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SILICON WEB PROCESS DEVELOPMENT

LOW COST SOLAR ARRAY PROJECT
Large Area Silicon Sheet Task

Quarterly Report for October 1—December 31, 1979

By
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R. Seidensticker
R. H. Hopkins
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Work Performed Under Contract No. NAS-7-100-954654

Westinghouse Research & Development Center
Pittsburgh, Pennsylvania

MASTER

U.S. Department of Energy

Solar Energy

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Contract No. NAS 954654

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1. SUMMARY

Silicon dendritic web is a ribbon form of single crystal silicon produced from the melt without die shaping, and capable of fabrication into the second quarterly report on Phase III of a DOE/JPL-sponsored effort to develop silicon web process technology for the production of low cost terrestrial solar cells and arrays.

Melt-replenished web growth is a key objective of the present effort, both for technical and economic reasons. During this quarter we have reproduced, on several occasions, our earlier achievement of a four to five hour period of web growth with replenishment, have extended the period of web growth with replenishment, to nearly five and a half hours of growth. The runs were terminated by factors unrelated to the replenishment technique, e.g. the end of a work shift. The results are very encouraging and the conversion of a second web growth furnace to accomodate melt replenishment equipment will be completed shortly.

We have updated the economic analysis of the web process. Diminishing returns set in for growth cycle times in excess of three days. In fact, our calculations indicate that at web output rates of $25cm^2$/min and a silicon cost of $10/kg, the 1986 DOE/JPL wafer plus polysilicon cost goal can be met for web with about a two day cycle. As part of our economic evaluation we have examined the technical feasibility of employing a potentially lower cost solid state power supply to grow web. Experimentally the unit works quite well and consideration should be given such equipment as a long run cost reduction alternative to power web furnaces.

2. INTRODUCTION

Silicon dendritic web is a ribbon form of silicon which grows directly from the melt without dies and can produce solar cells with AM1 conversion efficiency over 15%. The primary objective of this program is to develop the technology to produce silicon web at a cost compatible with the national goal of 50 cents per peak watt (70 cents per watt in 1980$) of photovoltaic output power. This is the third quarterly report of the Phase III effort under JPL Contract 954654, Silicon Web Process Development.

In Reference 1 we presented a detailed description of the major technical results underlying the development of silicon web for low cost solar cells. Briefly, we had shown that most of the technical requirements to meet the 1986 cost goals have now been demonstrated. However, to sustain the necessary area output rates, and to grow web for periods long enough to attain economic viability, the development of an operational melt replenishment system and closed-loop growth system controls were identified as necessary. These two developments thus form major objectives for the Phase III effort.

Besides the development of replenishment and control techniques, the Phase III technical effort also calls for the systematic evaluation of advanced thermal trimming techniques to increase web width and speed still further, for coupling of output rate and replenishment technologies, design of a semi-automated experimental web growth machine, for detailed characterization of web material produced during the experimental program, and for an update of the economic analysis to reflect new technical and cost information generated during the program.

During the period covered by this report the dominant activities were directed at developing methods to increase the period of simultaneous growth of web crystal with melt replenishment. To further this work we have designed and tested an adjustable thermal trimmer to dynamically balance the thermal loads during melt replenishment. The highlights of the concept and initial tests are described in the text. In addition we have performed further studies of growth geometries to enhance web output rate, updated the economic analysis for web growth and tested a potentially lower cost solid state power supply for the growth furnace.

3. TECHNICAL PROGRESS

3.1 Melt Replenishment Development

For background,the basic features for melt replenished silicon web growth are shown in Figure 1. Recall that in this arrangement pellets of polycrystalline silicon are fed into a compartmented crucible which contains a large compartment for web growth and a small compartment for melt replenishment. An essential feature of the barrier which separates the two compartments is an opening within the barrier at a point below the melt surface which permits the melt level to equilibrate within the two compartments. Another essential function of the barrier is that it prevents pellets from floating to the region of web growth to interfere with growth. Finally, the barrier prevents ripples on the melt surface, caused by the dropping of pellets into the melt, from reaching and disturbing the growing web. For lower rates of melt replenishment a fixed thermal adjustment can be made in such a way as to accommodate the range of thermal requirements necessary in order to achieve melt-replenished growth. Such growth has been demonstrated for periods to greater than five hours within a single growth run. A fixed set of thermal conditions has, however, been found to be unsuitable for achieving melt replenishment at rates equivalent to high area throughput rates of growth, our long run objective. Adjustable shielding provides a way to circumvent such limitations.

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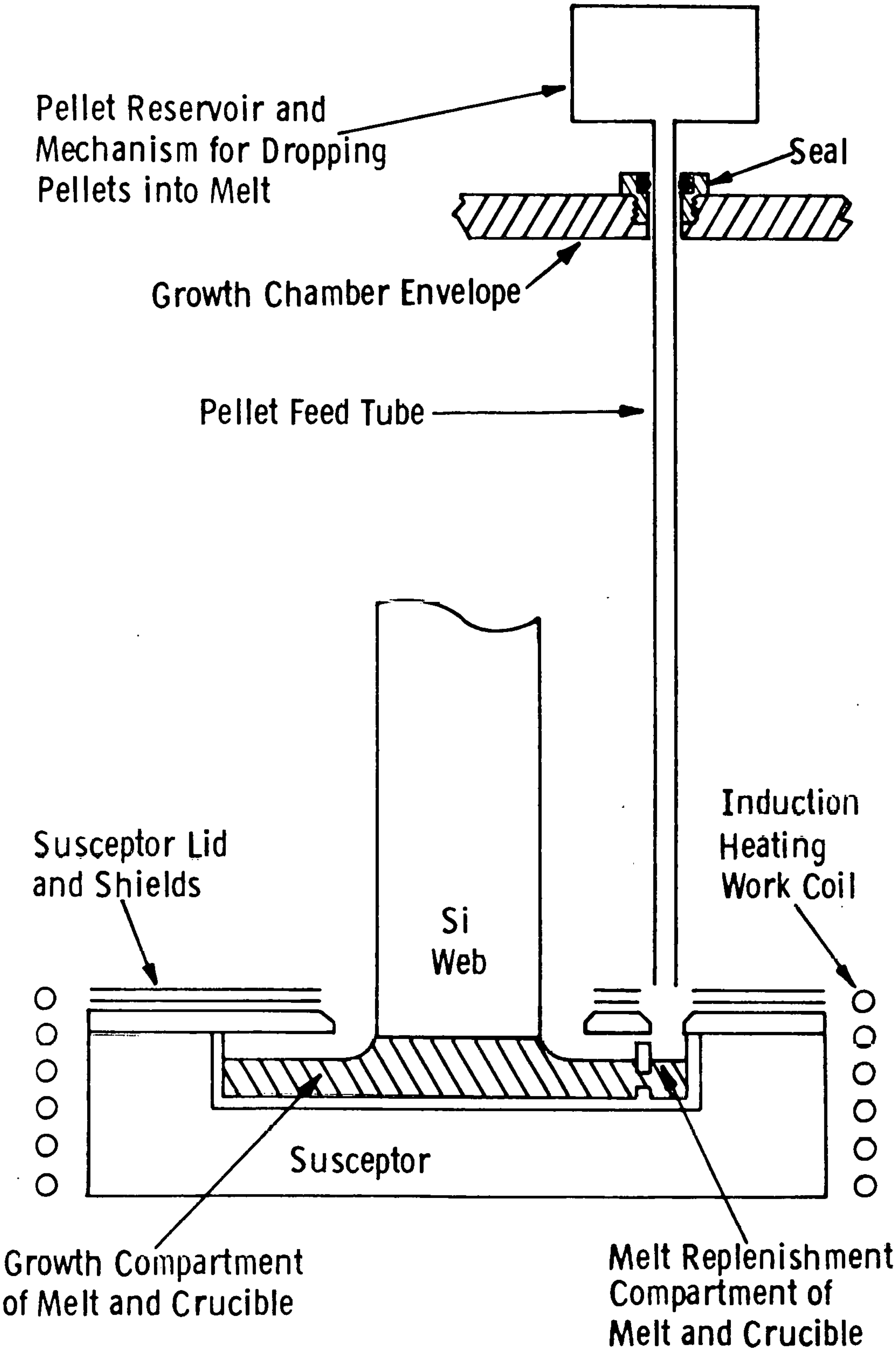

Figure 1 Simplified sketch of melt replenishment system.

3.1.1 Adjustable Thermal Trimming for Melt Replenishment

The Concept

Because different silicon feed rates are required at the start-up of web growth and at steady-state growth, the amount of heat to melt the silicon may vary with time. A fixed thermal adjustment does not span this range of requirements. Dynamic, or adjustable, thermal trimming, however, provides an excellent means for attaining symmetrical thermal conditions for all stages of growth ranging from start-up to full throughput rate. One way to accomplish this is by induction coil position changes. A better way is by means of an adjustable thermal shield like that illustrated in Figure 2 which is a top view of the growth susceptor system.

In this scheme, the vertically adjustable thermal shield can easily be positioned to provide a wide range of effectiveness. With the large skin depth of 10 KHz induction heating (as is used in web growth) a thin shield like that shown is heated very little and behaves as an excellent thermal shield. Thus a small number of shield positions should be adequate to cover the full required range of pellet feed rates. The adjustments to compensate for changes in pellet feed rate need be made only during the early manually-controlled period of growth prior to achieving full throughput. We have fabricated a movable shield for experimental test; it is shown with a susceptor in Figure 3.

Methods to Characterize the Adjustable Shield Performance

In order to best use an adjustable thermal shield with melt replenishment, it is most expeditious to first characterize the effect of the shield in various positions and also to evaluate the thermal effect of various rates of melt replenishment. In essence, we need to know the amount of shielding needed to compensate for the thermal effect of various rates of melt replenishment. When the two effects are in balance, optimal web growth conditions will prevail. Three types of measurements are available and have been used to characterize these thermal effects. Referring again to Figure 2, an infrared pyrometer was used to evaluate the effects in the molten silicon along the traverse route shown.

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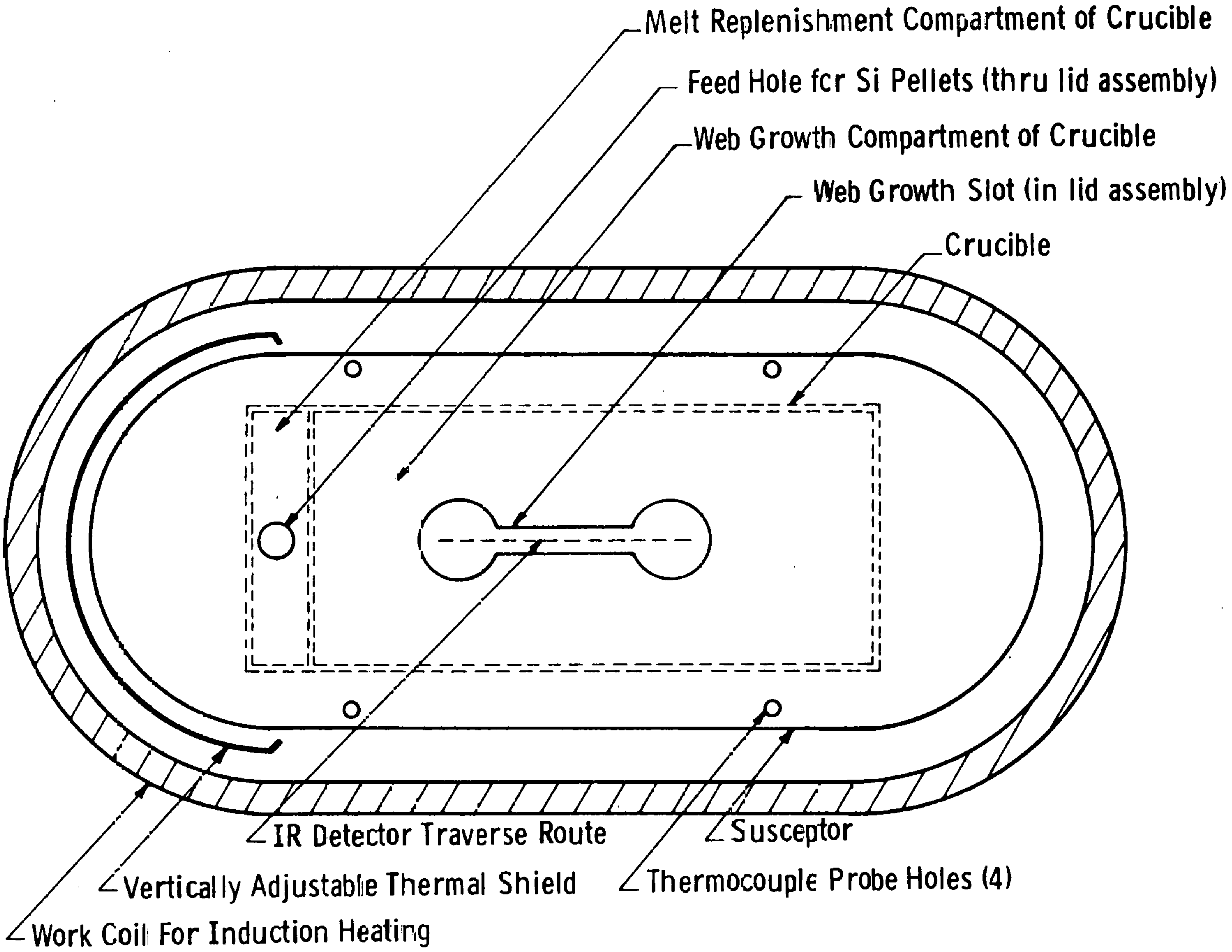

Figure 2 Top View Susceptor System Showing location of vertically adjustable heat shield, melt temperature profile measurement and thermocouple probe holes.

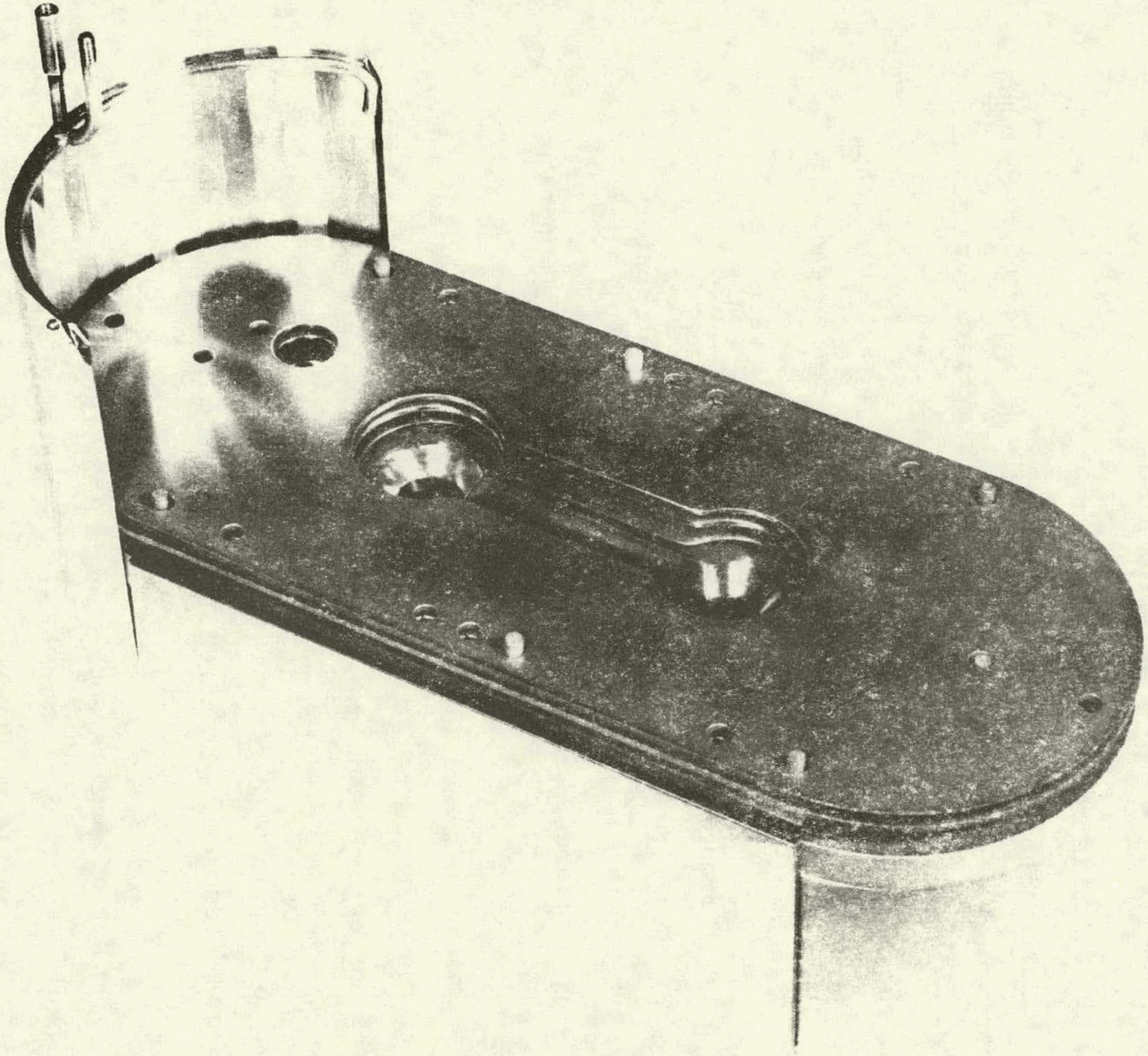

Figure 3   Adjustable thermal shield surrounding feed end of susceptor used for web growth

Dendrite probing to determine the thermal profile under different conditions along the traverse route has also been used. Finally, thermocouples were inserted in the two rear probe holes shown in order to evaluate the effects within the susceptor itself.

