microprocessor control software, interface and demonstration of microprocessor control of the crystal growth process.

To date, a series of software problems have not allowed achievement of this demonstration.

For the first two months of this reporting period, the CG2000 puller was engaged almost totally on microprocessor controlled growth development. A decision was made to provide another grower (at Kayex expense) for microprocessor development. This would allow development of the accelerated growth program to continue separately. Microprocessor interface wiring to the new grower is scheduled for completion July 11, 1980.

A new molybdenum heat sink was designed and fabricated. Several crystal growth runs have been undertaken with encouraging results. Run #23, started June 25, 1980, yielded three crystals totalling 59.5 kg with a 93.25% zero dislocation yield. The total machine time for this run (from switch on to switch off) was 37 hours 35 minutes. This represents an overall machine throughput of 1.58 kilograms per hour. Actual straight growth time was 21.33 hours which represents a straight growth throughput of 2.58 kilograms per hour. An added feature of the molybdenum heat sink is that the argon flow has been redirected to advantage. A significant reduction in the amount of oxide formation on the crucible wall and rim was observed during Run #23; also, the three crystals were totally free of any visible surface oxide formation when removed from the pull chamber. It is thought that this reduction in oxide formation is related to the high zero dislocation free yield obtained.

The cold crucible premelter has been assembled and operated off the crystal puller. It was felt necessary to undertake a series of "bench-top" experiments to fully evaluate the feasibility of the approach. To date, six experiments have been run. Silicon chunks were preheated and then passed to the silver boat. The silicon was melted and levitated using a multiturn RF coil and allowed to flow through the boat into a quartz crucible. Work is continuing on interfacing the system to the Hamco CG2000 RC puller. The modified furnace tank for interfacing of the cold crucible has been received and fitted.

The various programs relating to the overall contract are now reported in detail separately.

2.1 Microprocessor Controls

During this quarterly reporting period, a technical direction memorandum was issued by JPL giving the development of a microprocessor control of the crystal growth process as the number one priority. The crystal grower utilized in this project was made totally available for this section of the project during the months of April, May and part of June.

A demonstration of microprocessor controlled growth was scheduled initially for the week ending May 2, 1980. A fault developed in the A/D printed circuit board which, at first, was thought to require replacement. Prolonged bench testing failed to reproduce the fault. Interrupts to the memory system also caused problems. The memory was diagnostically tested for bad cells and 35V (peak-to-peak) square wave pulses were observed on the A.C. line. A power line conditioner was obtained and incorporated into the system. The pulses were traced back to the power supply used in the Hamco CG2000 RC crystal grower. Both of these problems necessitated rescheduling of the demonstration to May 19, 1980.

Prior to the above discussed problems, a series of crystal growth runs were made so that microprocessor interfacing and various control systems could be checked, calibrated and adjusted as necessary. All of these evaluation runs were performed using 12 inch diameter quartz crucibles and ancillary graphite piece parts to conserve cost. The first run (No. 11) was made April 23. The neck and crown were grown utilizing control through the MPU. Calibration values were established for all motors. Software adjustments were made such that the motor control sequence would be first.

Dry runs were made on April 25 and 29 to check out previous corrections and to implement the seed travel and crucible travel interface.

Run #12 was made April 30 when the heater was initially powered manually and then actual melt down and melt stabilization was achieved through the MPU.

Run #13 was made May 6 to check out and comprehend all the corrections that were made were operable.

Run #14 was made May 8 when the MPU was interfaced parallel with the crystal grower. The seed and crown were grown to the shoulder by adjusting the puller control sequencing through the microprocessor. Adjustments were made to alter the display sequencing from 3 seconds to 1 second.

Two further crystal growth runs, i.e. Nos. 15 and 16 were made in an attempt to integrate the Reticon camera system into the second loop (growth control) program. Software malfunction was traced to the Reticon system giving an imaging problem causing false diameter read outs. This created severe diameter control problems resulting in a decision being made to abandon the Reticon control system and to utilize the standard Hamco CG2000 RC crystal grower photocell diameter sensing technique. This changeover was completed June 6, 1980.

At this time, a critical review of the program was undertaken. It was felt that the MPU program was utilizing the CG2000 puller full time and so preventing development work associated with the accelerated growth program from continuing. A decision was made to provide an additional crystal grower to the project at Kayex expense for microprocessor development. Microprocessor interface wiring to this grower was commenced and is scheduled for completion July 11, 1980.

A revised microprocessor control program plan (Fig. 1), together with the overall program outline, (Figures 1a through 1g) follow.

