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ABSTRACT

An analysis of the grapple drive stem temperature during operation of the IVTM (In-Vessel Transfer Machine) indicates that the maximum stem wall temperature at the seals will be 270°F when the system is at dynamic thermal equilibrium. If the transfer operation is initiated with the grapple drive stem initially at thermal equilibrium in the lowered position, a pre-cooling step will be required if the maximum temperature of the grapple drive stem wall at the seals is to be limited to 300°F.

This report supercedes and cancels TI-097-241-007, Rev. A, and TI-097-241-009.

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I. INTRODUCTION

The results of an analysis of the maximum grapple drive stem temperature at the grapple drive stem reciprocating seals during fuel transfer operation of the In-Vessel Transfer Machine (IVTM) are presented.

This report supercedes and cancels TI-097-241-007, Rev. A, and TI-097-241-009. The results given in the latter documents have been found to be invalid.

II. SYSTEM DESCRIPTION AND ASSUMPTIONS

Figure 1 shows the in-vessel section assembly of the IVTM. The vertical travel of the grapple drive stem, which is shown in the lowered position, is such that the part of the grapple drive stem that is immersed in the hot sodium pool when in the lowered position, reaches to within a foot of the grapple drive stem reciprocating seals located in the seal housing at the upper end of the support body and shielding structure. Of concern, due to the temperature limitation of the seals, is the maximum grapple drive stem temperature seen by the reciprocating seals during fuel transfer operation.

The dimensions of the IVTM given in Ref. 1, were used in the analysis.

The following assumptions were made in the analysis:

1. Ambient temperature = 80°F
2. Sodium pool temperature = 500°F
3. Cover gas = Argon
4. Emissivity of stainless steel = 0.3
5. Vertical travel of grapple drive stem = 18 Ft
6. Grapple drive stem speed = See Fig. 3
7. The Fuel Transfer Port wall and the Ring Adapter temperature remains constant during the fuel transfer operation and is assumed to be as shown by the solid curve in Fig. 2. It can be seen by comparing this assumed temperature distribution for the top shield during operation and shutdown, respectively, shown by the dashed curves in Fig. 2, that the assumed temperature distribution for the Fuel Transfer Port wall and Ring Adapter is that which should approximately prevail very shortly after shutdown.

8. The fuel transfer operation is that in which there is no waiting between each fuel transfer cycle for execution of a fuel handling cycle. This approach yields a conservative result of the grapple stem temperature reciprocating through the seals.

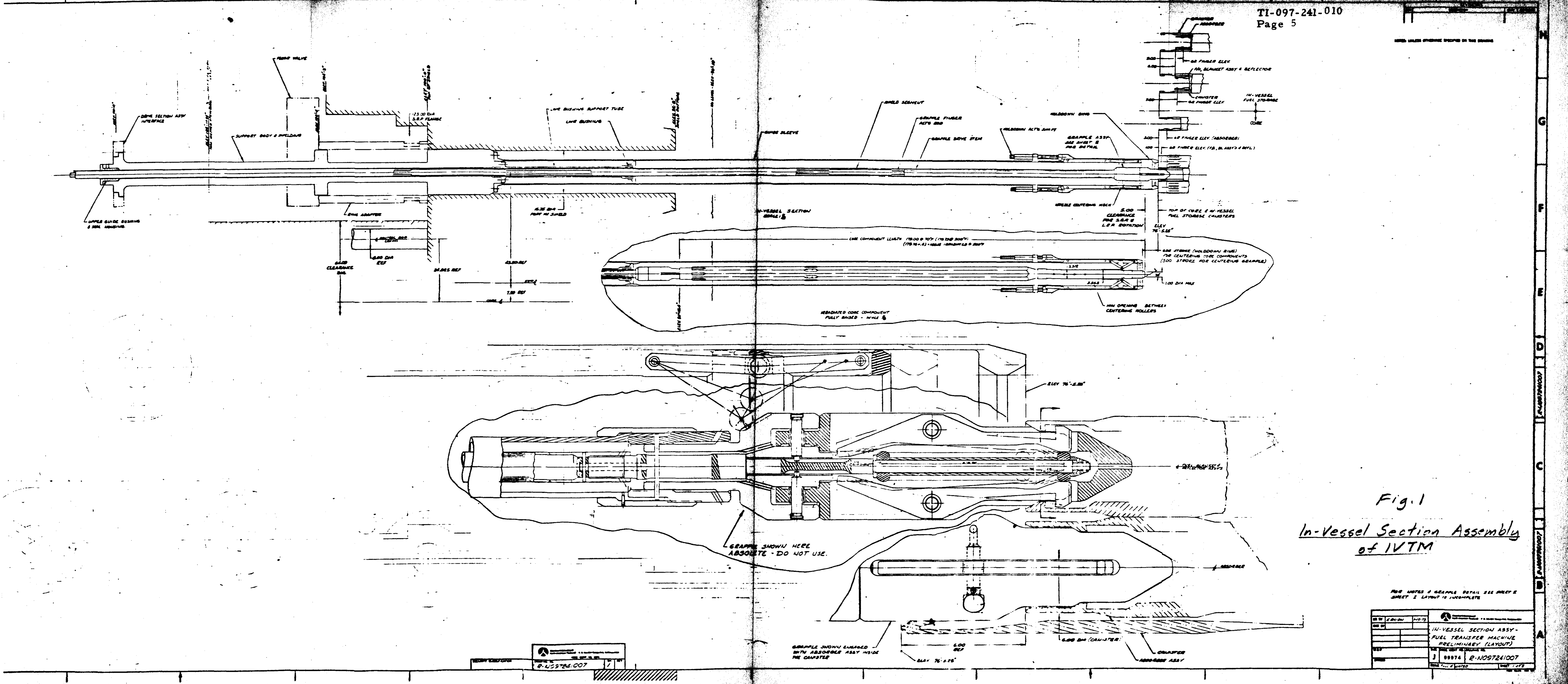


Fig. 1

In-Vessel Section Assembly of IVTM

Fig. 2

Assumed Fuel Transfer Port Wall and Ring Adapter Temperature During Fuel Transfer Operation