Experimental Shield Evaluation

During the latter part of this reporting period the emphasis of the experimental studies was on quantifying temperature variations resulting from adjustable shielding and feeding rate changes. By determining the effect on the melt temperature of a particular change in one of either variable appropriate compensation can be made.

As noted, the primary measurement methods were:

1) Thermocouple measurements in the susceptor,
2) Dendrite "hold" points, measured in the center of the melt, and
3) Infrared pyrometer determination of melt temperature changes.

Two of the thermocouples were located in the back wall of the susceptor, near the bottom, 4 1/8" apart. A third thermocouple was located in the center of the susceptor, below the crucible. The infrared measurements were made by placing the infrared pyrometer either at the center of the dogbone slot, or one inch to either side. For the infrared measurements, the pyrometer was temporarily mounted above the growth chamber as in Figure 4.

One set of measurements compared the thermocouple readings as the end shield; Figure 3, was moved with a dendrite "hold" temperature being found at each shield position to maintain a constant melt temperature at the center. These measurements are plotted in Figure 5. As expected, the axial thermocouple held essentially constant, within the accuracy of the "hold point." The changes in temperature determined from the thermocouples in the susceptor wall indicate that the shield shifts the total thermal distribution in the susceptor. With the shield inserted 4cm, for example, a temperature change of over 10° compared to the case with no shielding was achieved.

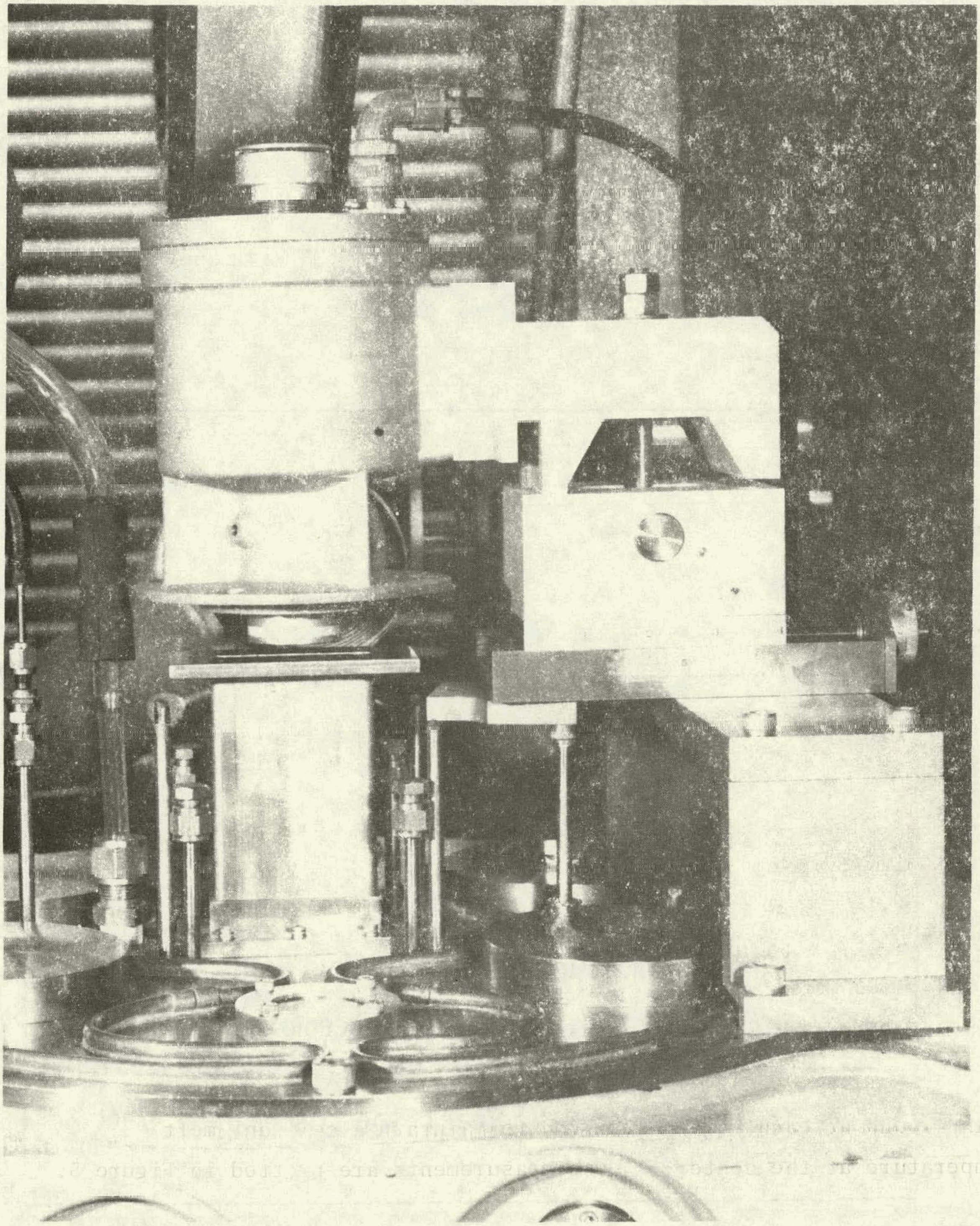

Figure 4   Infrared pyrometer temporarily mounted above growth chamber

Curve 720698-A

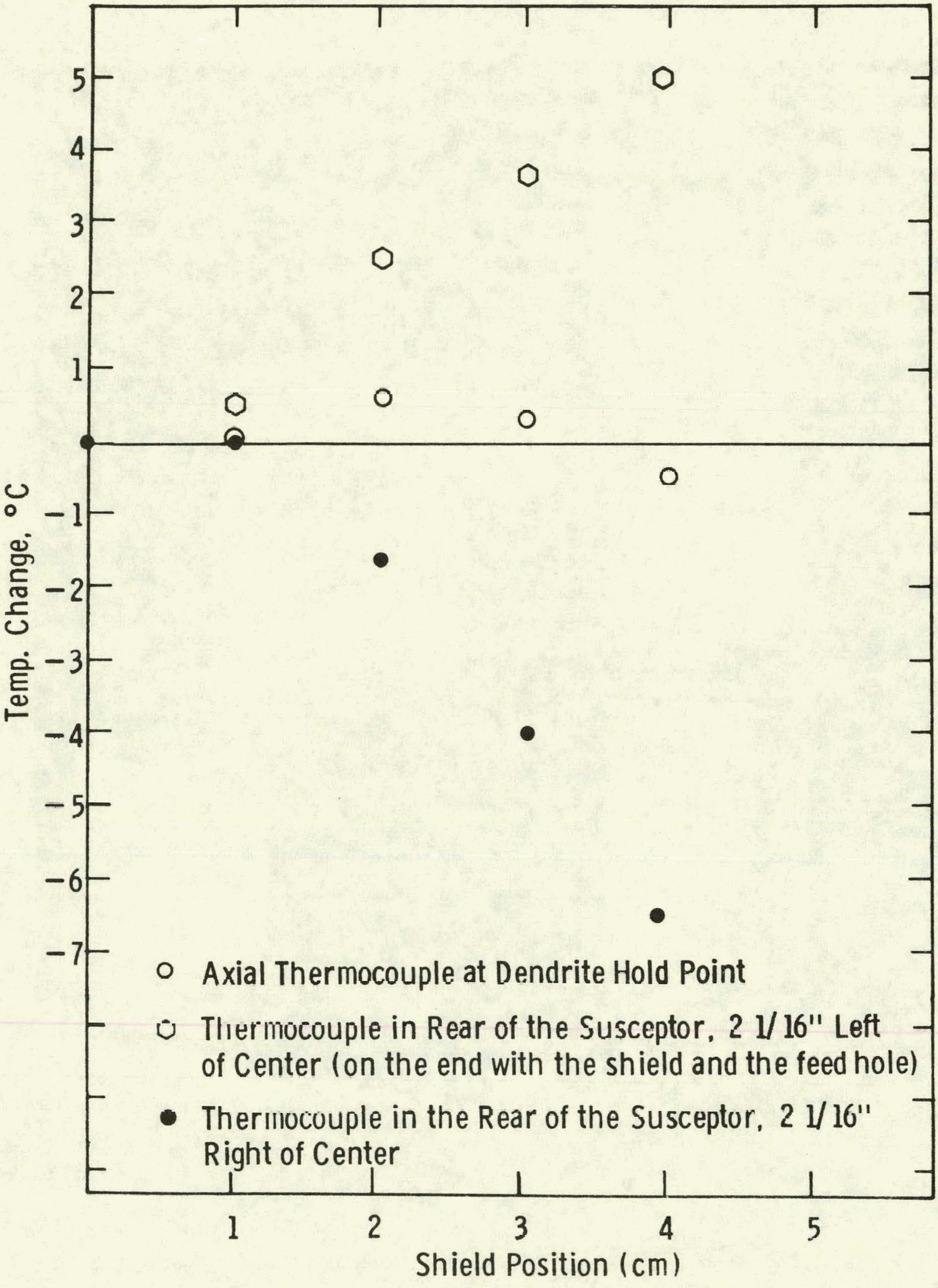

Figure 5 Comparison of temperature changes at various susceptor points vs the end shield position. At 0 cm the shield is not affecting the susceptor; at 1 cm the shield has been lowered, and is shielding the top centimeter of the susceptor.

Since a dendrite could not be inserted while the infrared pyrometer was in position, and since the axial thermocouple essentially followed the "hold" temperature, the thermocouple was used thereafter as the control. The Ircon readings at the center of the melt held fairly constant, $\pm \sim 2/3°$. Again, as the shield was lowered, the relative changes in melt temperatures (at the points one inch from the center) became large, Figure 6 over 10°C with the shield lowered 4.8cm. Since the measurement points are closer than in Figure 5 this implies the gradient in the liquid is actually larger than in the susceptor wall.

In using the Ircon, we found that temperature fluctuations of ± 1/4° at a given point were generally present. This was confirmed to be in the melt rather than an instrument problem by sighting the Ircon onto the lid and observing no fluctuations. Since the magnitude of the fluctuation was fairly constant, the Ircon values in Figure 6 are the average of the extremes measured at a given point without error bars. Also, the Ircon detector is quite sensitive to the back/front location in the slot. Part of this sensitivity is due to "clipping" of the view angle by the chimney through which the Ircon views the melt surface. Although small dimensional variations in the chimney add to alignment difficulties and make actual temperature measurement along the slot very difficult, relative temperature changes still can be made easily.

In the last set of measurements the infrared pyrometer was mounted one inch from the center on the left or feed side. The results of this set of data, where temperature changes were recorded as the feed rate was changed for various shield positions, can be seen in Figure 7.

Pellet feed rates of 2 per minute introduce a negligible thermal effect; at 10 pellets per minute a depression of about 1°C was observed (at the sensor location one inch to the left at the melt center). The temperature depression in the feed chamber is actually somewhat lower than this as shown in other experiments where freezing occurred with partial shield insertion. By use of the movable shield we have

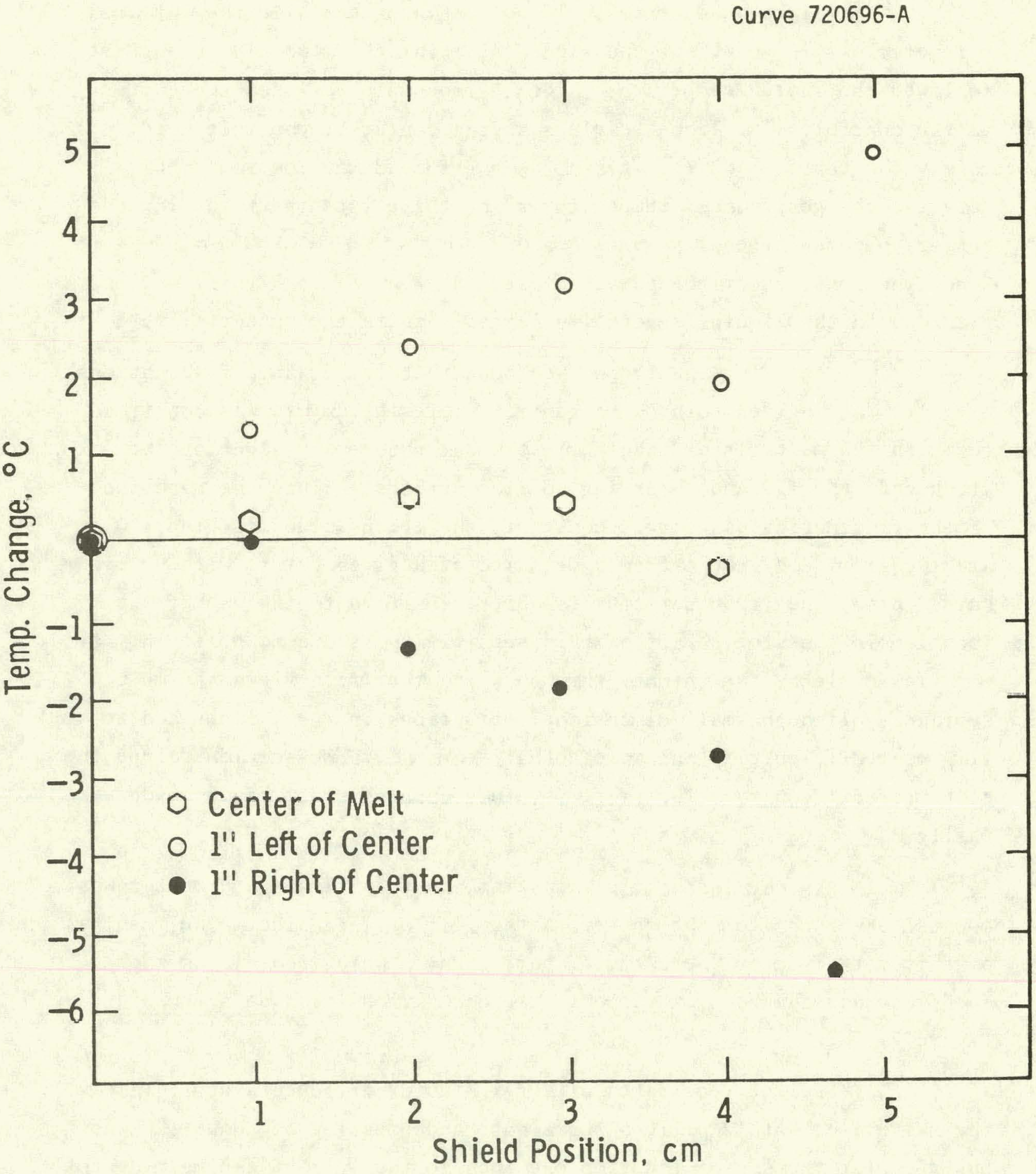

Figure 6 Comparison of temperature changes in the silicon melt at different end shield positions. Points represent average values of Ircon readings at each location.

Curve 720697-A

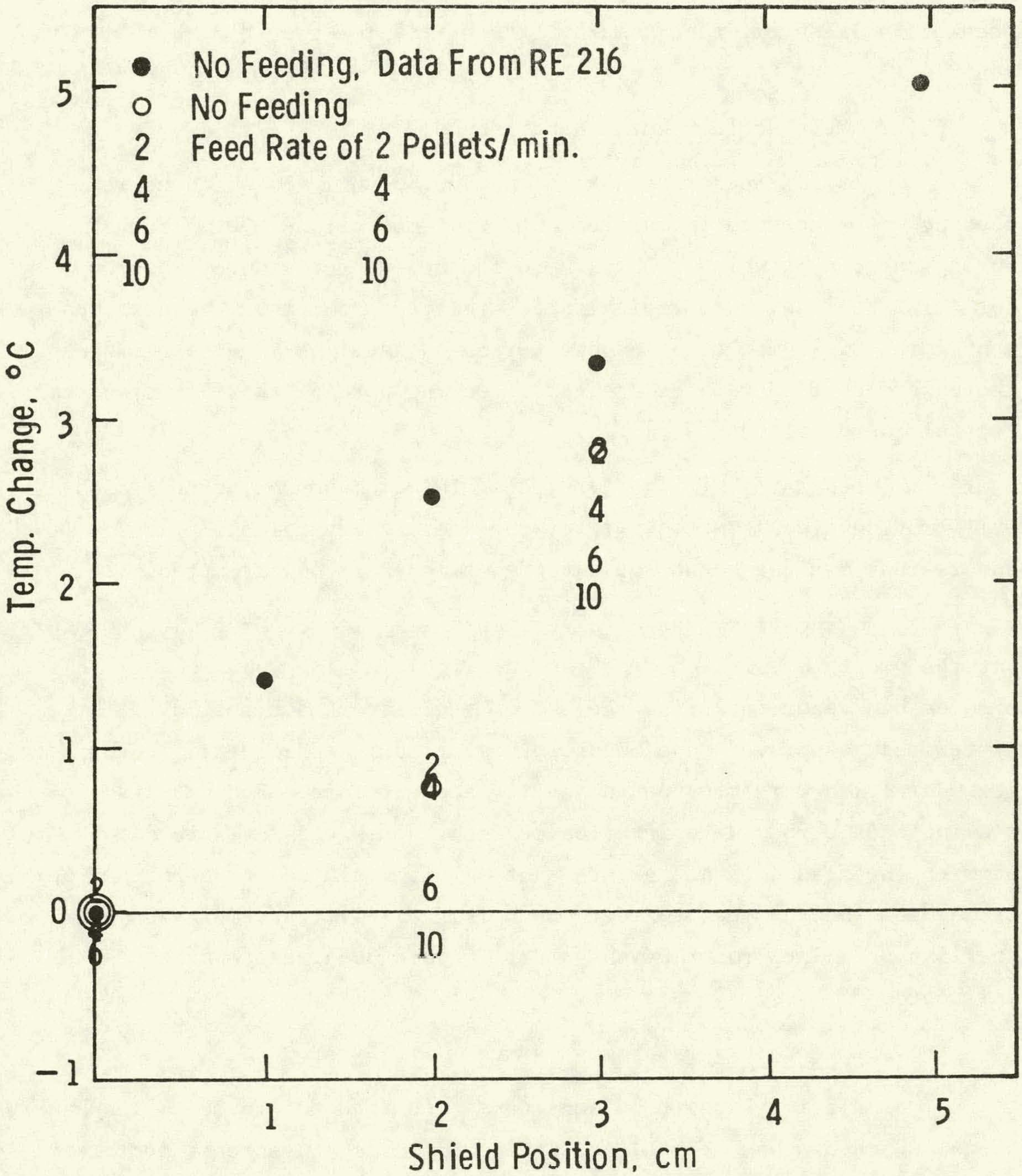

Figure 7 Effects of pellet feeding rate on temperature, compared at various end shield positions.

improved our understanding of the thermal geometry required for pellet feeding and also extended somewhat the period for growth with replenishment.