2.2 Accelerated Growth Program

Several crystal growth runs (Run Nos. 7, 8, 9 and 10) were made in an attempt

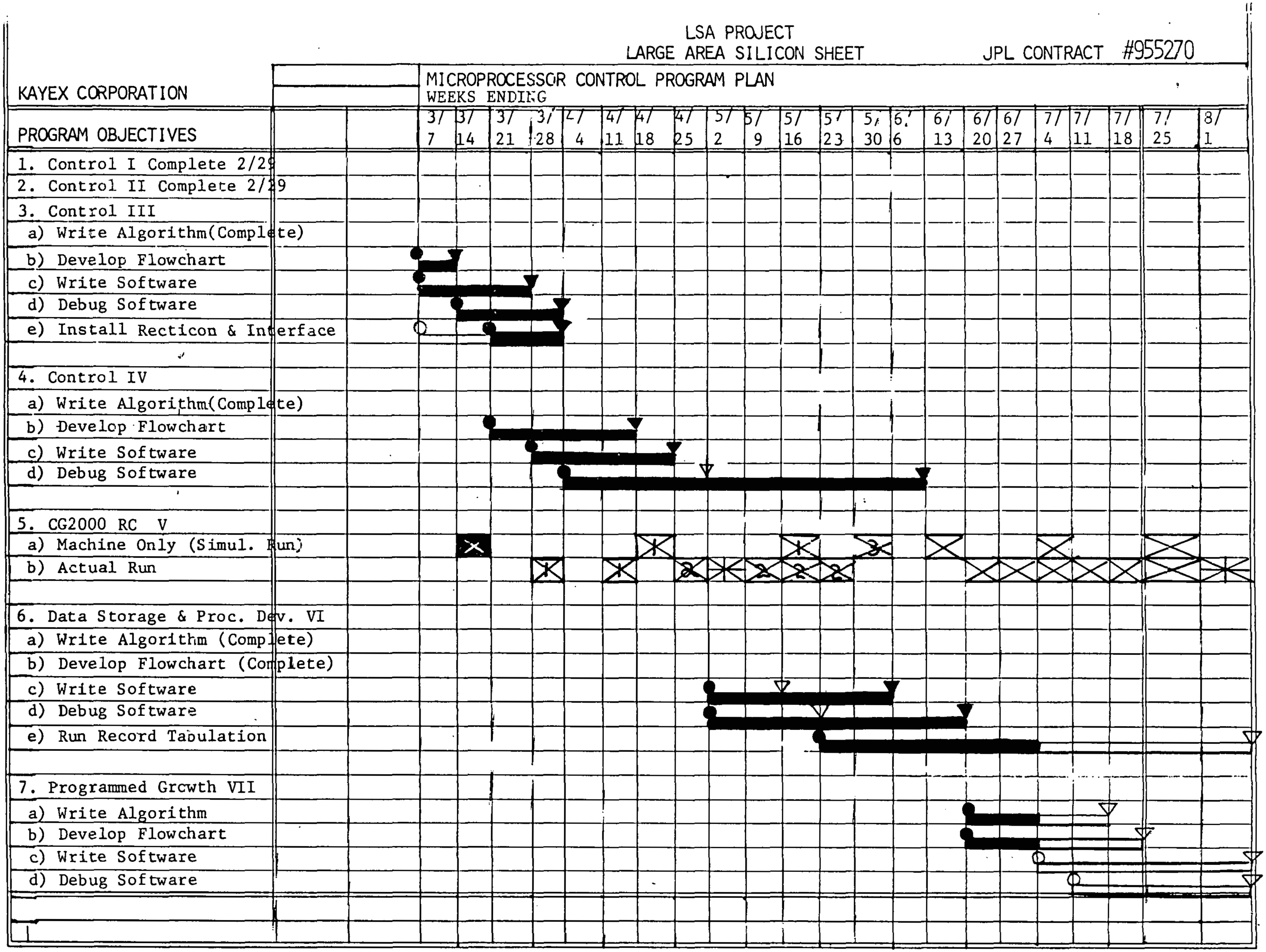
LSA PROJECT
LARGE AREA SILICON SHEET
JPL CONTRACT #955270
KAYEX CORPORATION
MICROPROCESSOR CONTROL PROGRAM PLAN
WEEKS ENDING
3/7 3/14 3/21 3/28 4/4 4/11 4/18 4/25 5/2 5/9 5/16 5/23 5/30 6/6 6/13 6/20 6/27 7/4 7/11 7/18 7/25 8/1
PROGRAM OBJECTIVES
1. Control I Complete 2/29
2. Control II Complete 2/29
3. Control III
a) Write Algorithm(Complete)
b) Develop Flowchart
c) Write Software
d) Debug Software
e) Install Recticon & Interface
4. Control IV
a) Write Algorithm(Complete)
b) Develop Flowchart
c) Write Software
d) Debug Software
5. CG2000 RC V
a) Machine Only (Simul. Run)
b) Actual Run
6. Data Storage & Proc. Dev. VI
a) Write Algorithm (Complete)
b) Develop Flowchart (Complete)
c) Write Software
d) Debug Software
e) Run Record Tabulation
7. Programmed Growth VII
a) Write Algorithm
b) Develop Flowchart
c) Write Software
d) Debug Software

Figure 1

JPL 955270 PROGRAM OUTLINE (8063)

I. CONTROL I

A. GOALS

1. PROMPT OPERATOR FOR PROPER SEQUENCE OF OPERATION.

2. CAUSE "CRUCIBLE ROTATION" TO BE UNDER CONTROL.

   A. MOTOR CONTROL ROUTINE

3. CAUSE "CRUCIBLE LIFT" TO POSITION CRUCIBLE.

4. PERFORM "BAKEOUT" BY OPERATOR DETERMINED PARAMETERS.

   A. TEMPERATURE LEVEL (ENTERED)
   B. SOAK TIME (ENTERED)
   C. CRUCIBLE POSITION (ENTERED)

5. PERFORM "MELTDOWN" BY OPERATOR DETERMINED PARAMETERS.

   A. TEMPERATURE LEVEL (ENTERED) MELTDOWN
   B. SOAK TIME (ENTERED) MELTDOWN
   C. CRUCIBLE POSITION (ENTERED) MELTDOWN
   D. TEMPERATURE LEVEL (ENTERED) STABILIZE
   E. SOAK TIME (ENTERED) STABILIZE
   F. CRUCIBLE POSITION (ENTERED) STABILIZE

6. MONITOR ALARM SENSORS AND SHUTDOWN IF MAJOR.

   A. WATER FLOWS (MAJOR)
   B. WATER TEMPERATURES (MINOR)
   C. PRESSURES (MINOR/RAPID RISE MAJOR)
   D. POSITIONING (MINOR)