3.1.2 Melt Replenishment Experiments

Several feed runs have been made recently in which pellet feeding was successfully carried out for time periods over 4 hours. During one run in which pellets were fed at two per minute, we grew for 4 1/2 hours with no replenishment-related problems. The next run went for 5 hr 20 min (the longest period to date) at 4 pellets/min; again there were no feed-related problems. During both of these runs several crystals were pulled.

Feed rates of 6 to 8 pellets/min,which appear quite feasible, will provide a constant melt level for present crystal pull rates. In future runs replenishment for extended times will be attempted.

An ancillary set of experiments was also conducted to counteract the growth of silicon "ice" in the liquid during web growth. This problem had recurred during the end of the last report period.[2] Three system changes proved beneficial. First, small leaks identified by He leak detection were plugged in the furnace envelope. Second, a set of alumina and Mo rods were interleaved with the shields at a location between the feed hole and growth slot. This minimized transport of any oxide from the the feed to melt chambers. Finally, accumulation and spalling of oxide from the web guides (a rare occurrence) was also corrected.

3.1.3 Liquid Level Sensing System

Melt level position sensing is required to provide a feedback signal which can be used to program the proper melt replenishment rate. Our concept, reported before[2,3] and illustrated in Figure 8 uses a 2 mW He-Ne laser which generates a coherent light beam that is directed through the furnace growth chamber, reflecting from the silicon melt surface, and finally striking the solid state position detector. This system, Figure 9, has been fabricated and installed on the RE furnace.

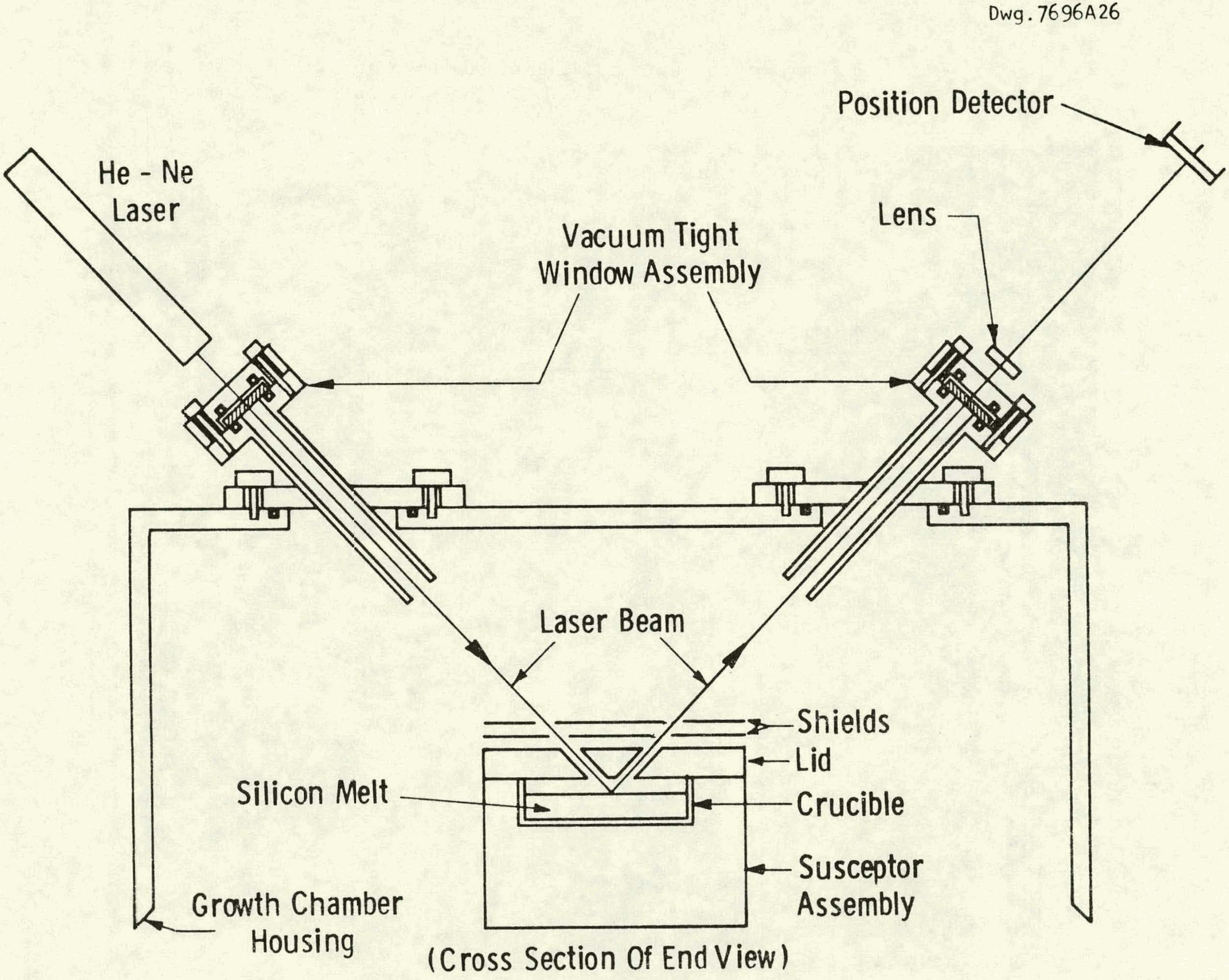

Figure 8 Schematic of melt level sensor

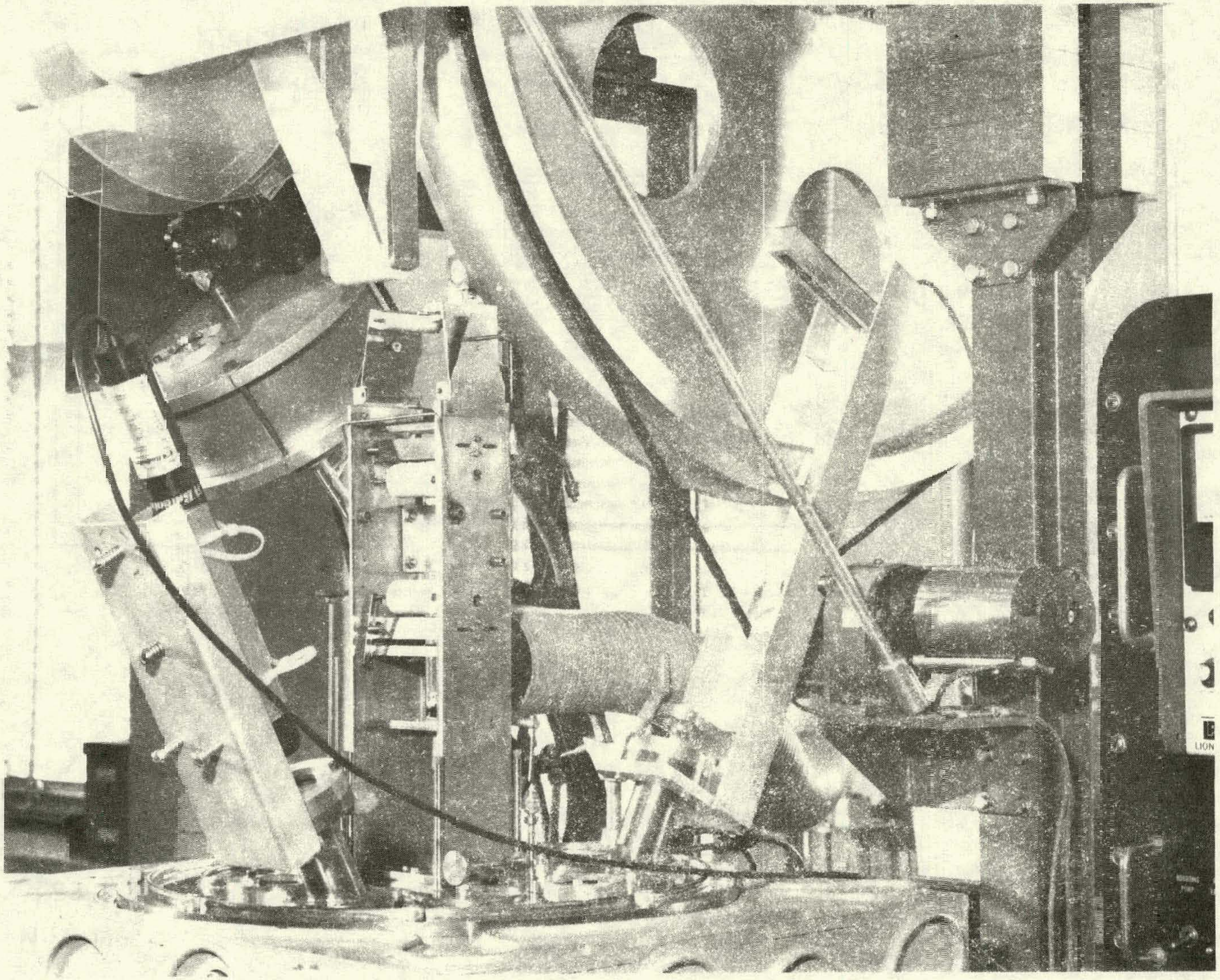

Figure 9   Laser-sensor System for Melt Level Position Detection Shown Mounted in Position for Use on the RE Furnace

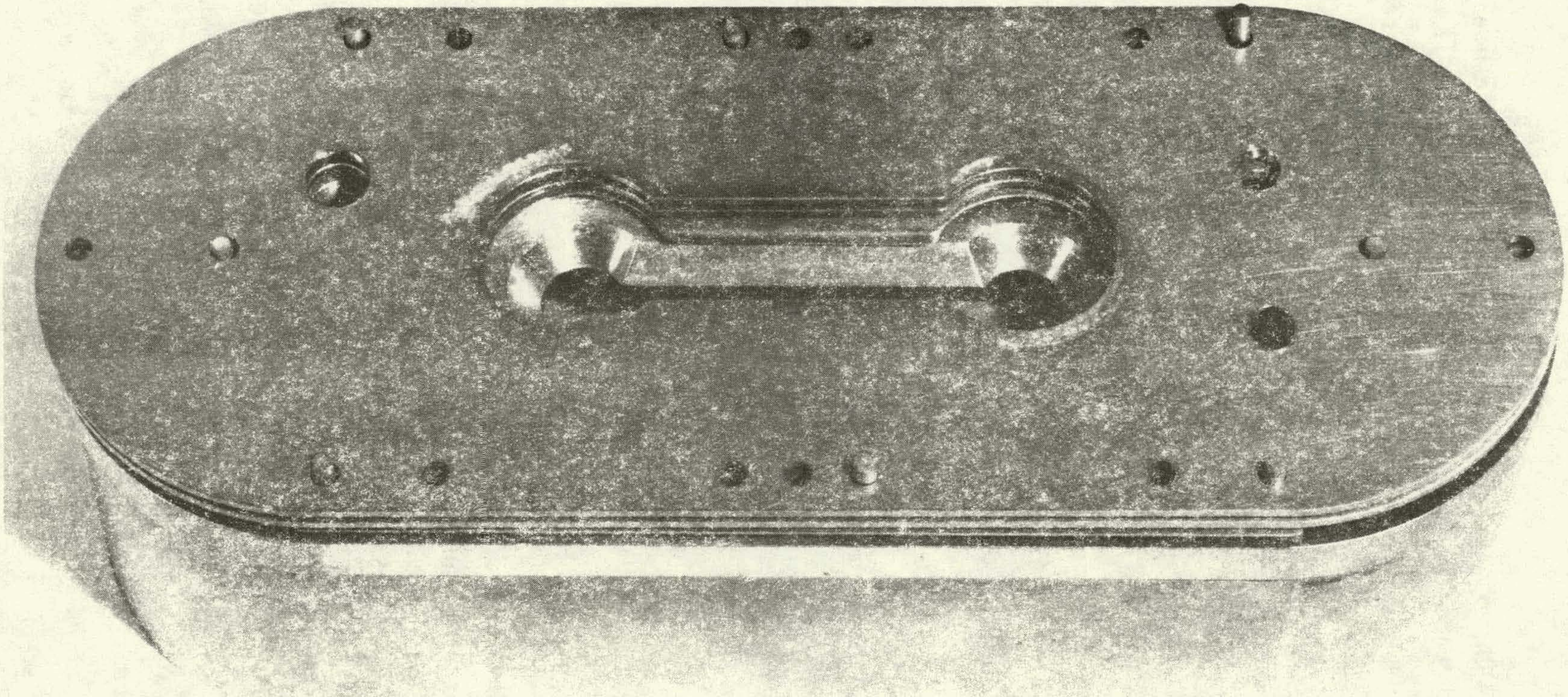

Figure 10 Susceptor-Lid System Showing Laser Beam Route Holes to the Right of the Dogbone-Shaped Growth Slot. Entry Port for Polycrystalline Silicon Pellets is at the Left of the Growth Slot.

The laser, windows, condensing lens and detector have been optically aligned such that the light beam passes through the growth chamber and strikes the detector as intended. The light beam passes through the susceptor lid and shields, as shown in Figure 10, then reflects from the surface of the silicon melt. Full operation of the sensor system has been temporarily delayed because of a fault in the output amplifier of the position detector. The unit has been returned to the vendor, and we expect this problem to be corrected in January 1980. The system then will be operable with meter readout for manual control of the melt replenishment feed rate and melt level. Closed loop control will be added in the future.

3.1.4 Modification to Melt Replenishment System

Pellet Feeder Re-Design

Experience with the motor driven polysilicon pellet feeder[1] used with the RE furnace melt replenishment system has revealed some occasional mis-operation. Although the occurence is infrequent, the feeder has been observed to drop two or more pellets simultaneously. Because we believe the concept of the design itself to be feasible, we have undertaken a re-design of the feeder principally to eliminate multiple pellet feeding. The feeding of multiple pellets can thermally overburden the melt within the melt replenishment compartment of the crucible. If such a condition continues a blockage of solid pellets can close the feed system and prevent further melt replenishment during that web growth run.

We are using this opportunity, also, to bring about some other design improvements. The re designed pellet feeder is expected to have the following improvements: 1) elimination of multiple pellet feeding, 2) four times greater range of pellet feed rates, 3) capability to handle pellets with less risk of contamination, 4) improved provision for reloading, 5) improved shaft seal. Detailed design drawings for the modifications are identified by design specification D903149 and are included in the Appendix.

Conversion of J Furnace to Melt Replenishment

The initial development of high throughput melt replenishment was carried out in the RE web growth furnace. This development has progressed sufficiently that the decision has been made to install essentially identical melt replenishment hardware in the J web growth furnace. This will permit continued development of melt replenishment to proceed more quickly and will also double our capacity for utilization of melt replenishment in conjunction with other developmental activity, especially of high output rates. The detailed design drawing 699F576 which covers only the differences between the J and RE melt replenishment hardware, is included in the appendix. Otherwise the melt replenishment systems are identical. Conversion of the J furnace is expected to be completed in January 1980.

3.2 Output Rate Technology Development

Over fifty experimental runs were made during this period in the J and WA facilities to investigate parameters controlling web width and speed. Details are given in the Appendix. There were two principal objectives: 1) to generate quantiative growth data for input to and correlation with the thermal modeling and design effort, and 2) to test the effects of top shield and lid geometry variations on overall growth behavior. The former principally involved the generation of thickness-velocity and web stress data, while the latter encompassed a variety of behavioral phenomena including for example, ease of growth initiation, crystal quality, growth stability (ease of maintaining growth), oxide accumulation, if any, etc. Thus,the objectives were to expand the data base of relating various system parameters to increase web width and output rate.