B. MINIMUM ACCEPTANCE: (SCHEDULED 2/22/80)

1. PROMPTING

2. CRUCIBLE MOTIONS

3. AUTO; BAKEOUT, MELTDOWN & STABILIZATION

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Figure 1a

JPL #955270

II. CONTROL II

A. GOALS:

1. ALLOW CONTROL OF ALL MOTORS (SPEED ONLY)

   A. CRUCIBLE LIFT & ROTATION (NO JOG)
   B. SEED LIFT & ROTATION (NO JOG)

2. ALLOW FOR TEMPERATURE VARIATIONS

3. ROUTINE EXIT

   A. ABORT BY OPERATOR
   B. ABORT DUE TO MAJOR ALARM
   C. EXIT TO AUTO-DIAMETER CONTROL

B. MINIMUM ACCEPTANCE: (SCHEDULED 2/29/80)

1. ALL MOTORS UNDER CONTROL

2. TEMPERATURE VARIATIONS POSSIBLE

3. OPERATOR TO BE ABLE TO PERFORM MANUAL GROWTH

   A. DIP SEED
   B. GROW NECK
   C. GROW CROWN
   D. SHOULDER CRYSTAL
   E. ABORT BY OPERATOR OR EXIT TO AUTO (THIS STAGE STILL ABORTS)

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Figure 1b

CONTROL III

III. CONTROL III

A. GOALS:

1. CONTROL SEED LIFT VIA DIAMETER INPUT.

   A. OPERATOR CAN CHANGE DIAMETER REQUIRED
   B. RETICON (OR PHOTOCELLS IF RETICON UNACCEPTABLE) DIAMETER INPUT. (RETICON INSTALLED & TESTED).

2. LOCKOUT OPERATOR ATTEMPTS TO CHANGE ROTATIONAL SPEEDS. OPERATOR MAY ABORT OR EXIT TO AUTO OR MANUAL.

3. CRUCIBLE LIFT A FUNCTION OF SL, CAL. XTAL WEIGHT, AND CRUCIBLE SIZE.

4. ABORT DUE TO MAJOR ALARM.

B. MINIMUM ACCEPTANCE: (SCHEDULED 3/28/80)

1. CONTROL SEED LIFT BY DIAMETER INPUT.

2. SLAVE CRUCIBLE LIFT TO SL, XTAL WEIGHT, AND C. SIZE.

3. LOCKOUT UNACCEPTABLE OPERATOR COMMANDS.

   A. ROTATIONAL SPEED CHANGES. (ABORT OR FULL AUTO OR MAN. ALLOWED).

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Figure 1c

IV. CONTROL IV

A. GOALS:

1. INCREASE AND DECREASE TEMPERATURE SET POINT AS A FUNCTION OF THE AVERAGE DEVIATION OF THE SEED LIFT FROM THE SEED LIFT SET POINT.

2. OPERATOR ALLOWED TO:

A. ABORT
B. EXIT MANUAL
C. EXIT AUTO DIAMETER
D. CHANGE SL OR DIAMETER SET POINTS.

3. ABORT DUE TO MAJOR ALARM.

B. MINIMUM ACCEPTANCE: (SCHEDULED 4/18/80)

1. TEMPERATURE SET POINT A FUNCTION OF AVERAGE SEED LIFT DEVIATION FROM ITS SET POINT.

2. OPERATOR MAY ABORT ON EXIT TO CONTROLS II OR III.

3. OPERATOR MAY CHANGE SEED LIFT OR DIAMETER SET POINTS.

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Figure 1d

V. CG 2000 RC USAGE

A. SIMULATED RUNS:

1. REQUIRES ALL MACHINE FUNCTIONS EXCEPT FOR TEMPERATURE & DIAMETER SENSING.

2. TEMPERATURE CHANGES PERFORMED BY MONITORING THE APPROPRIATE D/A OUTPUT. (COMPARE VOLTAGE TO AN ACTUAL VALUE FOR THE SAME SET POINT READING.)

3. DIAMETER TESTING BY VARIOUS FORMS OF LIGHT SOURCES.

4. TEST ACTUAL MOTOR SPEEDS VERSUS REQUIRED AND DISPLAYED ACTUAL.

B. ACTUAL RUNS:

1. REQUIRES:

   A. BAKEOUT - FROM COLD MACHINE
   B. MELTDOWN - FROM FINISH OF BAKEOUT
   C. VARIOUS STAGES OF ACTUAL CRYSTAL GROWTH, I.E. NECK ONLY OR NECK & CROWN, ETC.

2. GROWER SHOULD NOT BE IN USE FOR MORE THAN ONE SHIFT IN MOST CASES.

Figure 1e

VI. DATA STORAGE AND PROCESS DEVELOPMENT

A. GOALS:

1. TO STORE RUN DATA AT FIXED TIME INTERVALS (UND. AS YET).

   A. ALL MOTOR SETTINGS
   B. ALL MOTOR TACH READINGS
   C. DIAMETER SETTING
   D. TEMPERATURE SET POINT
   E. ACTUAL DIAMETER (REQ. RETICON OR SIMILAR)

2. TO STORE RUN DATA WHEN OPERATOR CAUSES A CHANGE TO OCCUR, I.E. ENTERS NEW SET POINT.

3. PRODUCE A HARD COPY OF ALL RUN DATA FROM THE FLOPPY DISK.

   A. SUITABLE FORMAT TO BE USED FOR EASE IN ANALYSES OF DATA

B. MINIMUM ACCEPTANCE: (SCHEDULED 8/1/80)

1. RUN DATA STORAGE ON FLOPPY DISK.

Figure 1f

VI. PROGRAMMED GROWTH

A. GOALS:

1. ALLOW OPERATOR TO ENTER RUN DATA POINTS.

   A. PARTICULAR DATA POINTS, I.E. SL, CR, ETC.
   B. PARAMETERS FOR USE OF DATA POINTS, I.E. TIME INTO RUN OR XTAL WEIGHT OR BOTH, ETC.

2. ALLOW FOR PERMANENT STORAGE OF DATA POINTS.

3. RETRIEVAL OF STORED FOR USE IN SUCCESSIVE RUNS.

   A. ELIMINATES NEED FOR OPERATOR ENTRY AT START OF EACH RUN

4. ALLOW OPERATOR TO EDIT AND CHANGE GROWTH PROGRAM.

5. ALL ENTRY AND EDIT FEATURES TO BE IN PLAIN ENGLISH AND ENGINEERING UNITS SO AS TO REQUIRE NO PROGRAMMING KNOWLEDGE ON THE OPERATOR'S PART.

B. MINIMUM ACCEPTANCE: (SCHEDULED 8/1/80)

1. ALL GOALS LISTED PREVIOUSLY.

2. OPTION TO POSTPONE UNTIL LATER DATE DUE TO PROCESS DEVELOPMENT PROBLEMS.

3. IF POSTPONED, THEN SOME FORM OF PROGRAMMED TAILING OPERATION OF CRYSTAL TO BE DEVELOPED TO JPL CONTRACT REQUIREMENTS.

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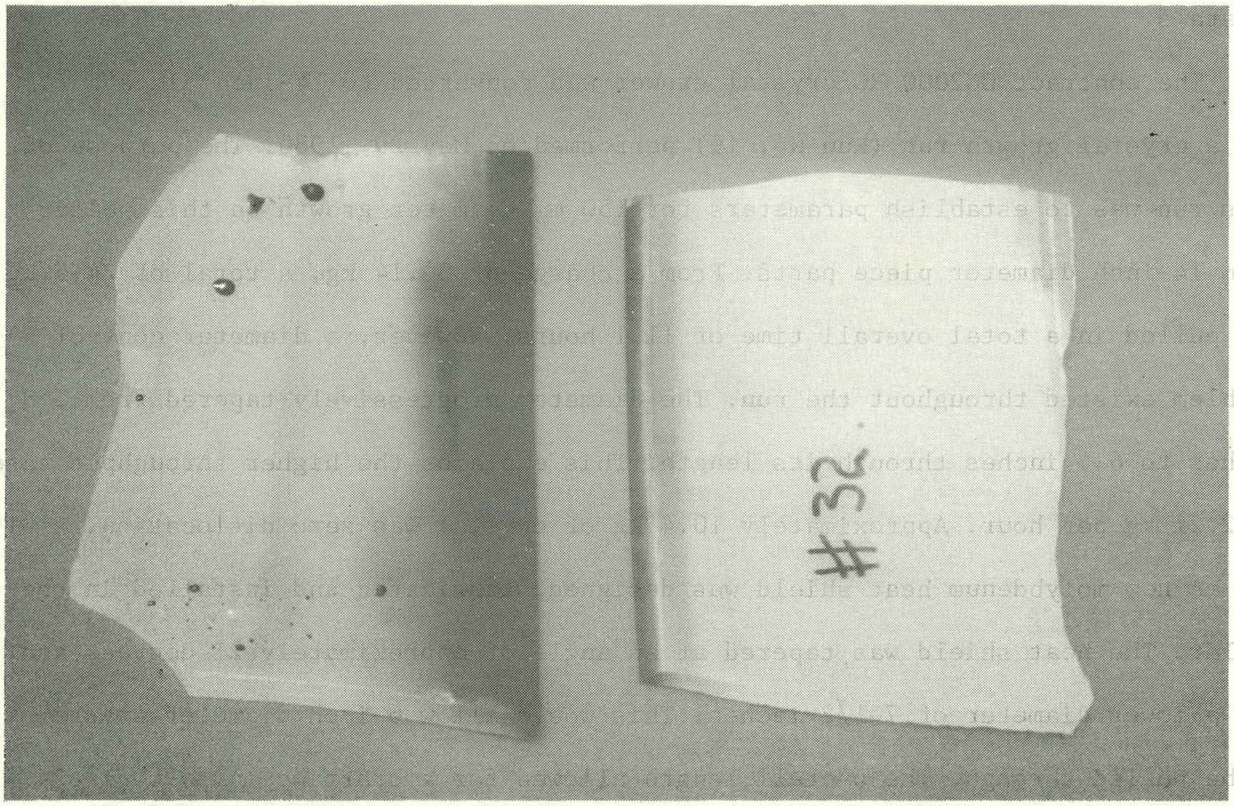
Figure 1g

to demonstrate accelerated crystal growth. Accelerated growth rate increases throughput and directly improves on add-on cost. By utilization of a suitable heat sink to remove the heat of fusion released during the growth cycle, it is anticipated that improved growth rates can be achieved.

The initial growth runs were made by utilizing 12-inch diameter crucible and ancillary graphite parts. A water-cooled copper coil previously used as the induction heated work coil in the accelerated rod melting program was utilized as the heat sink. Excessive oxide formation on the water-cooled surface of the work coil occurred, resulting in oxide falling back into the melt with resulting "twinning" of the crystal. All of these crystal growth runs were undertaken prior to making the CG2000 RC crystal grower totally available to the microprocessor program, i.e. from April 1, 1980 to April 21, 1980.

As a result of the oxide formation on the water-cooled heat sink coil, it was decided to design and fabricate an alternative heat shield arrangement. A conical shaped molybdenum heat shield was fabricated to accommodate a 14-inch diameter crucible. The total system was installed in a different Hamco crystal puller from the contract puller so that the microprocessor development could continue uninterrupted. A crystal growth run (noted as special radiation shield development run) was undertaken on May 20, 1980 utilizing the new 14-inch set-up. An initial charge of 26.2 kg was cold charged into an Amersil crucible. Problems were encountered initially in establishing optimum crucible start position in relation to heat shield distance from the melt level. An initial crystal, 5-1/2 inches in length was pulled from the melt to establish parameters. Once these parameters were set, crystal No. 1 was removed from the grower, and growth commenced on crystal No. 2. Crystal diameter pulled was 5.3 inches. A total of 15.6 kg of material was grown in 7.66 hours (from seed dip to taper out of the crystal) representing a total throughput of 2.03 kg per hour.