Two principal lid designs were used as base lines in work to evolve wider web, the J-181, Figure 11, and a more open-lipped slot geometry like that illustrated in Figure 12. Variations tested included modifications in the configuration of the top shields-number, geometry and spacing. The J-181 modifications were in general good growth

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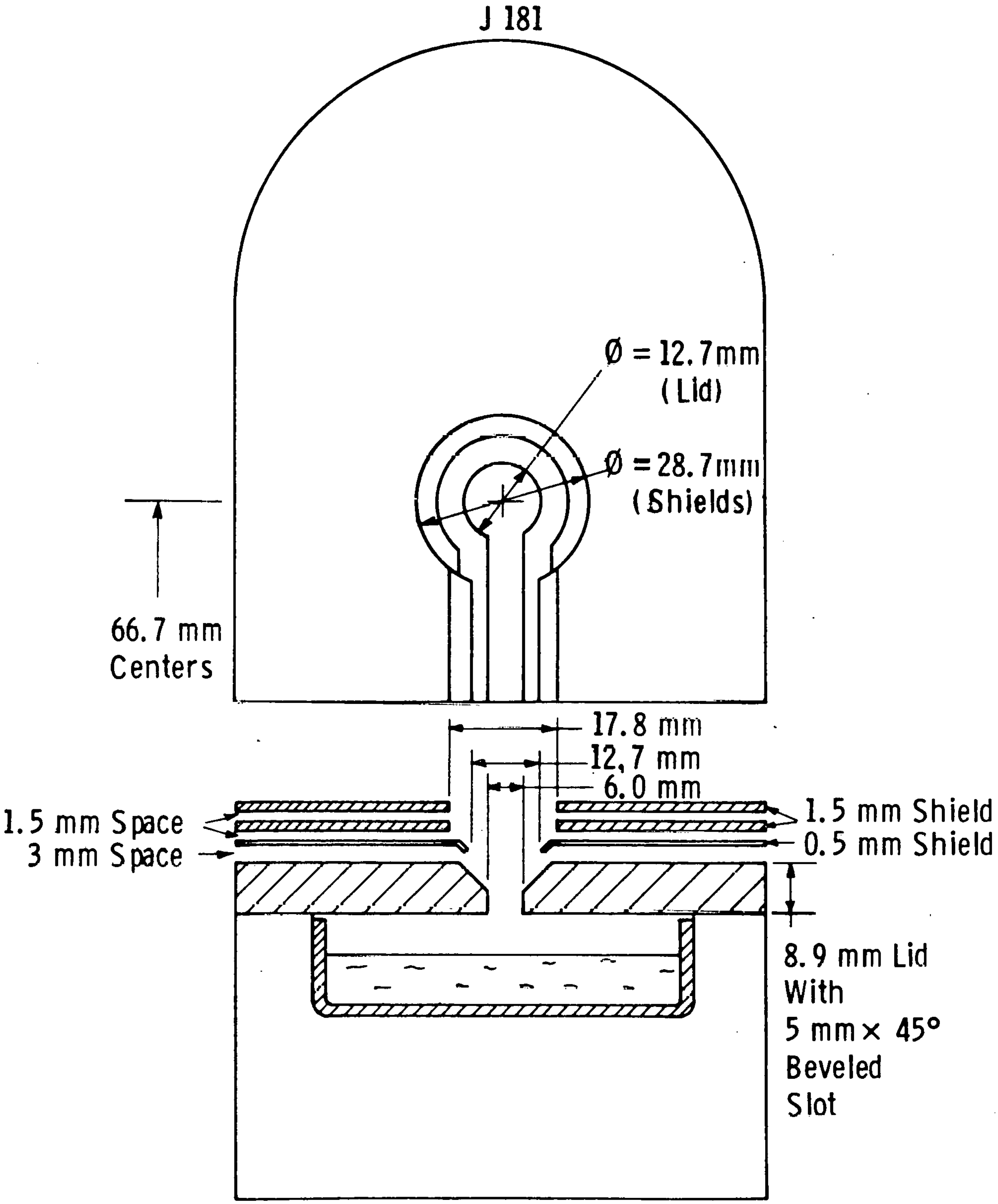

Figure 11 The J-181 Baseline Lid and Top Shield Configuration

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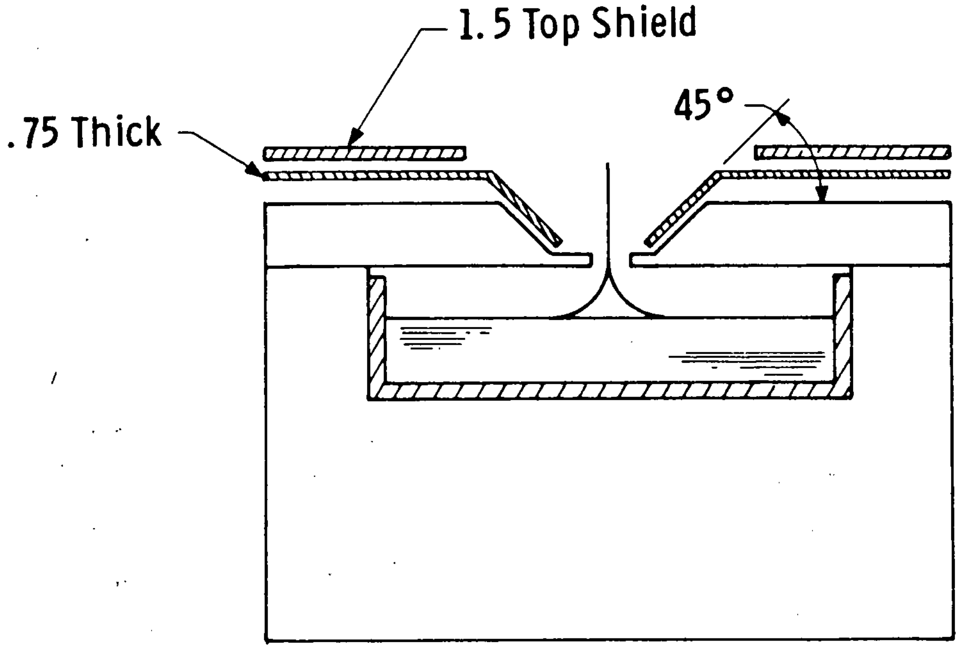

Figure 12 Lid Slot Design with Large Radiative View Factor

configurations; growth initiated easily, and was very stable once underway. In particular, with the addition of a fourth shield with slitted periphery (see last quarterly report[2]) crystals of good quality can be started at the initial (high) melt level (high radiative loss) which has positive implications in terms of increasing growth velocity when melt level maintenance is achieved via the replenishment system. This is because the growth velocity for a given crystal thickness decreases with the lowering of the melt level, as has been discussed in detail in previous reports.[1] This behavior is in contrast to earlier shield configurations we tested in which early crystals (at high melt level) tended to go polycrystalline until the level was lowered somewhat.

With this background, further modifications were made in which the overlap of the lower formed shield was increased by about 1mm and then the shield spacing was decreased. These modifications were undertaken on the basis that both velocity and stress are both greatly affected by the thermal environment in the first cm or so above the interface, i.e. within the region of the lid and shield stack. Systematic compression of the shield stack resulted in a progressive increase in oxide deposition on the edge of the formed shield, to the point that the oxide accumulation interferred with the otherwise very stable growth. With these close spaced shield configurations, the use of barrier type separators between the shields (instead of washers), to inhibit gas flow between the shields seemed to reduce the rate of oxide deposition, but did not extend the available growing time sufficiently to fully evaluate the effects on growth behavior of close spaced top shields. Aspirator or other convective gas flow management techniques to control oxide deposition thus appear necessary to utilize the close-spaced arrangements.

As a consequence of the experiments we did identify the potential utility of hot pressed molybdenum shield elements for long term growth stability. Some months ago, we switched from arc cast molybdenum sheet to pressed and sintered sheet for shield material in order to obtain a substantial cost savings. We have discovered that the pressed material does not warp even with repeated heating. Shields made from arc cast material warped badly after only a few runs. Thus shield spacings as close as half a millimeter now can be configured reproducibly, in sharp contrast to the shields made from arc cast molybdenum.

A second lid geometry under evaluation in the J furnace, Figure 12, because of its substantially wider view factor, offers the potential for considerably enhanced growth velocity provided the view to the hot lid bevel can be minimized. Although recent experiments have been encouraging with regard to speed, oxide accumulation on the lower edge of the formed shield has hindered widening of the web.

Finally a few runs were made with a thin (3 mm) lid, as a method of bringing the total lid plus shield stack closer to the growth interface. It was hoped that the increased number of top shields would keep the thin lid hot enough to prevent oxide accumulation in the slot. (Thick lids are heated sufficiently by r.f. coupling that the lid slot itself normally remains oxide free.). Although a marked increase in growth velocity was observed, the edge of the lid slot was not hot enough as presently configured. Oxide did collect, eventually blocking the slot. Further modifications are thus required to use this configuration.

During the next period, efforts will be made to control the vertical temperature distribution in the web near the growth interface by varying slot shape in the top shields, particularly the width, while using spacings conducive to growth without interference from oxide accumulation. The J-furnace will then be converted for melt replenishment studies as described in the last section.

In the WA furnace,most of the experiments center on techniques to increase radiative transport from the web and hence to increase growth velocity. A direct approach is to increase the view angle between the growing web and the hot susceptor lid.[2] This can be accomplished by decreasing the bevel angle on the lid. Figure 11, shows the standard J-181 lid shield configuration employs a 45° beveled lid. In Figure 13 we show how the J-181 top shielding can be combined with a lid that has a decreased bevel angle of 30° (WA-17). With the decreased bevel the

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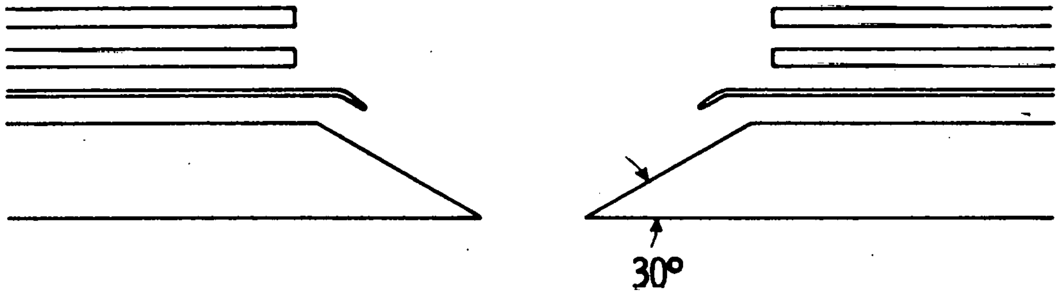

Figure 13 Schematic Depiction of a Growth Geometry in Which the Standard J-181 Top Shielding is Combined with a 30° Beveled Lid (WA-17)

amount of radiation leaving the hot lid and intersecting the web is decreased. This allows more heat to radiate from the web and also radiates less heat back-in.

Another technique being used at this time involves the use of a thin shield to cover up the bevel on the hot lid, thus reducing radiation back to the web. For example, Figure 14 displays a 30° beveled lid with a closed over top shield for this purpose. (WA-36) In contrast, Figure 15 shows a configuration with "open" shielding. (WA-32). This arrangement permits radiation to leave the web with very little interference or back reflection, and is being run for comparative purposes.

During the past quarter all four of these configurations have been run and comparable thickness-velocity data has been obtained. There were no data obtained for the closed over configuration (Figure 14 (WA-36)) because of growth related problems, particularly oxide formation on shielding.

These data were analyzed using the assumption that there is an inverse linear relation between the pull speed and thickness parameters. (See Reference 2 for the thermal model). This relation can be expressed:

$$v = a + b/t$$

where v is the web growth velocity (pull speed), t is the web thickness and a and b are constants from fitting the experimental data.

Using linear regression analysis, the a and b terms for various configurations were calculated. The desired result is of course to increase both the a and b terms, so that the velocity is increased for a given thickness value. Pull speed parameters for three of the configurations discussed are shown in Table 1.

The data indicate that the WA-17 configuration raises the a parameter relative to the baseline case but at the sacrifice of lowering the b parameter. The major benefit thus falls at the lower end of the speed range rather than at the higher end. The WA 32 configuration produces

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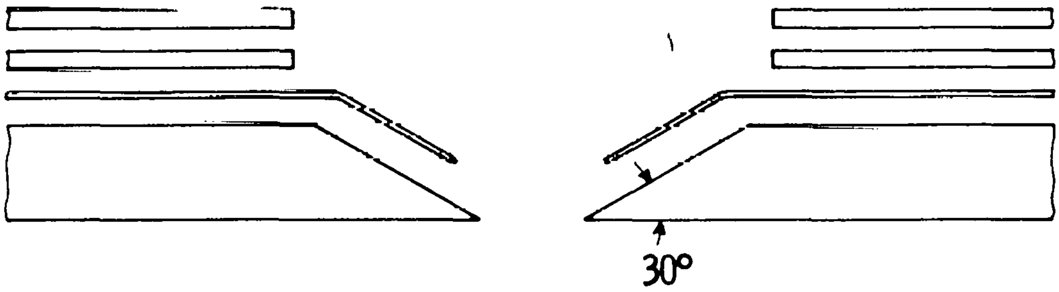

Figure 14 A 30° Beveled Lid with "Closed Over" Top Shields (WA-36)

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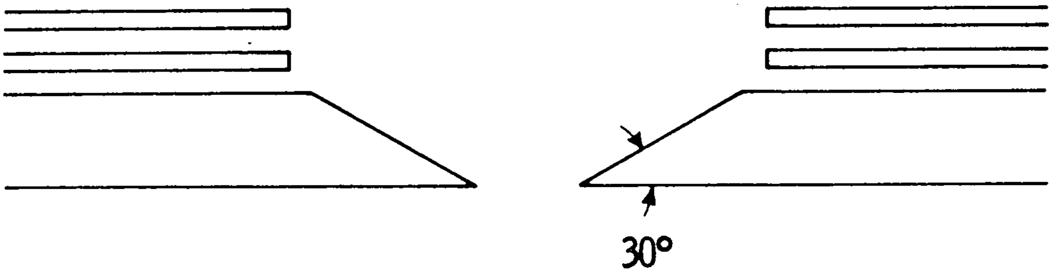


Figure 15 A-30° Beveled LId with Open Top Shielding (WA-32 Configuration)

TABLE 1

PULLSPEED PARAMETERS FOR VARIOUS LID SHIELD CONFIGURATIONS IN THE WA-FURNACE

$$v = a + b/\tau \quad *$$

Configuration	$a\ (\frac{cm}{min})$	$b\ (\frac{cm^2}{min})$
J-181 (Baseline)	0.760	0.0120
WA-17 (Figure 13)	1.135	0.0089
WA-32 (Figure 15)	1.010	0.0122

v = pull speed $(\frac{cm}{min})$

t = thickness of web (cm)

---

* This data assumes a straight line approximation and was obtained through linear regression analysis.

an increase in a, and a small increase in b, overall a desirable result and suggests a direction for future experiments.

During the next quarter we expect to begin combining melt replenishment and output rate technologies to provide for steady-state high output rate growth.

3.3 Material Characterization

The averaged diagnostic solar cell data for a number of crystals grown during the period are given in the Appendix. The number of crystals and cell runs are somewhat reduced over previous quarters due to shifts in emphasis toward melt replenishment studies during the period. The feed run experiments tended to produce fewer large crystals usual when thermal adjustment techniques were being developed.

Two sets of data in the table are worth particular mention: W180-1.3 and W185-1.4. The first represents a crystal grown from the experimental Battelle material and the cell data reproduces very well the preliminary data given in the previous report for a second crystal in the run.[2] The material represented by W185-1.4 was grown from a melt intentionally heavily doped with boron. Even though the resistivity is only 0.02 Ω-cm, there was no problem in growth, and the cell efficiency was almost 6%. The large OCD lifetime in inconsistent with the low I_{SC} and is being rechecked.

3.4 Economic Considerations for Web Growth

3.4.1 Update of Previous Economic Analysis

Economic analysis indicates a melt replenished growth period of the order of two days is necessary to satisfy the DOE/JPL 1986 cost goal for silicon wafers.[1] The dependence of the time length of the growth period, Figure 16, also shows that the cost improvement diminishes rapidly as the growth period extends beyond a period of three days. Note that the growth cycle consists, in all cases, of seven hours of non-growth time which is required for such activities as furnace loading, heat-up, start of growth, cool-down and cleaning. Thus, for example,

Curve 719676-A

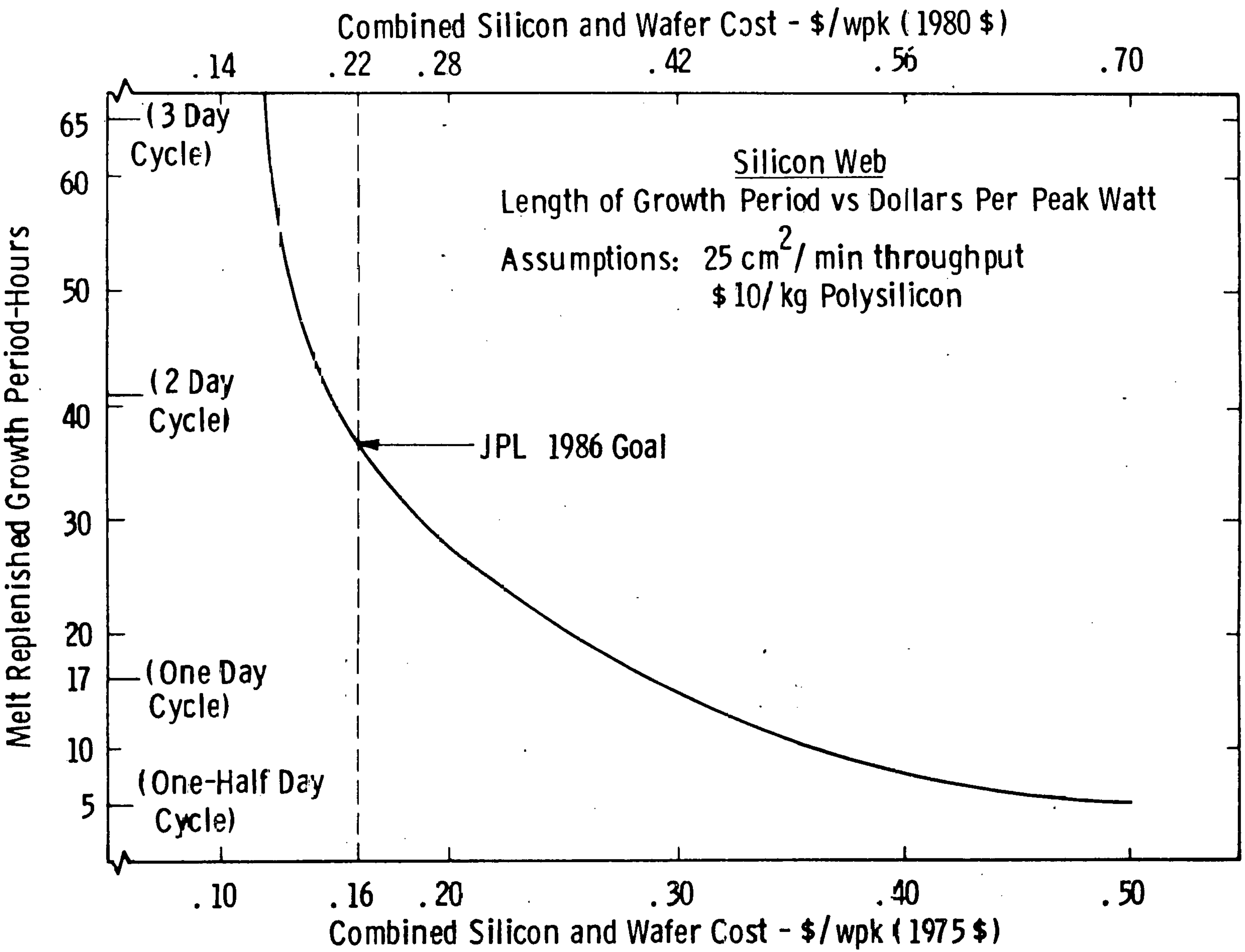


Figure 16 Variation in Web Wafer Cost (Including Polysilicon) with Replenished Growth Cycle Time

the actual time available for growth in a one day cycle is 24-7 = 17 hours. The growth period of a two day cycle would be 41 hours.

Including the key assumptions for this analysis, 25 cm^2/minute throughput rate and $10/kg polysilicon price, the economic analysis predicts that the silicon web process can produce wafers at a cost below the DOE/JPL 1986 goal.

3.4.2 Evaluation of Potentially Low Cost Alternative Power Supply

Because it offers important unique features, 10 kilohertz introduction heating is used with the silicon web process. Since its inception, 10 Khz induction heating for all applications has employed almost exclusively motor-generator rotating machines. As these machines are a substantial portion of the web growth capital cost, a lower cost alternative would, of course, be welcome. For this reason, we have evaluated the technical feasibility of using a solid state electronics high frequency generator developed by Westinghouse at its Defense Center.

A bread-board version of this generator, Figure 17, was connected to a silicon web furnace. In this figure the generator components are shown in the foreground mounted on a laboratory cart; the furnace and controller are visible in the background.

We found the solid state generator functioned well in the silicon web application. The quality of control and the web growth behavior were undistinguishable from the behavior normal with motor-generators. No effort has been made at this time to predict the cost of solid state units designed especially for web growth and produced in volume. Rough order of magnitude estimates of cost indicate that the solid state units would, at the worst, be competitive. We believe that cost of solid state generators should be thoroughly studied prior to any large scale installation of web growth furnaces.

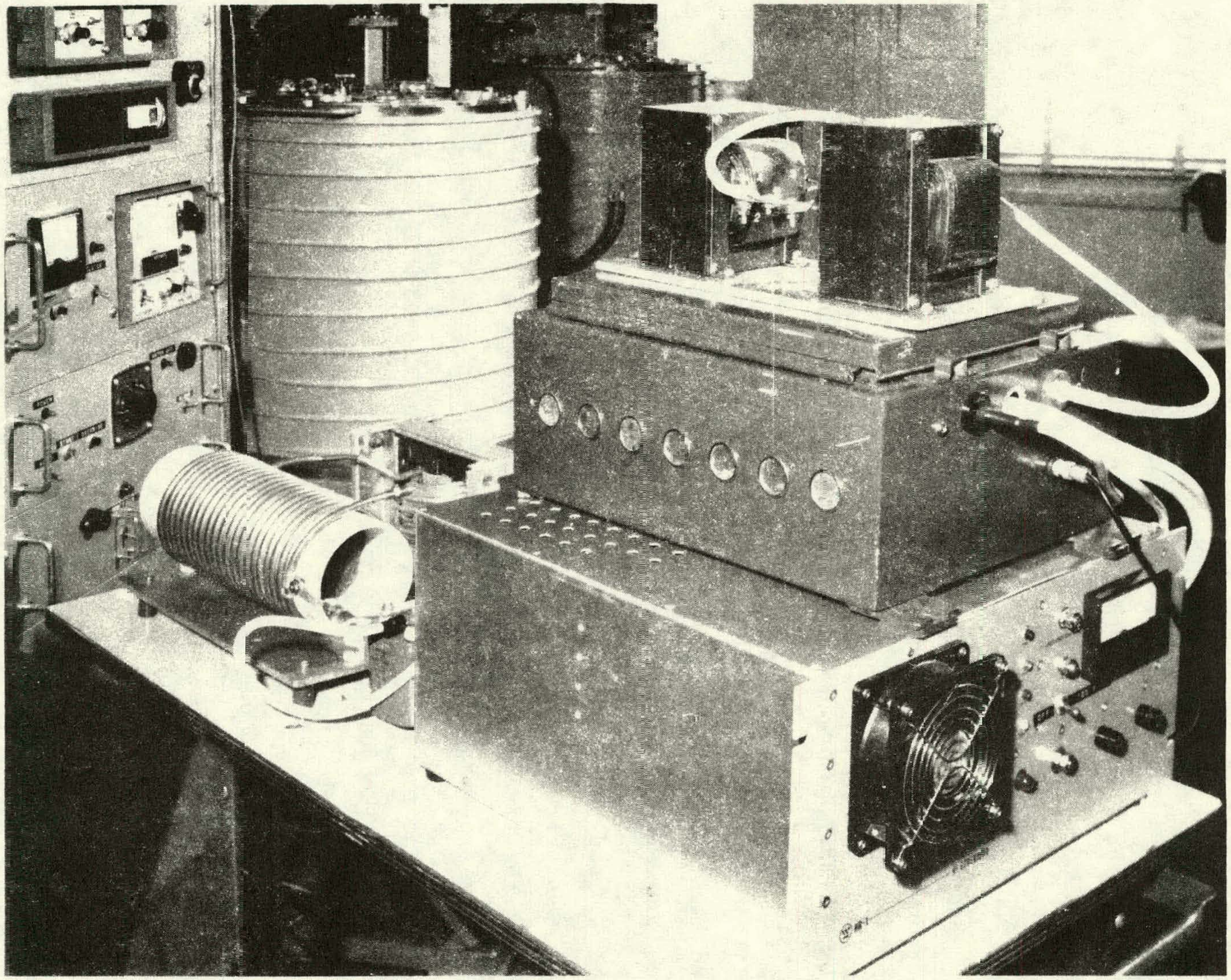


Figure 17 Components of a Solid State Electronic Low Frequency (10 kHz) Generator (foreground)

4. CONCLUSIONS

We have duplicated earlier results of extended web growth period with melt replenishment and increased the replenished growth period to nearly 5 1/2 hours. In the latter case the end of the work shift terminated the experiment. The results are encouraging and the conversion of a second web growth furnace to melt replenishment will be completed shortly. An update of the economic analysis indicates that diminishing returns set in with growth cycle times over 3 days. For sustained high output rate operation (25 cm^2/min) the DOE/JPL wafer cost goal could be met with approximately a two day growth cycle, assuming $10/kg silicon. The use of potentially lower cost solid state power sources is technically feasible and should be considered as along run cost reduction alternative.

5. FUTURE ACTIVITY

Further developments to extend the time period for replenished growth will be emphasized during the next quarter. Both the RE and J furnaces will be used to implement the work. The melt level sensor now under repair by the vendor will be tested and used for manual control of the feeding operation. Further optimization of parameters to control web width and output rate will continue.

6. NEW TECHNOLOGY

No new technology is reportable for the period covered.

7. REFERENCES

1. C. S. Duncan, et al., Annual Report Silicon Web Process Development, DOE/JPL-954654-79/2, April (1979).
2. C. S. Duncan, et al., Quarterly Report, Silicon Web Process Development, DOE/JPL-954654-79/9 October (1979).
3. C. S. Duncan et al., Quarterly Report, Silicon Web Process Development, DOE/JPL 954654-79/3 July (1979).

8. ACKNOWLEDGEMENTS

We would like to thank P. A. Piotrowski, H. C. Foust, E. P. A. Metz, W. B. Stickel, J. M. Polito, A. M. Stewart, J. P. Fello, and C. H. Lynn for their contributions to the web growth studies and P. Rai-Choudhury, R. B. Campbell, E. J. Seman, J. B. McNally, W. Cifone, D. N. Schmidt, and H. F. Abt for the processing and testing of the web solar cells.

9. APPENDICES

Appendix 9.1 Growth Run Summaries

All melt replenishment experiments were performed in the RE furnace. Studies designed primarily to enhance web width were conducted in the J-furnace. The major activities in the WA furnace were studies to optimize web growth velocity for high output rate operation.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	MAX. VELOCITY (cm/min)	DESCRIPTION/RESULT
J-216	2	401	33.5	3.3	J-181 modification with added shield, Total 4, upper two slitted. Overhang of lower formed shield increased by 1mm. V-T data. Easy growth initiation, stable growth. Oxide forced termination of growth.
J-217	4	427	22.6	3.3	J-216 modified by bringing shield stack 1.5mm closer to lid. V-T data. Oxide problems.
J-218	Not productive of web				Lid and shield configuration shown in Figure 2. modified by adding two additional top shields in effort to improve growth behavior. Oxide accomulated in slot growing from bottom edge of folded over (lower) shield.
J-219	3	482	36.7	3.3	Same lid as J-218, but the J-181 shield stack, upper two slitted was used. Oxide deposition minimal, able to grow most of day, although early starts (high melt) were poly.
J-220	4	494	36.2	3.3	Repeat J-219 configuration. Very similar growth behavior.
J-221	No significant web production				Test RE-1 configuration with top shield slitted to provide cooler view to web. V-T data indicated this configuration faster than others tested, but oxide deposition and icing prevented any significant web growth.
J-222	No significant web production				Modification of J-218 in attempt to alter convective gas flow patterns. J-181 shield stack placed directly on full formed shield. Excessive oxide build up prevented growth.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	MAX. VELOCITY (cm/min)	DESCRIPTION/RESULT
J-223	4	367	30.7	3.3	Test of the 4 shield J-181 mod., with stack condensed by spacing between shields at 0.5mm instead of 1.5mm. T-V data. Generally stable growth. Oxide deposited on lower shield.
J-224	2	439	36.0	1.7	Repeat J-223. Good growth, except for oxide deposition on lower shield.
J-225	2	170	17.3	3.3	Test J-218 lid. Gap between formed shield and lid lip increased in effort to reduce oxide build up. Three full top shields, upper two slitted. Early crystals poly, oxide growth on lower shield, falling into melt.
J-226	1	93	21.7	2.7	Repeat J-225 with the additon of alumina barriers between lid and lower shield in effort to change gas flow and reduce oxide accumulation. Not successful., oxide, poor growth.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	MAX. VELOCITY (cm/min)	DESCRIPTION/RESULT
J-227	2	∼ 200	-	3.3	Four shield modification of J-181 with compressed shield spacings. 1.5mm between lid and formed shield, 0.5mm between rest. Top two shields slitted. Oxide grew rapidly from edge of formed shield forcing premature termination of growth. Thickness velocity data.
J-228	1	147	-	5.0	Repeat J-227 except a solid barrier was used as spacer between lid and formed shield in attempt to inhibit gas flow. Oxide still grew from lower shield, inhibiting growth and forcing early termination. Grew 105 cm at constant 5 cm/min. before crystal terminated by oxide growth.
J-229	4	360	23.8	3.3	Test J-98B configuration for widening characteristics and thickness-velocity behavior. Crystals picked up ice particles and degenerated. Ice caused by oxide spalling from bottom of lid.
J-230	No significant crystal production.				Repeat J-229, with extra care with lid preparation. Similar ice problems.
J-231	3	225	25.9	5.0	Repeat J-228 configuration. Oxide growth from lower shield inhibited growth. Overall growth behavior poor. V-T data.
J-232	3	280	26.8	3.3	Repeat J-228 except overhang of lower top shield decreased. Growth behavior poor, even though oxide less.
J-233	2	253	19.1	1.8	J-98B (short slot) configuration. Test for width control. Feed hole plugged. Lid upside down to present different surface to melt in effort to control spalling. Ice in afternoon, due to spalling.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	MAX. VELOCITY (cm/min)	DESCRIPTION/RESULT
J-234	3	437	28.4		Modify J-228 configuration using 0.5mm barriers instead of washers as spacers between shields. Better growth. Oxide growth on right end limited growth duration to about 1.5 hours per crystal. T-V data.
J-235	Not productive of web crystals.				Modification of J-234, in which lid is ported on lower edge around periphery, in effort to modify convective gas flow and oxide deposition. Oxide deposition and ice formation prevented growth.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	MAX. VELOCITY (cm/min)	DESCRIPTION/RESULT
J-236	2	172	22.7	2.0	Test J98B configuration with new lid. Partial lower shield. Growth hampered all day by ice fronts moving in from left.
J-237	No significant web growth				Test new thin lid. 3mm thick, RE-1 slot geometry, RE-1 lower shield + 3 J-181 shields, upper two slitted. Fast growth configuration, but floating ice prevented significant web growth.
J-238	1	82	14.7	2.4	Repeat J-237, except narrower slot in lower shield in effort to make lid slot hotter. Severe and rapid oxide accumulation in slot prevented significant growth.
J-239	No significant web growth				3mm thick lid with 3 full top shields. T-V data. Rapid oxide deposition along slot inhibited growth.
J-240	1	126	-	-	J-181 configuration. Repeated ice nucleation prevented growth. Post-mortem showed heavy spalling on bottom of lid.
J-241	1	325	39.7	1.9	Repeat J-240. Ice particles in morning. Good growth during afternoon.
J-242	No significant growth				Repeat J-240. Ice nucleation all day prevented growth.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	DESCRIPTION/RESULT
RE198	Nonproductive			J-181 lid with melted bottom; solid end shield; barrier made with 2mm rod and microscope slide. Ice occurred several times; other times poor starts led to polycrystalline growth.
RE199	5	414	19.6	J-181 lid for feeding, solid end shield. The run purpose was to determine whether ice occurred without feeding; it did. However after the run it was seen that the feed chamber was empty, which made the presence of ice inconclusive.
RE-200	4	438		J-181 feed lid and shields; no barrier. Run purpose again was to determine whether ice occurred without feeding. Several specks of ice were picked up.
RE201	Nonproductive			Repeat set up of RE-200 to verify problem. Again ice was a problem, preventing crystal growth.
RE202	Nonproductive			J-181 lid and shields used from J-furnace. This was done to eliminate the feed lid as the cause of the ice problems.
RE203	1	109		J-181 lid and shields. Ice was not a problem. Before this run the furnace was leak tested and several leaks were repaired.
RE204	1	172	22.9	Repeat of RE-203 to verify results. Ice was not a problem.
RE205	Nonproductive			J-181 feed lid and shields. Ice was a problem from a leak in the pellet feeder.
RE206	2	210	18.9	J-181 feed lid. Ice was a problem; there was strong evidence of spalling.
RE207	2	335	39.0	J-181 feed lid arrangement. A misalignment of the feed tube prevented replenishment experiments. One speck of ice occurred, but did no damage to the crystal which picked it up.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	DESCRIPTION/RESULT
RE208	Nonproductive			J-181 feed lid, straight feed tube. The barrier end of the crucible was reworked-this may have caused the problem of an emptv feed chamber.
RE209	Nonproductive			J-181 feed lid, straight feed tube. Again the feed chamber was empty.
RE210	Nonproductive			J-181 feed lid and shields. Ice was a problem; suspect particulate blow over from between shields.
RE211	Nonproductive			J-181 feed lid and shields. A piece of molbydenum tubing was placed on the lid around the feed hole to try to prevent ice.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	DESCRIPTION/RESULT
RE212	Nonproductive of Web			First run with movable end shield. Run purpose was primarily for measurement of effects of various shield positions.
RE213	2	359	29.7	J-181 feed set-up, low barrier in crucible, movable end shield. The end of the feed tube was below the level of the top shield and was quickly blocked with oxide. This prevented melt replenishment.
RE214	Nonproductive of Web			J-181 feed set up. The run purpose was to measure temperatures along the slot with various end shield positions using Ircon.
RE215	Nonproductive of Web			J-181 feed set up. Pellet feeding was done with end shield not in shielding position. As a result, the feed chamber froze and the run was ended.
RE216	2	257		J-181 feed arrangement. The run purpose was to make thermal measurements in melt and in susceptor at various end shield positions.
RE217	3	473	35.6	J-181 lid and shields, not a feed run.
RE218	2	175	-	J-181 feed lid arrangement. Thermal measurements of the melt were made with varied end shield positions.
RE219	Nonproductive of Web			J-181 feed lid arrangement.
RE220	Nonproductive of Web			J-181 feed lid arrangement. Thermal measurements were recorded as end shield position and feed rates were varied.
RE221	1	115	20.5	J-181 feed arrangement, high barrier in crucible, movable end shield. When argon was blown through the feed tube, ice occurred both with and without feeding. When this flow was stopped there were no ice problems.