The initial heat shield design required some modification, primarily to the positioning method, to insure optimization of the thermal conditions. One immediate



Crucible 1 Crucible 2
(37.5 hrs continuous operation)

Oxide Formation on Crucible Sections and Rims

Figure 2

advantage of using this form of heat shield was that it readjusted the argon flow pattern such that: a) the crystals produced were totally free of any oxide formation down their length, b) significant improvement was made to the amount of oxide formation on the crucible wall freeboard and rim. It was thought that this could have a significant impact on the ability to grow multiple dislocation free crystals.

The contract CG2000 RC crystal grower was converted to 14-inch piece parts and a crystal growth run (Run No. 19) performed on May 29, 1980. The purpose of this run was to establish parameters for 150 mm diameter growth on this puller from 14-inch diameter piece parts. From a charge of 30.14 kg, a total of 24.5 kg was pulled in a total overall time of 11.1 hours. However, a diameter control problem existed throughout the run. The diameter progressively tapered from 5.8 inches to 6.4 inches through its length. This explains the higher throughput rate of 2.21 kg per hour. Approximately 10.4 kg of crystal was zero dislocation.

A new molybdenum heat shield was designed, fabricated and installed in the puller. The heat shield was tapered at an angle of approximately 21 degrees and had a lower diameter of 7-1/2 inches. This would allow 6-inch diameter crystals to be pulled through. The overall length allowed for a starting melt level of 2 inches below the rim of the heater for a 30 kg charge in a 14-inch diameter crucible. Also, a design using three locating and positioning feet was built into the system.

Four crystal growth runs (Nos. 20, 21, 22 and 23) were made during the month of June. Nos. 20 and 21 were single runs and Nos. 22 and 23 were multiple runs. All runs, with the exception of Run No. 21, produced high zero-dislocation yields at relatively improved throughput rates. An example of the improved cleanliness of the crucible wall obtained is illustrated in Figure 2. The section on the left illustrates oxide build-up after normal growth without the heat sink. The section on the right illustrates the relative cleanliness of the crucible wall after

37.5 hours of multiple growth (Run No. 23).

An illustration of the heat shield is shown in Figure 3.

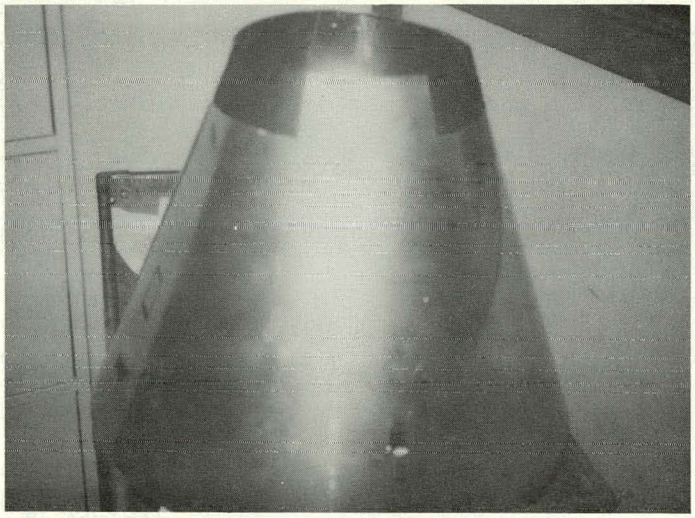
Details of crystal growth runs are included in Table 1. To date, cold filling of 30 kg of silicon into the crucible has not been attempted with the heat sink attangement in position, but no problems are anticipated. Approximately 20 kg was cold filled and melted and the remaining 10 kg was hot filled utilizing developed hopper recharging techniques to get the 30 kg melt.

2.3 Induction Premelting of Lump/Granular Silicon

A cold crucible silver boat system is being developed to allow molten silicon to be charged directly into a quartz crucible. This will avoid present cold fill techniques and temperature cycling of the quartz crucible.

The boat was fabricated from copper and then silver plated. Delivery of the high voltage multiturn work coil and quartz tubing was received in April. The total system has been designed so that it can be interfaced directly with the puller via a port in the puller furnace tank wall. Figure No. 5 shows a cross section of the silver boat, work coil and quartz outer tubing. Figure No. 6 shows the total system interfaced to the crystal puller furnace tank.

The cold crucible system will be operable on a continuous melt and flow principle during the crucible replenishment process. A storage/feed arrangement for silicon lumps will be interfaced to a silicon preheater and to the cold crucible itself. Lump silicon will be fed into the preheater, where the silicon temperature will be raised to approximately 500 degrees Centigrade. The silicon will then pass into the silver boat and be RF induction melted using the multiturn RF coil. The induced magnetic field will allow the molten silicon to be levitated and so flow along the silver boat to recharge the crucible. The total system is designed to be retractable and so allow it to be adjusted after completion of the recharge process such that it will not interfere with normal crystal growth.