GROWTH RUN SUMMARY

RUN	NO. OF CRYSTALS	LENGTH (cm)	MAX. WIDTH (mm)	DESCRIPTION/RESULT
RE-222	3	417		J-181 feed lid and shields; barriers between shields, movable end shield. About 1 1/2 hr. successful feeding was achieved before a failure in the feeder occured
RE-223	Nonproductive of Web			Set up like RE-222. The feed chamber did not wet, resulting in a poor thermal situation and preventing successful feed experiments.
RE-224	3	246		Set up like RE222. Again the feed chamber did not wet.
RE-225	2	233		J-181 feed lid and shields with laser holdes; movable end shield. Feeding was done for 1 hr. at a 2 pellet/min rate; the rate was then increased, freezing the feed chamber.
RE-226	Nonproductive of Web			Same set-up as in RE-225, shield in a lower position. Several hours of feeding were achieved as short crystals were grown. A source of ice was seen to be oxide on the web guides. The web rubbed oxide off the guides, dropping it into the melt where it nucleated ice. This contributed to the absence of long crystals.
RE-227	1	136	26.1	J-181 feed lid and shields with laser holes; fixed solid end shield; high barrier. Fed at 2 pellets/min for over 4 1/2 hours with no feed related problems. Several crystal starts were made during this period.
RE-228	5	536	21.4	Set up of RE227. Fed at 4 pellets/min for 5 hr 20 min.

GROWTH RUN SUMMARY

RUN	MAX. WIDTH (mm)	TOTAL LENGTH (cm)	DESCRIPTION/RESULT
WA-21	3.20	281	Running a 30° beveled lid with J-181 top shields to get thickness—velocity profile. Had some difficulty with polycrystalline growth early in the run. This run is to repeat WA-17.
WA-22	3.50	307	Repeating WA-17 to get thickness velocity data. First run using the new solid state generator. Furnace was clean and free of oxide.
WA-23	Not Productive of Web		Repeating WA-17 to get additional thickness velocity data. Run was shut down early when web fell in melt and caused freeze out.
WA-24	Not Productive of Web		Repeating WA-17 to get thickness—velocity data. Had problems with polycrystalline growth throughout the run. New operator was being trained to run.
WA25	Not Productive of Web		Repeating WA-17 with first shield lowered 1/16" to cut down on view between lid and web. This run had difficulty with oxide and icing. New operator was being trained.
WA26	Run Aborted		Run was terminated during melt down when the generator malfunctioned.
WA27	3.30	256	Repeating WA-17 with first shield lowered 1/16". Oxide and ice formation were again a problem but some data was obtained.
WA28	3.45	293	Repeating WA-25 and WA-26 to get additional thickness—velocity data. New operator had some difficulty growing but data was obtained.
WA29	Not Productive of Web		Repeating WA-25 to obtain additional thickness velocity data. Oxide and icing problems limited growth but some data was obtained.

GROWTH RUN SUMMARY

RUN	MAX. WIDTH (mm)	TOTAL LENGTH (cm)	DESCRIPTION/RESULT
WA-30	3.65	324	Using J-181 configuration to obtain thickness velocity data for comparison with WA-17 configuration. This run was clean and free of oxide.
WA-31	No run		Problems were incurred during meltdown and the run was terminated. Susceptor was damaged by silicon and had to be replaced.

GROWTH RUN SUMMARY

RUN	MAX. WIDTH (mm)	TOTAL LENGTH (cm)	DESCRIPTION/RESULT
WA-32	215	260	The purpose of this run was to obtain thickness-velocity data for the open configuration, with a 30° bevel, shown in Figure 1. This run had difficulties with polygrowth but some data was obtained.
WA-33	Not Productive of Web		This run was to repeat WA-32 to obtain additional T-V data. Silicon dewet a portion of the crucible during this run, resulting in polygrowth throughout the run. This run will be repeated.
WA-34	265	310	This was a repeat of WA-32. Growth during this run was relatively good and T-V data was obtainable. These preliminary results show that the open configurations has significant effects on improving thickness at relatively high growth speeds.
WA-35	310	290	Repeating WA-32 for additional T-V data. This run was good and T-V data was obtained. The results correlated with those for the previous run and preliminary findings were supported. More work at higher speed should be performed with this configuration.
WA-36	Not Productive of Web		This run involved the use of an overlapping shield on the 30° beveled lid as shown in Figure 2. Icing from the right side of the crucible was a continual problem during this run and no T-V data could be obtained.
WA-37	Not Productive of Web		Repeat WA-36 to obtain T-V data for new lid-shield configuration. This run had recurring problems with oxide on the shields and with poly growth. This run will be repeated.
WA-38	Not Productive of Web		Repeating WA-36, this run again had problems with oxide and poly growth throughout the day. This run will be repeated. No evidence of crucible dewetting was found and the source of poly growth is not clear.
WA-39	Not Productive of Web		Repeating WA-36, problems were again associated with oxide formation and with poly. growth in particular. A J-181 configuration will be run to help isolate the source of poly growth. Malfunctions in the temperature control system may be contributing to this problem.

GROWTH RUN SUMMARY

RUN	MAX. WIDTH (mm)	TOTAL LENGTH (cm)	DESCRIPTION/RESULT
WA-40	Not Productive of Web		This is a baseline J-181 configuration for furnace shakedown tests. This run was unsuccessful because of temperature instability in the furnace. The controller appears to be malfunctioning.
WA-41	Not Productive of Web		This is a repeat of the J-181 baseline run. Temperature controller problems prevented long term growth. Some material was grown that was not polycrystalline, but only in short lengths. This run was not conclusive and will be repeated.
W-42	Not Productive of Web		Repeating the J-131 baseline configuration. Reseting and adjusting the temperature controller system did not correct the temperature stability problems. More checking of the controller must be performed.
WA-43	Not Productive of Web		This is another repeat of the J-181 baseline run. The source of temperature instability is still not clear. Growth was still unsuccessful because of this problem.
WA-44	Not Productive of Web		This objective of this run is to try and isolate the source of temperature instability within the control network. Adjustments were made to attempt to improve stability, but were not successful.
WA-45	Not Productive of Web		This run is to further isolate temperature control problems within the control system. Adjustments to the controller have not corrected the problem. The coil itself appeared to move during this run and may be effecting temperature stability.

APPENDIX 9.2

AVERAGED SOLAR CELL DATA FOR WEB CRYSTALS

The tables in this appendix give the averaged solar cell performance for cells fabricated from the crystals listed. Each entry in the table represents the average value for approximately four cells. Measurement conditions were a simulation of an AM1 illumination at a power density of 91.6 mW/cm^2 as determined by a standardized solar cell. The cells were nominally 10x10 mm square (actual area 1.032 cm^2), and had an active area of about 92.5%. The cell efficiency with an anti-reflective coating η_{AR}, is an estimated value based on an average improvement factor of 1.43, typical of the results we obtain in practice with a TiO_2-SiO_2 coating.

SUMMARY OF DIAGNOSTIC SOLAR CELL DATA

J-, RE-, and W- CRYSTALS

Crystal	Run	I_{sc} mA	V_{OC} Volt	FF	η_o %	η_{AR} %	τ_{OCD} μs	ρ Ω-cm	NOTES
J190-1.3	WQ44	21.8	.571	.780	10.2	14.6	7.3	2.9	
J208-1.4	WQ41	22.5	.528	.743	9.3	13.3	5.1	9.6	
J209-2.4	WQ41	20.1	.535	.747	8.5	12.2	1.0	3.1	
J210-3.6	WQ41	20.9	.521	.737	8.5	12.2	1.0	8.3	
J212-2.5	WQ45	20.2	.532	.759	8.6	12.3	2.0	8.5	
J223-3.3	WQ45	20.5	.529	.732	8.4	12.0	2.0	9.8	
J223-4.6	WQ45	20.6	.529	.763	8.8	12.6	2.2	10.5	
RE 91-2.3	WQ39	22.1	.563	.760	10.0	14.3	2.4	7.0	
RE108-3.3	WQ39	20.7	.533	.745	8.7	12.4	3.4	9.4	
RE207-2.3	WQ45	20.0	.531	.748	8.4	12.0	1.9	8.9	
W180-1.3	WQ45	18.2	.587	.793	8.9	12.8	1.1	.25	Battelle Si
W185-1.4	WQ45	11.5	.594	.791	5.7	8.2	1.5	.02	Heavily Doped
W186-1.6	WQ45	20.7	.553	.767	9.3	13.3	7.8	5.1	