Molybdenum Heat Sink

Figure 3

RUN NO. 20

Crystal #	Crystal Length (in)	Crystal Wt (kg)	Pt. of Dislocation (in)	% OD	Pt. of twin or Poly (in)	% Good
1	20"	19.45	-	100%	-	100%

Cold charge = 26.9 kg
Pulled yield = 72.3
Time start = 9:30 AM
Power off = 10:00 PM
Total run time = 12-1/2 hours
Overall throughput = 1.56 kg/hr
Straight growth start 3:00 - 10:00 = 7 hours
Straight growth throughput = 2.78 kg/hr

RUN NO. 21

Crystal #	Crystal Length (in)	Crystal Wt (kg)	Pt. of Dislocation (in)	% OD	Pt. of twin or Poly (in)	% Good
1	27.5"	27.7	7"	25.4%	9" Nucleation on crucible wall occurred at 5"/hr growth rate. Resulted in loss of OD.	32.7%

Cold charge = 18 kg
Hot fill = 12 kg
Total = 30 kg
Time start = 8:35 AM
Time finished = 1:00 AM
Total run time = 16.65 hrs
Pulled yield = 92.3%
Overall throughput = 1.66 kg/hr
Straight growth start 5:00 PM - 1:00 AM = 8 hours
*Difficulty establishing thermal parameters from 11:00 AM until 3:00 PM
Straight growth throughput = 3.46 kg/hr

RUN NO. 22

Crystal #	Crystal Length (in)	Crystal Wt (kg)	Pt. of Dislocation (in)	% OD	Pt of twin or Poly (in)	% Good
1	24-1/4"	22.8	None	100%	-	100%
2	16-1/4"	14.2	None	100%	-	100%
Totals	40-1/2"	37.0		100%		100%

Time start = 8:33 AM 6/19/80
Time finished = 10:20 AM 6/20/80
Total run time = 25-3/4 hours
Total throughput = 1.44 kg/hr

TABLE 1

RUN NO. 22 (cont'd)

Crystal #1 (90% of crystal grown manually)
Straight growth 4:45 PM - 12:05 AM = 7.3 hours
Straight growth throughput = 3.12 kg/hr

Crystal #2
Straight growth 5:30 AM - 10:20 AM = 4.8 hours
Straight growth throughput = 2.94 kg/hr; average pull speed = 3.36"/hr or 8.53 cm/hr

RUN NO. 23

Crystal #	Crystal Length (in)	Crystal Wt (kg)	Pt. of Dislocation (in)	% OD	Pt. of twin or Poly (in)	% Good
1	24" + 2" taper	22.2	None	100%	-	100%
2	18.25" + 4" taper	18.7	16"	87.7%	18"	98.6%
3	21.25" (no taper)	18.6	15.25"	71.8%	17"	80.0%
Total	63.5" + 6.25" taper	59.5 (4.5 kg est. for tapers = 55 kg	55.25"	86.5%	59"	92.9%

Total charged = 65.4 kg Wt pulled = 59.5 kg
Pull yield = 91%
Total run time 8:35 AM - 10:10 PM = 37.4 hours
Total throughput = 1.59 kg/hr

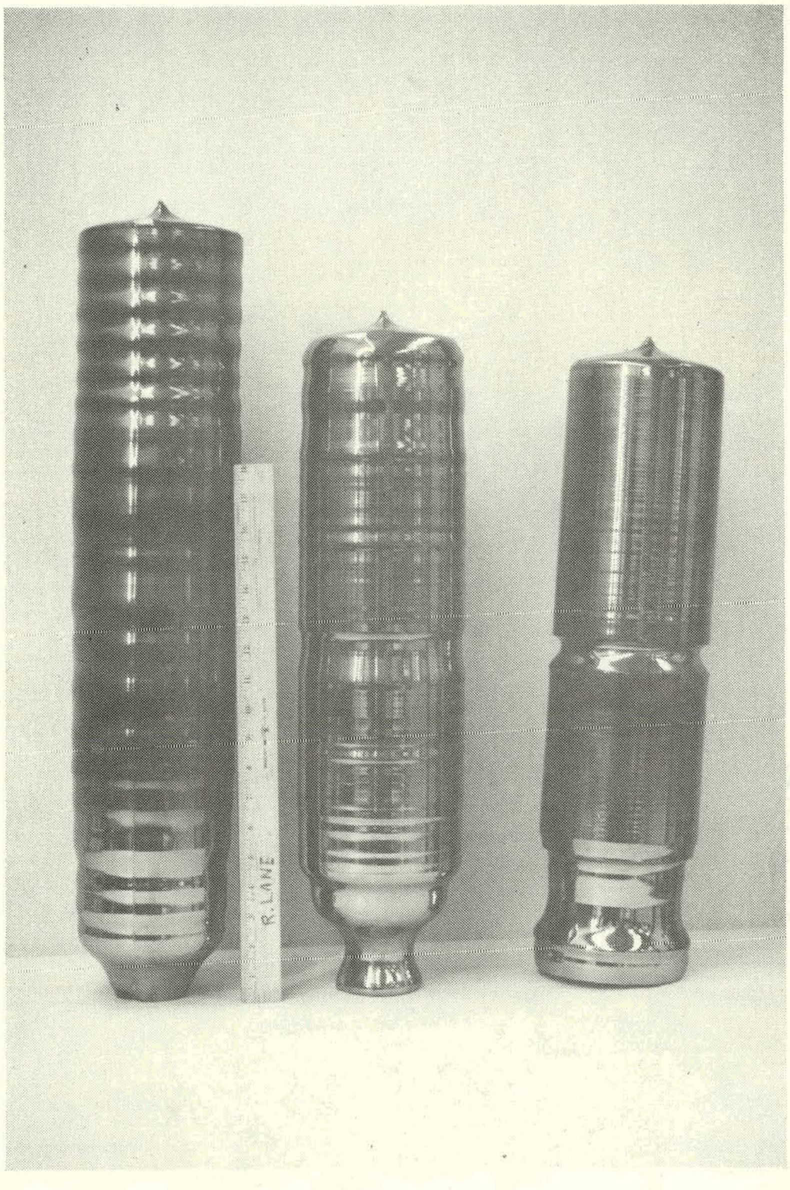
Crystal #1
21 kg in 7.8 hours
Straight growth throughput = 2.69 kg/hr = 3.06"/hr or 7.7 cm/hr

Crystal #2
16.7 kg in 5 hours
Straight growth throughput = 3.34 kg/hr = 3.65"/hr or 9.27 cm/hr

Crystal #3
14.8 kg in 5.5 hours
Straight growth throughput = 2.69 kg/hr = 3.09"/hr or 7.85 cm/hr

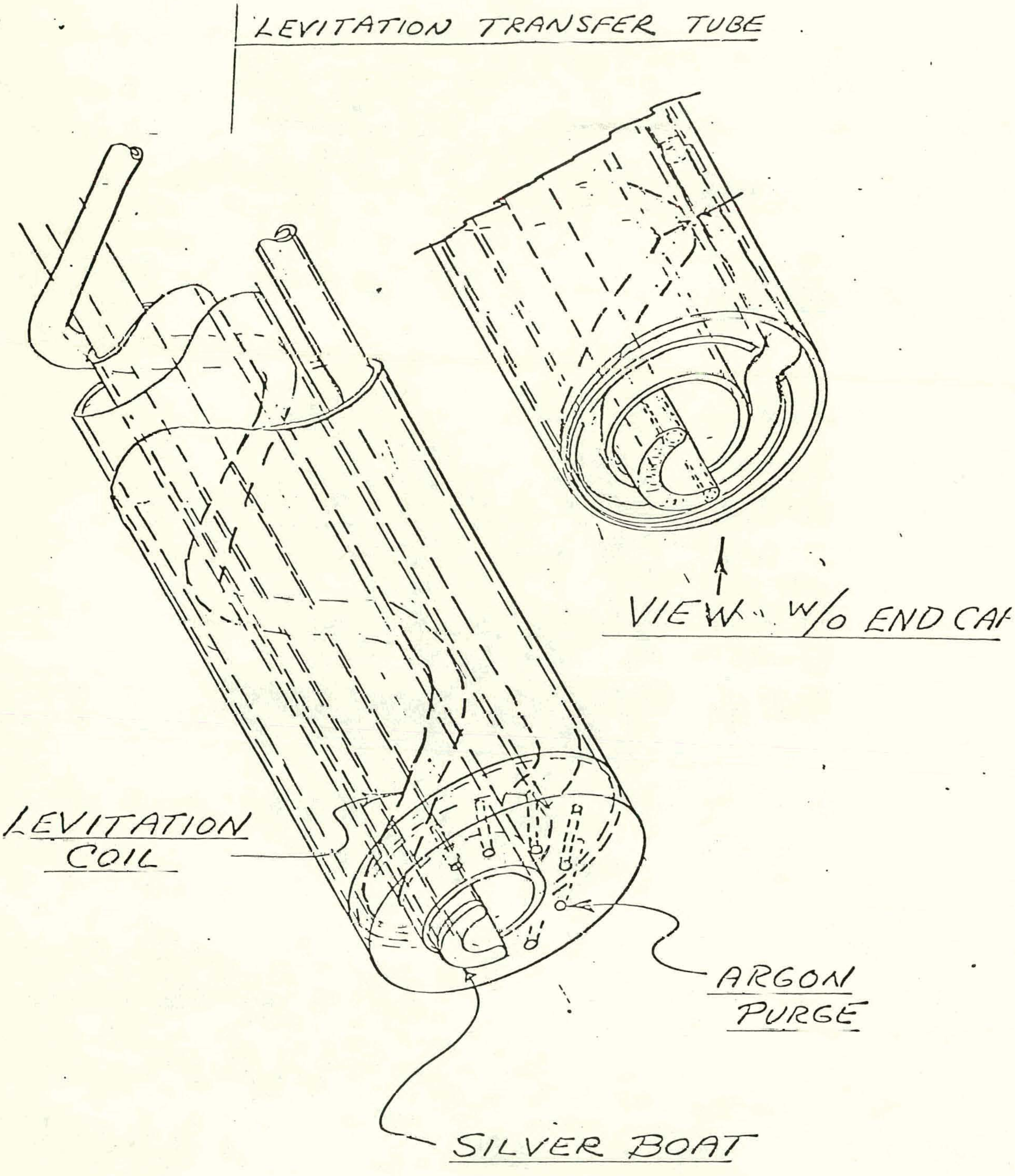
Straight growth calculations for Crystals 1 and 2 exclude (estimated) taper out lengths and weights. No. 3 was not tapered out of the melt.

TABLE 1 (cont'd)