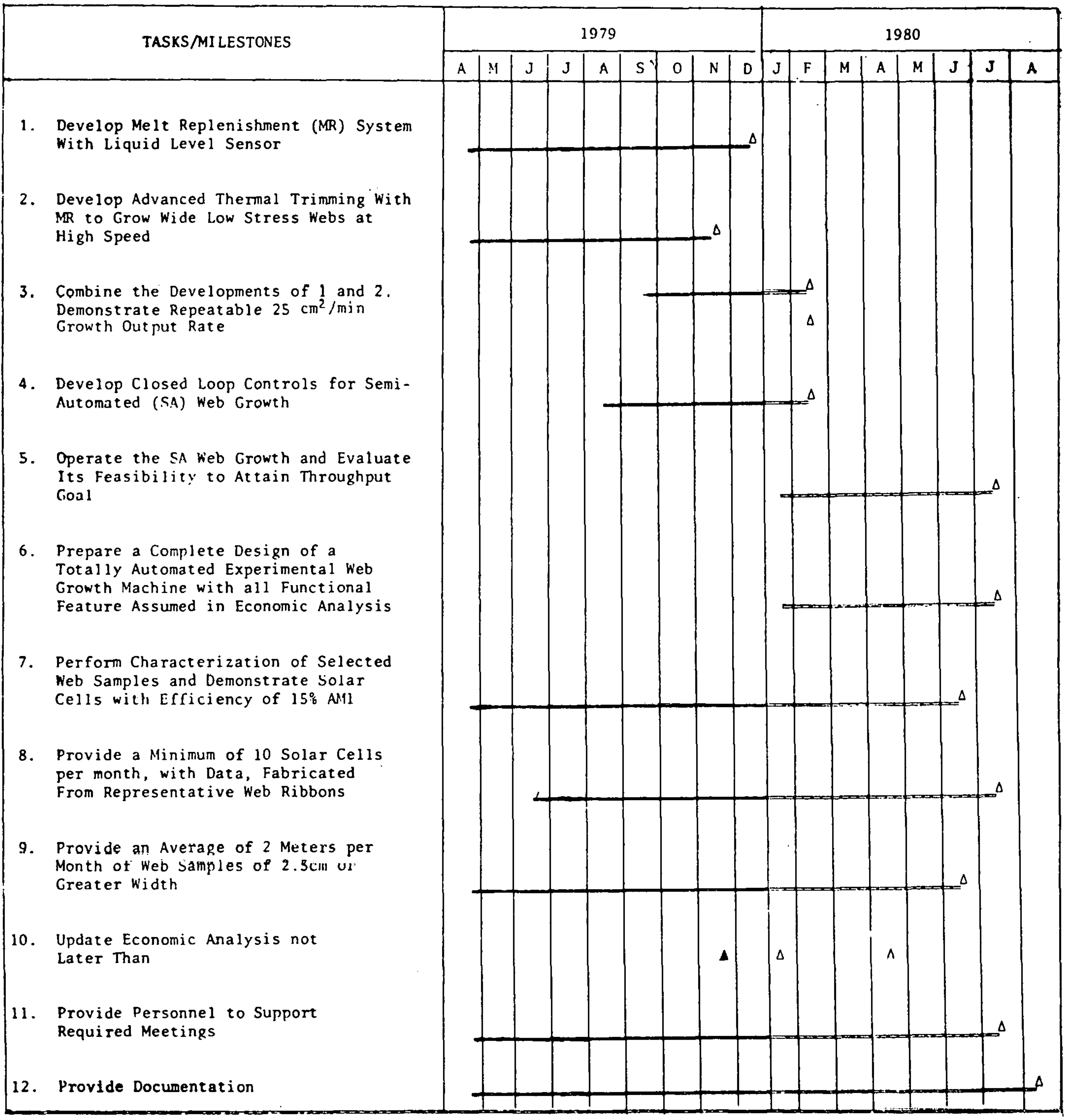
Appendix 9.3 Updated Program Plan

9.3.1

MILESTONE CHART

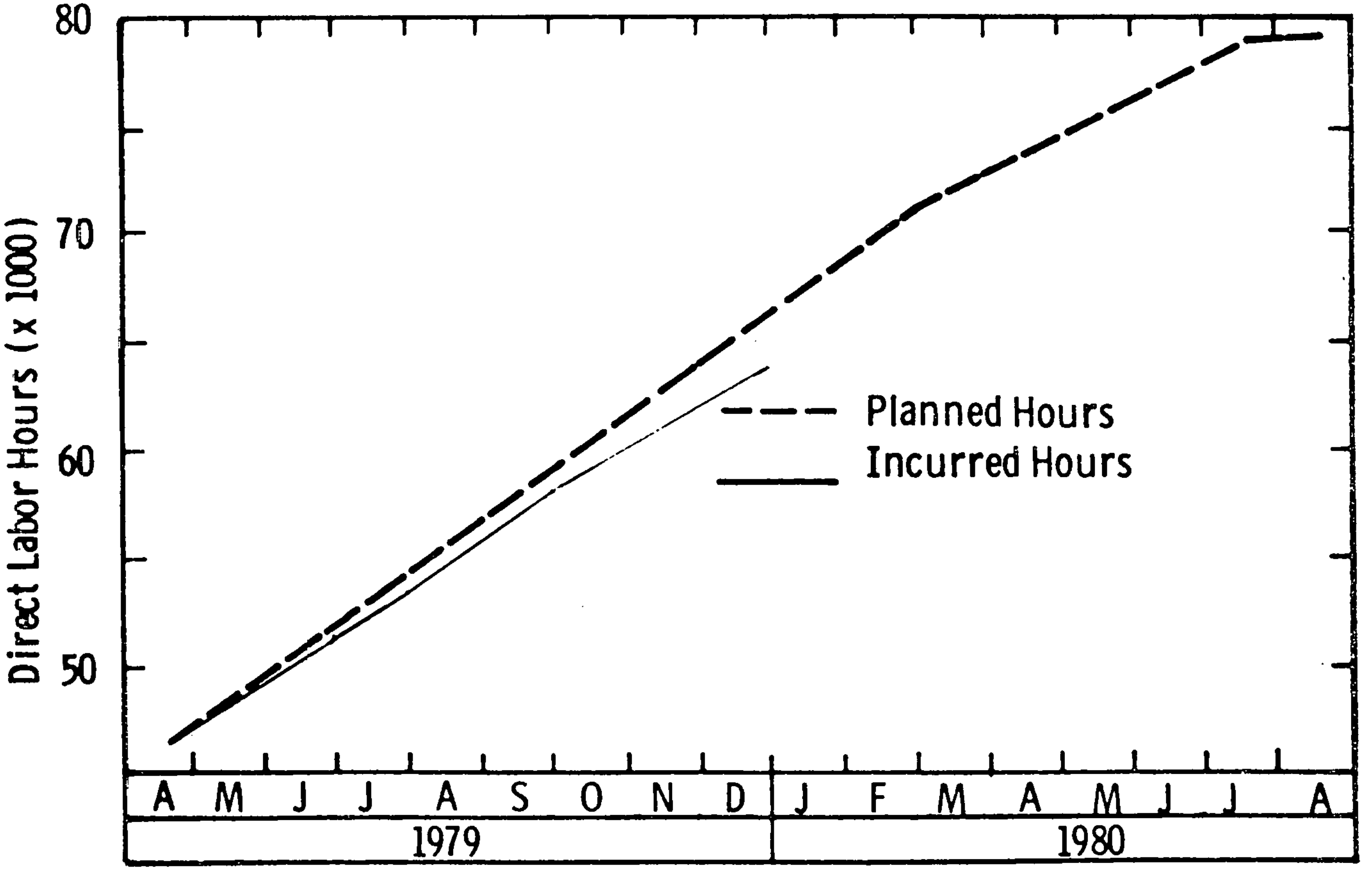
JPL CONTRACT 954654

PHASE III

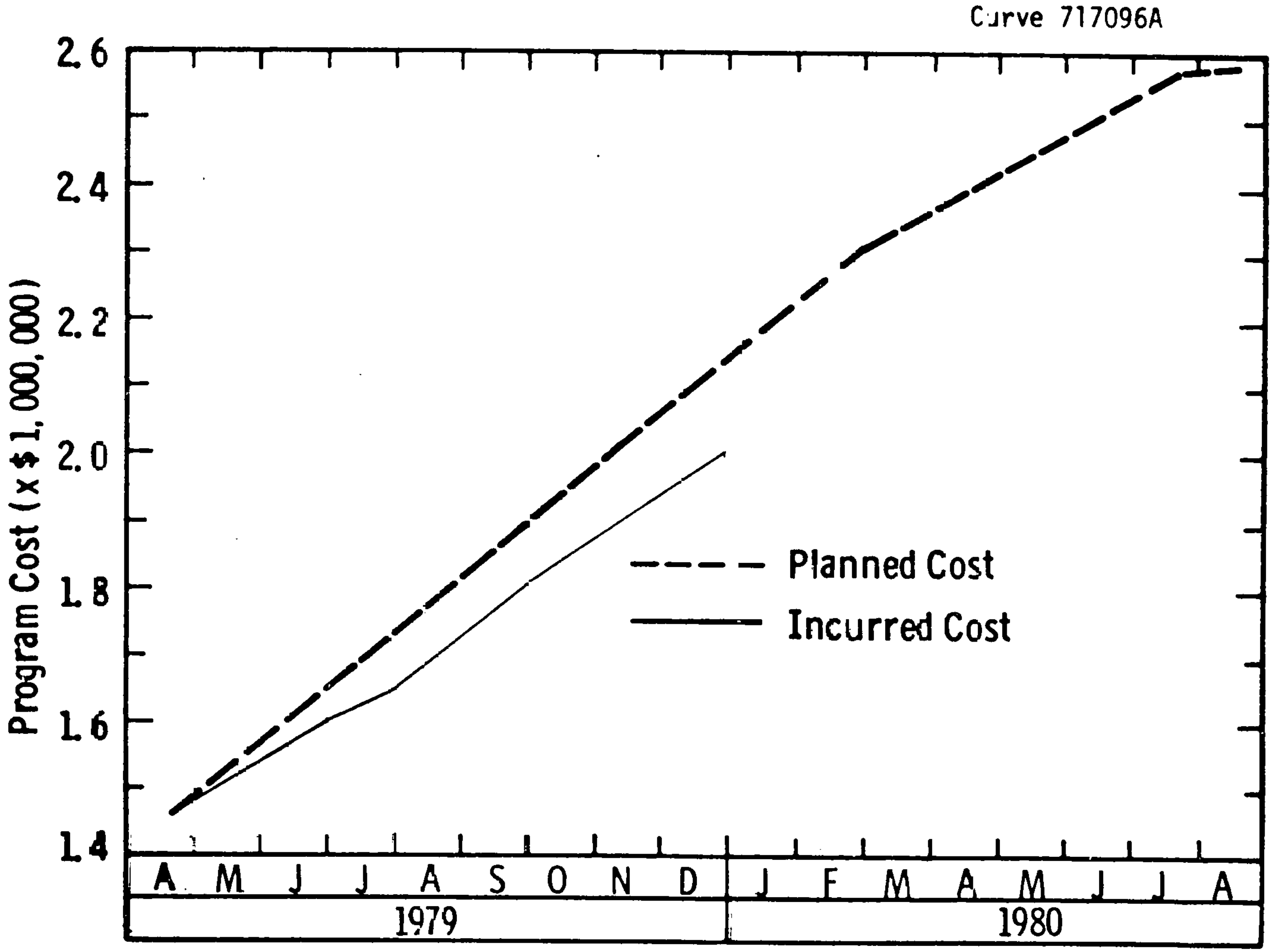


1. Develop Melt Replenishment (MR) System With Liquid Level Sensor
2. Develop Advanced Thermal Trimming With MR to Grow Wide Low Stress Webs at High Speed
3. Combine the Developments of 1 and 2. Demonstrate Repeatable 25 cm^2/min Growth Output Rate
4. Develop Closed Loop Controls for Semi-Automated (SA) Web Growth
5. Operate the SA Web Growth and Evaluate Its Feasibility to Attain Throughput Goal
6. Prepare a Complete Design of a Totally Automated Experimental Web Growth Machine with all Functional Feature Assumed in Economic Analysis
7. Perform Characterization of Selected Web Samples and Demonstrate Solar Cells with Efficiency of 15% AM1
8. Provide a Minimum of 10 Solar Cells per month, with Data, Fabricated From Representative Web Ribbons
9. Provide an Average of 2 Meters per Month of Web Samples of 2.5cm or Greater Width
10. Update Economic Analysis not Later Than
11. Provide Personnel to Support Required Meetings
12. Provide Documentation

Curve 717097A



9.3.2 Program Labor Summary JPL 954654, Phase III



9.3.3 Program Cost Summary JPL 954654, Phase III

Appendix 9.4 Engineering Drawings

ROUTING						
FIREPROOF VAULT						

DRAWING LIST

NDEX	LINE	TITLE OF DRAWING	DRAWING NO.	~~[illegible]~~ ← REV.	ITEMS OR STYLE NO.	CHECKED	DATE CHECKED
	1	ASSEMBLY	639F587	1			
	2	TOP COVER PLATE	8532D72	1			
	3	BOTTOM COVER PLATE	8532D73	1			
	4	DETAILS	8532D74	1			
	5	HOUSING	2624C99	1			
	6	GUIDE	2625C01	1			
	7	DOOR SUB-ASS'Y	1710B69	1			
	8						
	9						
	10						
	11						
	12						
	13						
	14						
	15						
	16						
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	18						
	19						
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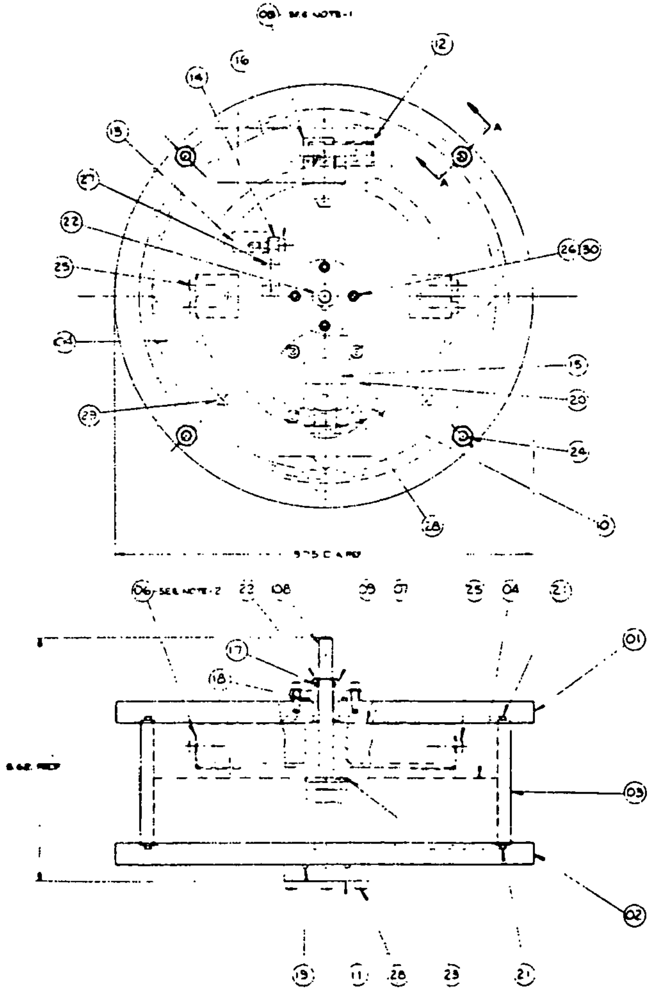
	24						
	25						
	26						
	27						
	28						
	29						

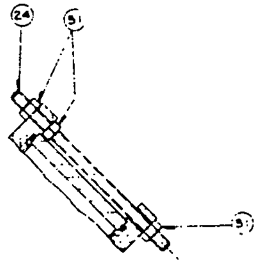
OCK ORDER (1ST S.O. ON WHICH INF. HAS BEEN SENT TO SHOP)

IDENTIFYING DATA: IN SPECIFYING THIS D NO. ON A STOCK ORDER THE ENGINEER MUST GIVE: -

ME OF APPARATUS: "J" FURNACE PELLET FEEDER

IECKED BY AND DATE					
SIGN SPEC. D 903149	SUB. LETTER	SUB. LETTER	SUB. LETTER	SUB. LETTER	SUB. LETTER
STINGHOUSE FORM 6541 J — PAGE 1 OF 1	SUB. LETTER	SUB. LETTER	SUB-LETTER	SUB. LETTER	SUB. LETTER





SECTION A-A
SCALE-1:1

'U' FURNACE PELLET FEEDER
ASSEMBLY
639F587

01		TOP COVER PL			[illegible]	1
02		BOTTOM COVER PL			[illegible]	1
03		HOUSING			[illegible]	1
04		GUIDE	DWG		[illegible]	2
05		DOOR SUB-ASSY	DWG		[illegible]	1
06		COVER	DWG		[illegible]	1
07		CAN	DWG		[illegible]	1
08		SHAFT	DWG		[illegible]	1
09		BUSHING	DWG		[illegible]	1
10		WINDOW HOUSING	DWG		[illegible]	1
11		FLANGE	DWG		[illegible]	1
12		CAM BRACKET	DWG		[illegible]	1
13		WIPER	DWG		[illegible]	1
14		WIPER BRACKET	DWG		[illegible]	1
15	A	WINDOW		.740 DIA × .125 THK GLASS		1
16	B	SHOULDER SCREW	BJS	CAT NO 4417		1
17	C	O RING	BJS	[illegible] CAT NO 2-105		1
18	C	O RING	BJS	[illegible] CAT NO 2-117		1
19	C	O RING	BJS	[illegible] CAT NO 2-119		1
20	C	O RING	BJS	[illegible] CAT NO 2-127		2
21	C	O RING	BJS	[illegible] CAT NO 2-172		2
22	D	RETAINING RING	BJS	EXTERNAL SERIES CAT NO [illegible]		1
23	E	ROLL PIN	BJS	[illegible] CAT NO 55-022-094-300		1
24		ALL THREAD		.250-20 × 3.25 LG ST	659W-[illegible]	4
25		MACH SCREW		#4-32 × .38 LG [illegible]		6
26		MACH SCREW		#4-32 × .62 LG [illegible]		4
27		MACH SCREW		#4-32 × .62 LG [illegible]		2
28		MACH SCREW		.190-32 × .62 LG SOC [illegible]		8
29		MACH SCREW		.190-32 × .75 LG [illegible]		2
30		LOCK WASHER		NO 8 [illegible]		4
31		NUT		.250-20 HEX ST		2

A-SUPPLIED BY ENGINEER
B-PIC DESIGN A BENRUS DIV 6842 VAN NUYS BLVD., VAN NUYS, CALIF 91405
C-PARKER SEAL CO. 10567 JEFFERSON BLVD CULVER CITY CALIF 90230.
D-WALDES KOHINOOR INC 47-16 AUSTEL PLACE LONG ISLAND CITY NY 11101.
E-ELASTIC STOP NUT DIV AMERACE ESNA CORP 2330 VAUXHALL ROAD
UNION, N.J 07085

NOTES:
1- 1 THRU 4 REQD DEPENDING UPON NUMBER OF PELLETS REQD PER CYCLE
2- 0 THRU 3 REQD. DEPENDING UPON NUMBER OF PELLETS REQD PER CYCLE.

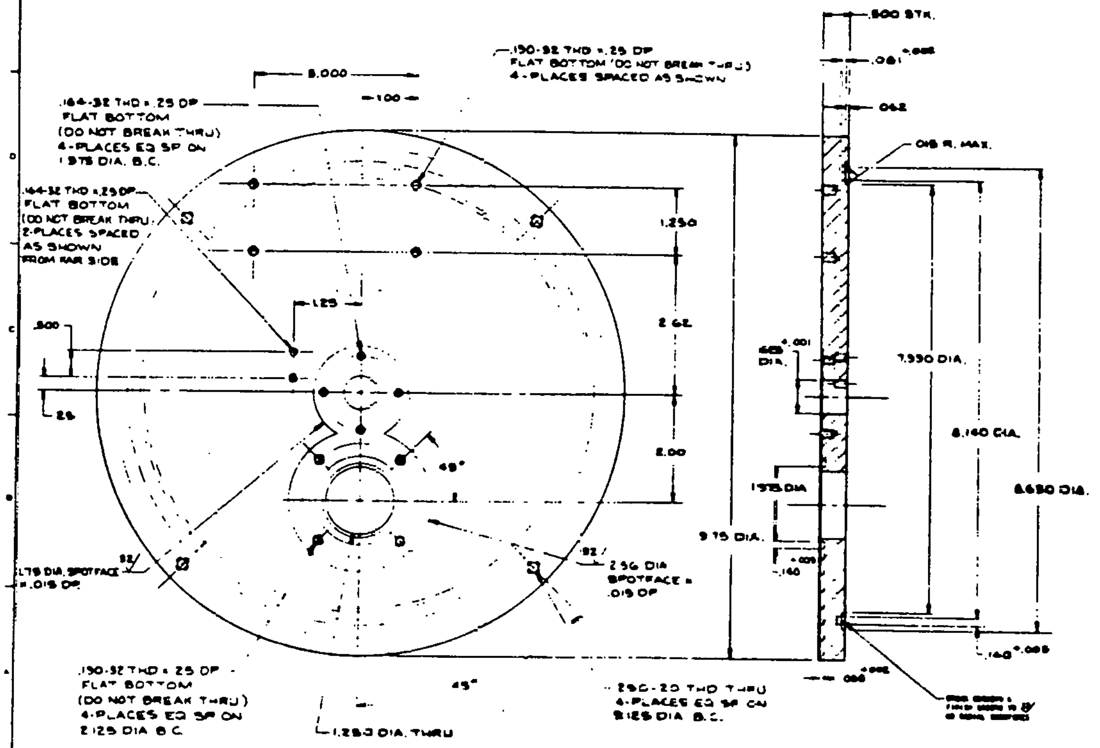
Westinghouse Electric Corporation

'U' FURNACE PELLET FEEDER
ASSEMBLY

639F587

TITLE J FURNACE PELLET FEEDER
TOP COVER PLATE DETAIL
8532D72

01		COVER PLATE		10.03 x 10.03 x .900 THK AL PL.	8403-0101	-7631	1



Westinghouse Electric Corporation

TITLE J FURNACE PELLET FEEDER
TOP COVER PLATE DETAIL
REV 1

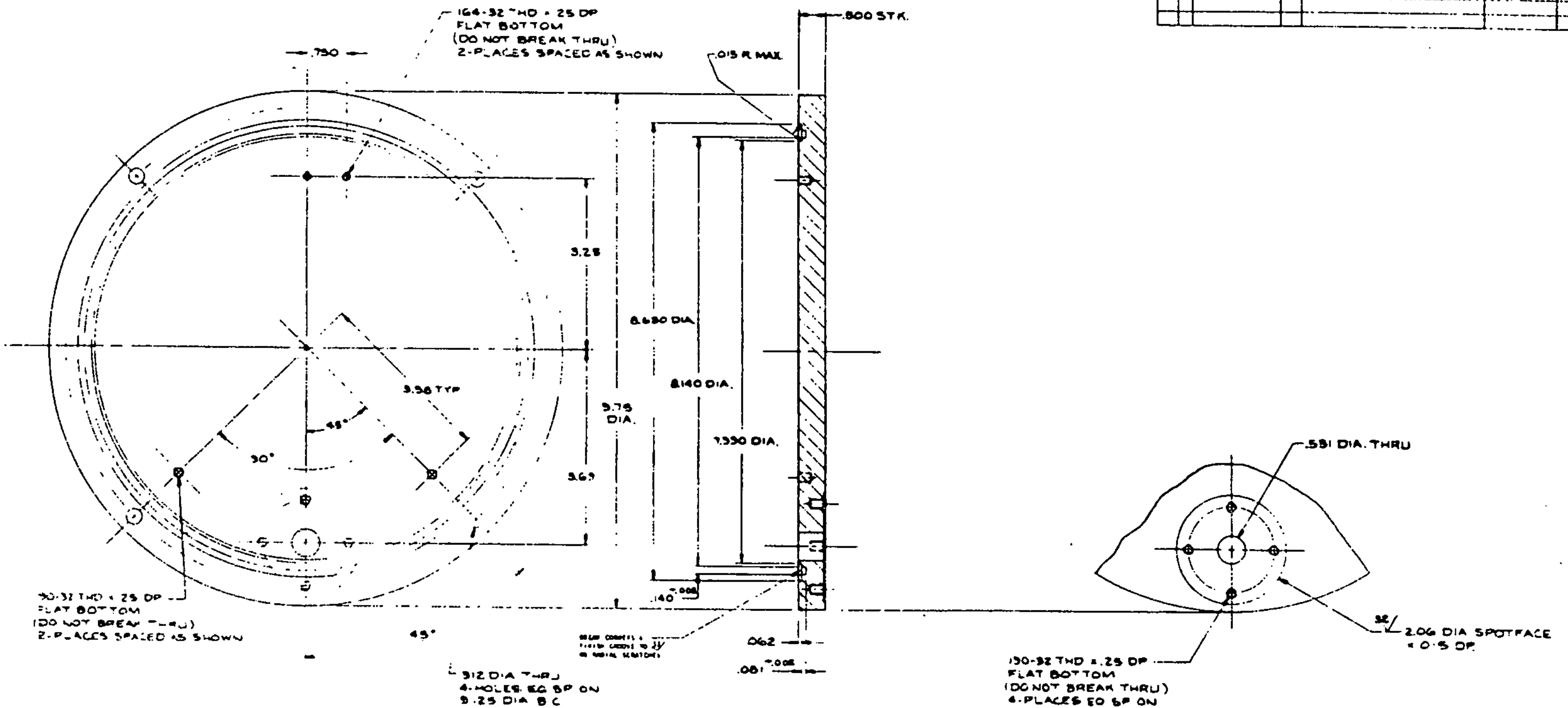
8532D72

639F567

903149

TITLE "J" FURNACE PELLET FEEDER
BOTTOM COVER PLATE DETAIL
DWG 8532D73 REV 1

ITEM		PART NAME		REFERENCE INFORMATION	REC STOCK NO		GROUP				
01		COVER PLATE		10.00 × 10.00 SF .500 THK. AL PL	8603-0101	6061-T651	1				

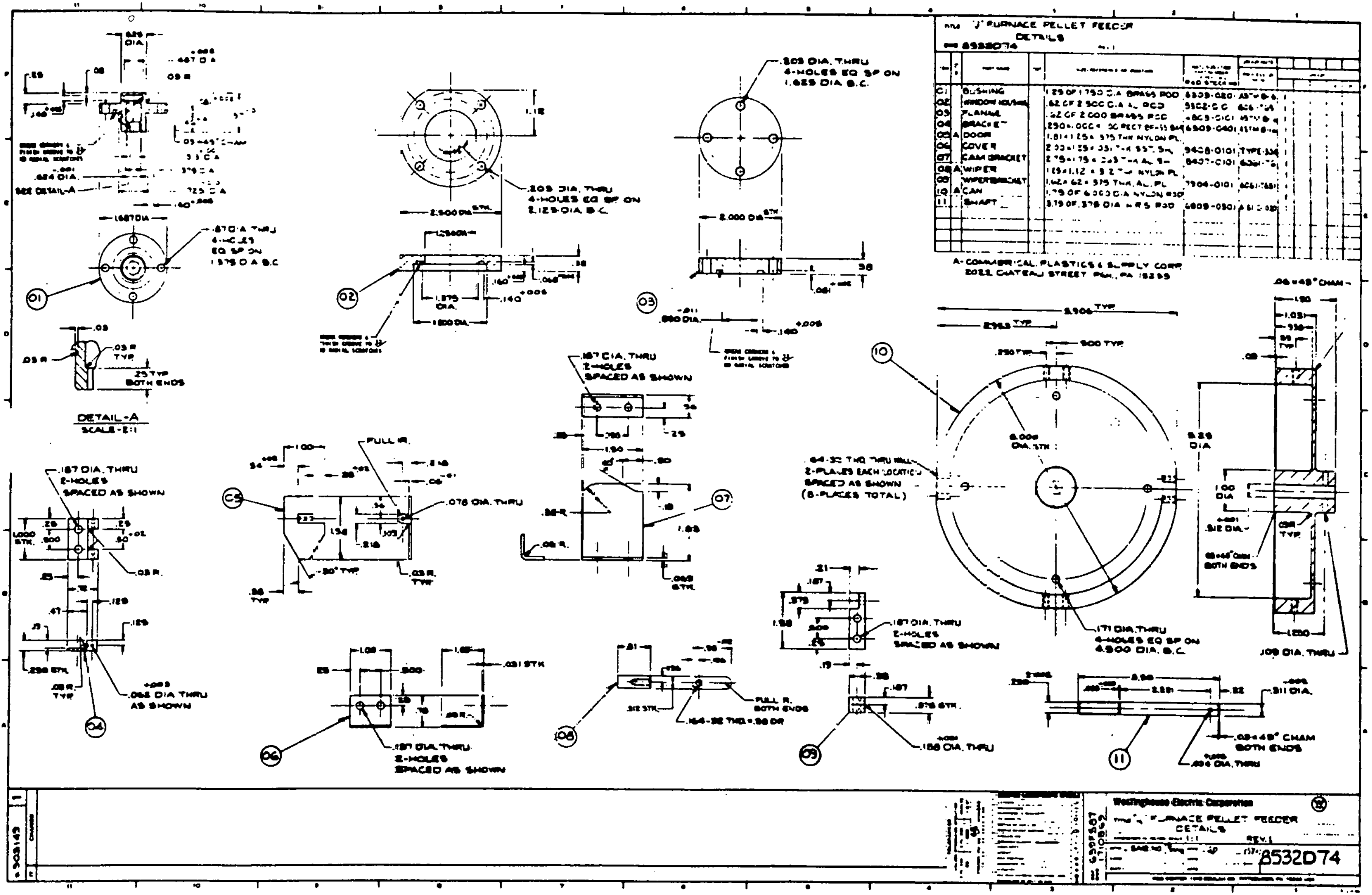


639F587

Westinghouse Electric Corporation

"J" FURNACE PELLET FEEDER
BOTTOM COVER PLATE DETAIL
REV 1

8532D73



"J" FURNACE PELLET FEEDER
DETAILS
8532D74

01		BUSHING	1.25 OF 1.750 DIA BRASS ROD	6809-0201	ASTM B-16
02		WINDOW HOUSING	.62 OF 2.500 DIA AL ROD	5502-0101	6061-T6
03		FLANGE	.62 OF 2.000 DIA BRASS ROD	6809-0101	ASTM B-16
04		BRACKET	.250 x .066 x ... RECT BRASS BAR	6809-0401	ASTM B-16
05	A	DOOR	1.81 x 1.25 x .375 THK NYLON PL		
06		COVER	2.00 x 1.25 x .031 THK SST SH	9408-0101	TYPE 304
07		CAM BRACKET	2.75 x 1.75 x .063 THK AL SH	8407-0101	6061-T6
08	A	WIPER	1.25 x 1.12 x .312 THK NYLON PL		
09		WIPER BRACKET	1.62 x .62 x .375 THK AL PL	7904-0101	6061-T651
10	A	CAM	.75 OF 6.000 DIA NYLON ROD		
11		SHAFT	3.75 OF .375 DIA HRS ROD	6809-0301	AISI C-1020

A- COMMERCIAL PLASTICS & SUPPLY CORP.
2022 CHATEAU STREET PGH., PA 15233

Westinghouse Electric Corporation

"J" FURNACE PELLET FEEDER
DETAILS

1:1
REV. 1

8532D74

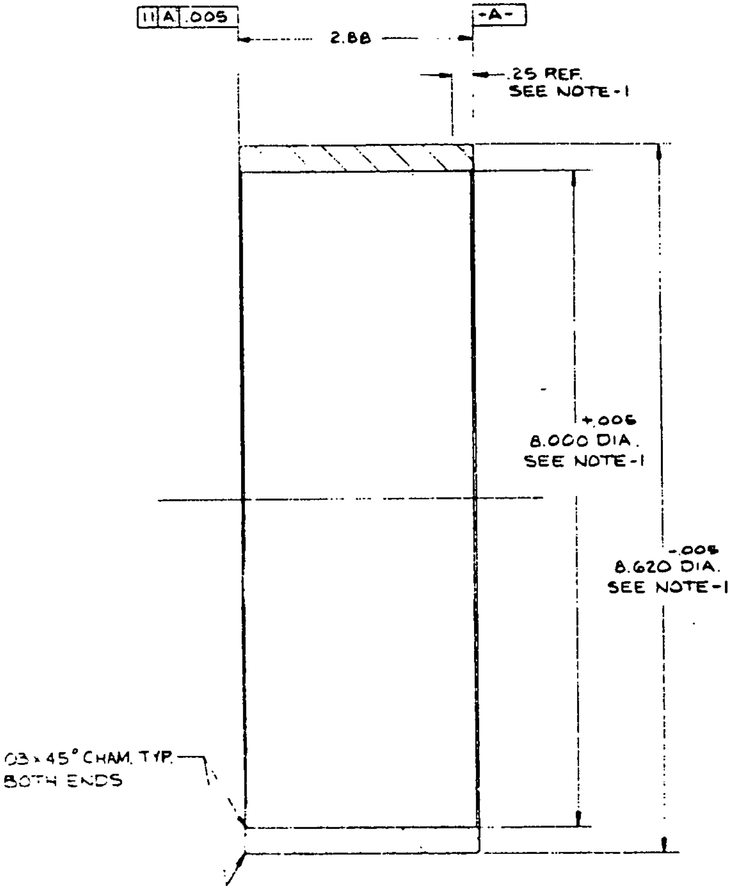
6305F507
170862

TITLE "J" FURNACE PELLET FEEDER
HOUSING DETAIL
DWG 2624C99
REV 1

ITEM	NOTE	PART NAME	QTY	SIZE REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	HOUSING	8.05	3.25 OF 8.00 SCH.40 AL. PIPE *6063-T6 (8.625 OD x .322 WALL)		ASTM B-241	1				

A-WILLIAMS & CO. INC., PGH., PA. 15233.

NOTES:
1- MACHINE BOTH ENDS TO DIMENSIONS AS NOTED APPROX .25 DEEP.



GEOMETRIC CHARACTERISTIC SYMBOLS

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE 3 UNLESS OTHERWISE SPECIFIED

REF. DWG. 699F587

Westinghouse Electric Corporation

TITLE "J" FURNACE PELLET FEEDER
HOUSING DETAIL

SCALE 1:1
REV.1

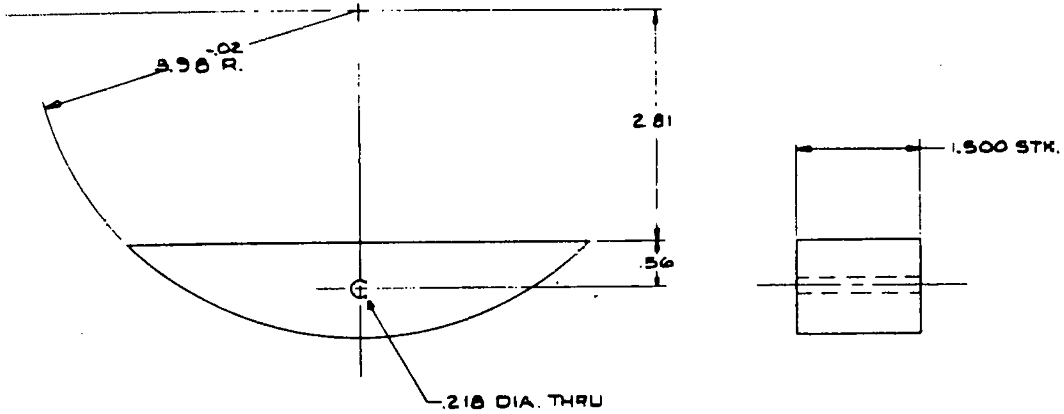
DRN J.SABINO
DWG NO 2624C99

TITLE "J" FURNACE PELLET FEEDER
GUIDE DETAIL

DWG 2625C01 REV 1

ITEM	NOTE	PART NAME	DEF	[illegible] REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01	A	GUIDE		6.50 x 1.50 OF 1.500 THK. NYLON PL			1				

A-COMMERICAL PLASTICS & SUPPLY CORP.
2022 CHATEAU STREET PGH., PA. 15233.



Westinghouse Electric Corporation

TITLE "J" FURNACE PELLET FEEDER
GUIDE DETAIL

DIMENSIONS IN INCHES SCALE 1:1 REV. 1

DFTR J. SABINO APPD CSD

2625C01

REF DWG 639F587

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

IRSD CENTER 1310 BEULAH RD PITTSBURGH, PA 15235 USA

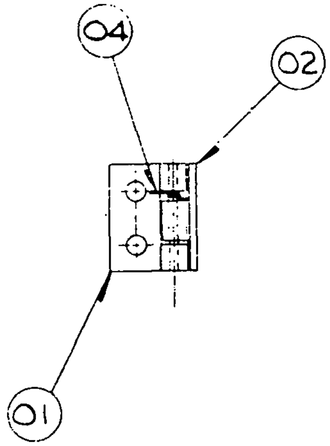
D 305149

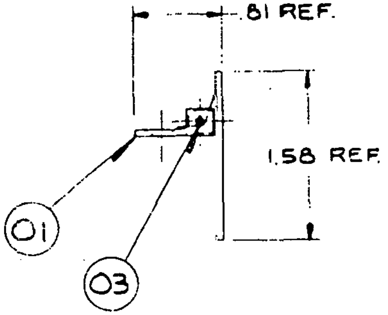
CHANGE

TITLE 'J" FURNACE PELLET FEEDER
DOOR SUB-ASSEMBLY
DWG 1710B69 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		BRACKET	DWG		8532D74H04		1				
02		DOOR	DWG		8532D74H05		1				
03	A	ROLL PIN	BOS	.062 DIA. x 1.00 LG CAT. NR. 59-012	-062-1000		1				
04	B	SPRING					1				

A-ELASTIC STOP NUT DIV. AMERACE ESNA CORP.
2330 VAUXHALL ROAD, UNION, N.J. 07083
B-SUPPLIED BY ENGINEER.





D 903149
1
CHANGE

TOLERANCES
UNLESS OTHERWISE SPECIFIED
2 PL. DEC ±.02
3 PL. DEC ±.005
ANGLES ±0.5°

FINISH TO BE √ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS
FLATNESS
STRAIGHTNESS
ROUNDNESS (CIRCULARITY)
CYLINDRICITY
PROFILE OF ANY LINE
PROFILE OF ANY SURFACE
PARALLELISM
PERPENDICULARITY (SQUARENESS)
ANGULARITY
RUNOUT
TRUE POSITION
CONCENTRICITY
SYMMETRY
MAXIMUM MATERIAL CONDITION (MMC)
REGARDLESS OF FEATURE SIZE

REF DWG 639F587

Westinghouse Electric Corporation

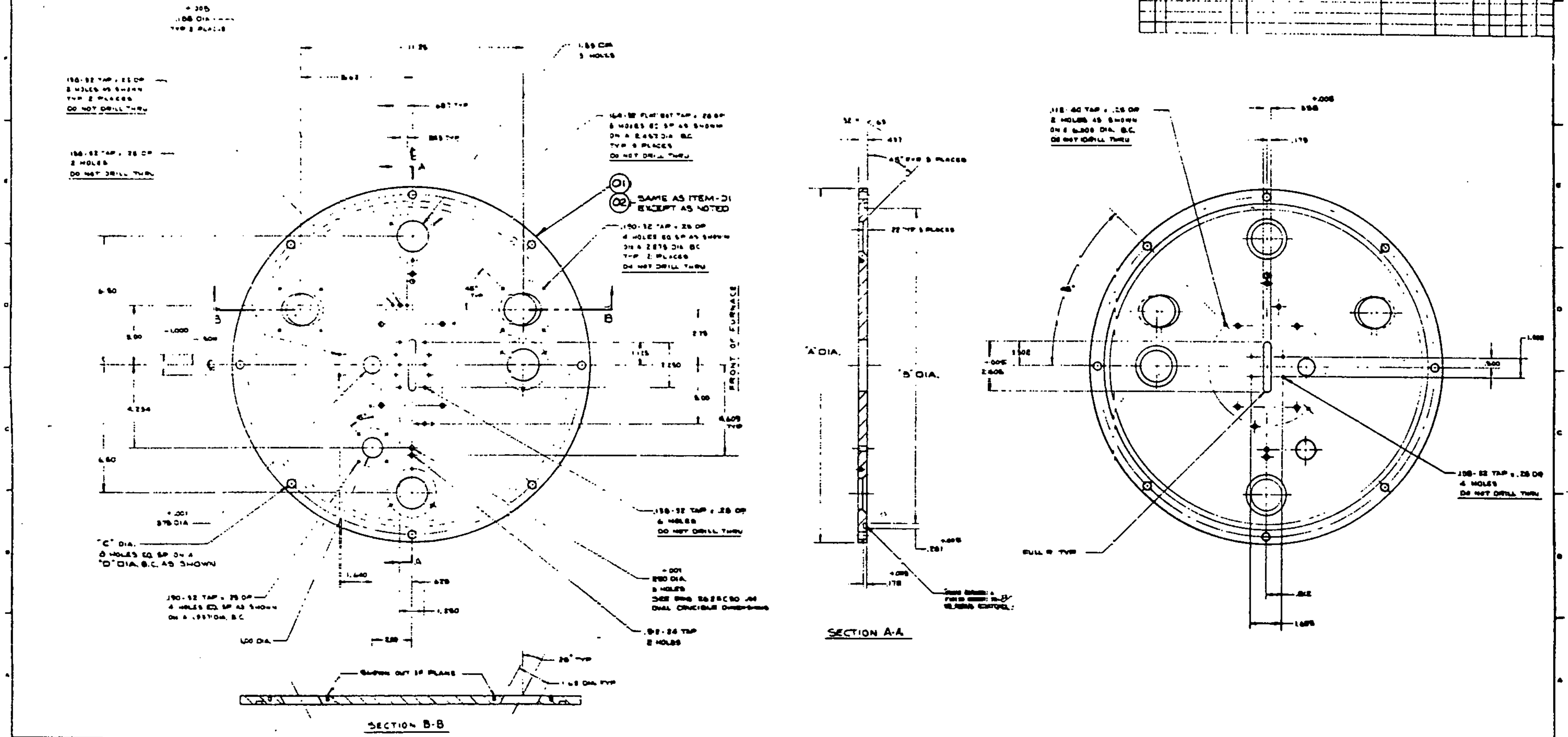
TITLE "J" FURNACE PELLET FEEDER
DOOR SUB-ASSEMBLY
DIMENSIONS IN INCHES—SCALE 1:1 REV. 1
DFTM J. SABINO 12/26/72 APPD JD 1/1/73
CHKD APPD
SUPV APPD
1710B69

RESEARCH LABORATORIES CHURCHILL BORO, PITTSBURGH PA 15235 U.S.A.

TITLE SILICON WEB FURNACE (R6)
TOP COVER PLATE DET

ITEM		PART NAME										
01		TOP COVER PL.		18.75 DIA OF .62 THK. SST 304	7875-0101							
02		TOP COVER PL.		18.12 DIA OF .62 THK. SST 304	7803-0101							

	ITEM	"A" DIA	"B" DIA	"C" DIA	"D" DIA B.C.
FURNACE (R6)	01	18.00	16.935	.406	17.250
FURNACE (J)	02	18.00	16.935	.406	16.125



Westinghouse Electric Corporation
TITLE SILICON WEB FURNACE (R6)
TOP COVER PLATE DET
1:2
639F576