Crystals Grown - Run #23

Figure 4



LSA PROJECT
LARGE AREA SILICON SHEET
KAYEX CORPORATION - JPL CONTRACT #955270

Figure 5

COLD CRUCIBLE PREMELTER SYSTEM

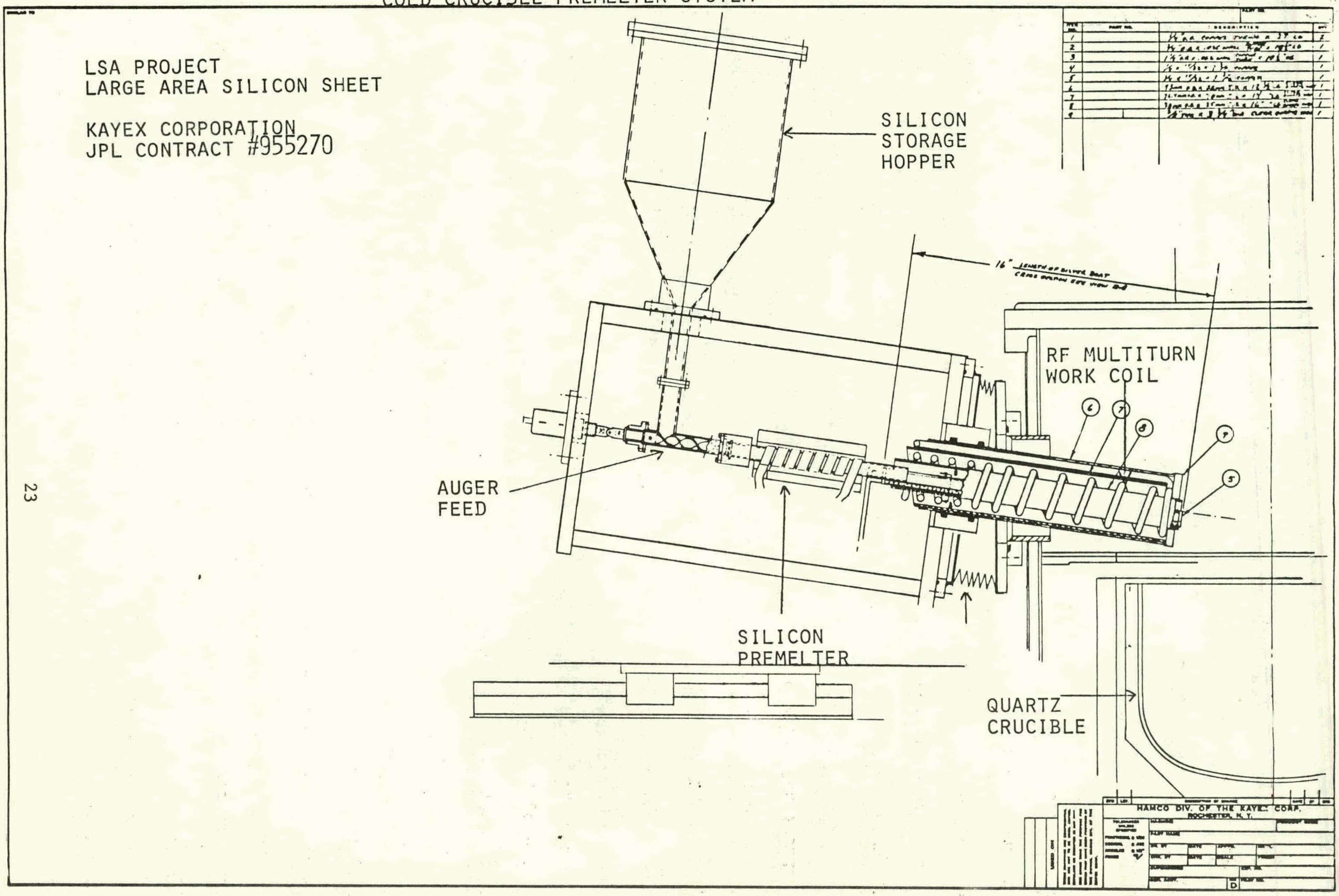


Figure 6

To date, the premelter system has been assembled and operated off the crystal puller. It was necessary that the feasibility of the melt, levitate, and pour approach be demonstrated prior to the interfacing of the assembly to the crystal puller.

Initial problems developed in the high voltage remote switching RF induction heating system due to arcing between an insulation package. This was corrected but then insufficient power output was experienced. A generator company representative was called in to rectify the fault. While making adjustments to the "tickler" or feedback coil, severe arcing occurred, causing the feedback coil to burn out. This caused just over a week's delay until a replacement was obtained.

A series of melt experiments were undertaken to evaluate and make necessary equipment adjustments. It was found necessary to fabricate some support sections for the multiturn work coil within the quartz tube. Applying power to the RF coil while it was free standing in the quartz tube produced carbonization on the reverse side of the silver boat. Supporting the boat just clear of the quartz tube eliminated this problem.

Some problems occured with solidification at the outlet of the silver boat because of temperature decrease. The RF coil was extended to the outlet of the silver boat to eliminate the problem.

Melt, levitation, and pour experiments were demonstrated off the puller such that the feasibility approach was satisfied.

2.4 Accelerated Melt Program

Meltback of Polycrystalline Silicon Rods using an RF Work Coil

As a result of the JPL issuance of the technical direction memorandum, the above program was de-emphasized and no work was undertaken during this reporting period.

Polycrystalline silicon rods of 5-inch diameter guaranteed crack free were unavailable. Also, rods exhibiting uniform diameter and free of bow were not obtainable. Diameter variances and excessive bowing down the rod axis created severe melting and arcing problems. The cost of polycrystalline silicon rods made it highly improbable that the overall cost goals could be met. No known programs are ongoing to produce low cost rods of suitable quality for this programs.

3.0 ECONOMIC ANALYSIS

No new economic analysis data were generated during this reporting period.

4.0 PLANS

a) Demonstrate microprocessor control of the crystal growth process.

b) Develop accelerated growth program and demonstrate 150 kg growth of multiple crystals.

c) Interface cold crucible to crystal grower and demonstrate quartz crucible recharging potential.

5.0 The program plan is illustrated in Figure 7.

PROGRAM PLAN LOW COST CZ CRYSTAL GROWTH

JPL CONTRACT #955270

KAYEX CORPORATION

Elapsed Time in Months: 1 A, 2 M, 3 J, 4 J, 5 A, 6 S, 7 O, 8 N, 9 D, 10 J, 11 F, 12 M, 13 A, 14 M, 15 J, 16 J, 17 A, 18 S

Program Objectives	Man Months Total Time	Man Months Sub-To Time
Program #1 Modification to CG2000 Crystal Grower	25.5	
1a) Overall Concept. Des.		4
1b) Microprocessor Cont.		3
1c) HF Coil & Heat Sink		3
1d) Modified Growth Cham.		7.5
1e) Cold Cruc. Develop.		6
Program #2 Definition of Process & Variables	11.5	
2a) Accelerated Rod Melt-back		1
2b) Cold Crucible Concept & Premelt		3.5
2c) Accelerated Growth		2
2d) Microprocess. Cont.		5
Program #3 Design Improve	3	3
Program #4 Process Eval.	9	9
Program #5 Documentation	11.5	
5a) Design Review		4
5b) Periodic Review & Reports		3.5
5c) Economic Model Update		2
5d) Final Report		2.5
Total Man Months	60.75	60.75

Figure 7