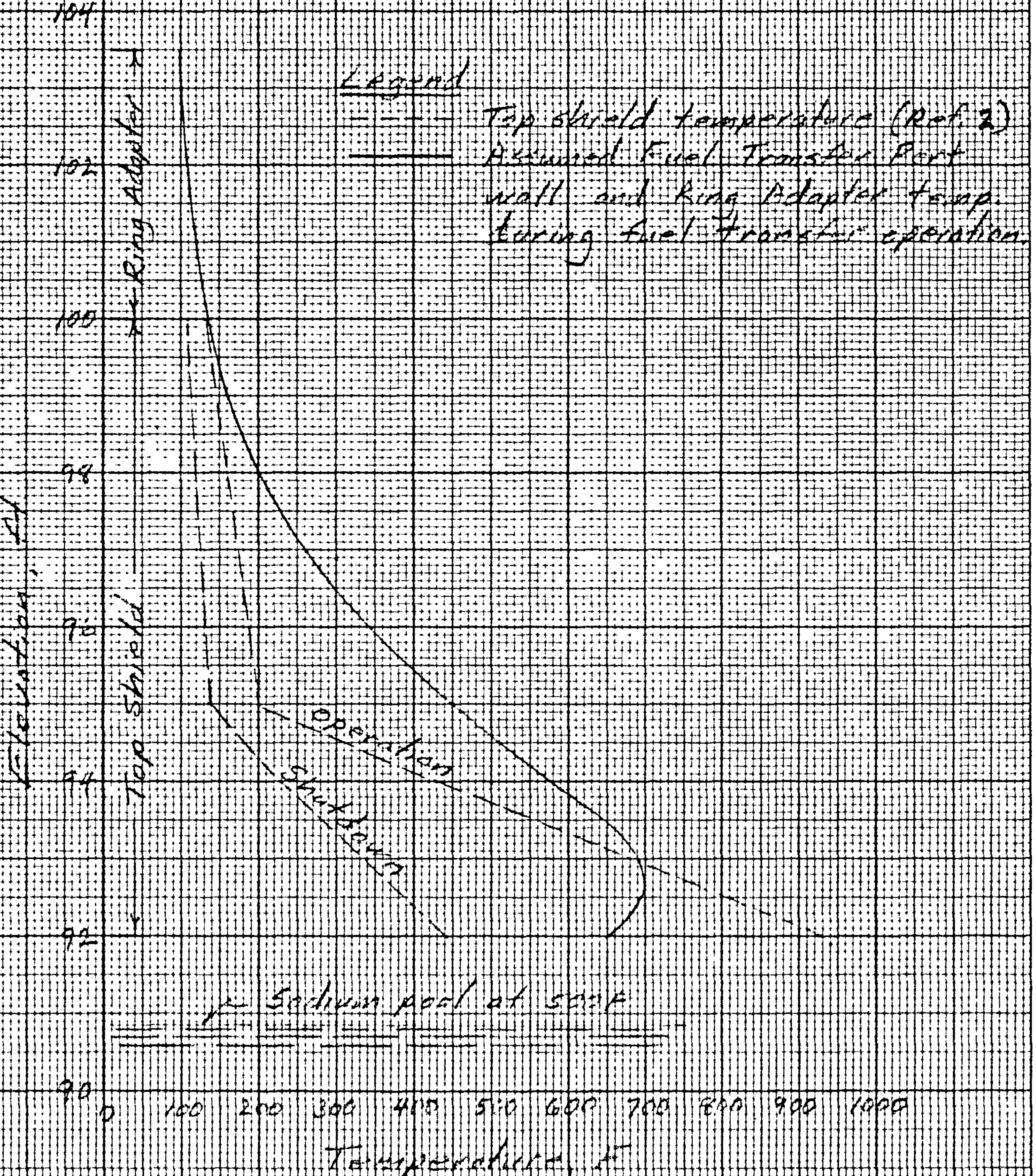


Figure 3 shows the fuel transfer cycle and the assumed time (in seconds) required to complete each step (Ref's. 3 and 4).

III. METHOD OF CALCULATION

Computer Program DEAP (Ref. 5) was used. To simulate the grapple drive stem motion, the moving boundary concept was employed in the formulation of the heat transfer network (Appendix A). The validity of this method of calculation was checked by applying it to the configuration and cycle of the IVTM Seal and Bushing Test. Comparison of computed temperatures with measured temperatures indicates that valid results are obtained by this method of calculation (Appendix B). (The method of calculation employed in superseded reports TI-097-241-007, Rev. A, and TI-097-241-009, differed in that the grapple drive stem motion was simulated by making the nodes in the grapple drive stem flow nodes. In this method, the boundary condition at the upper end of the stem cannot be simulated exactly in this problem. The approximation used for the boundary condition at the upper end of the stem was apparently inadequate or inappropriate, inasmuch as invalid results were obtained.)

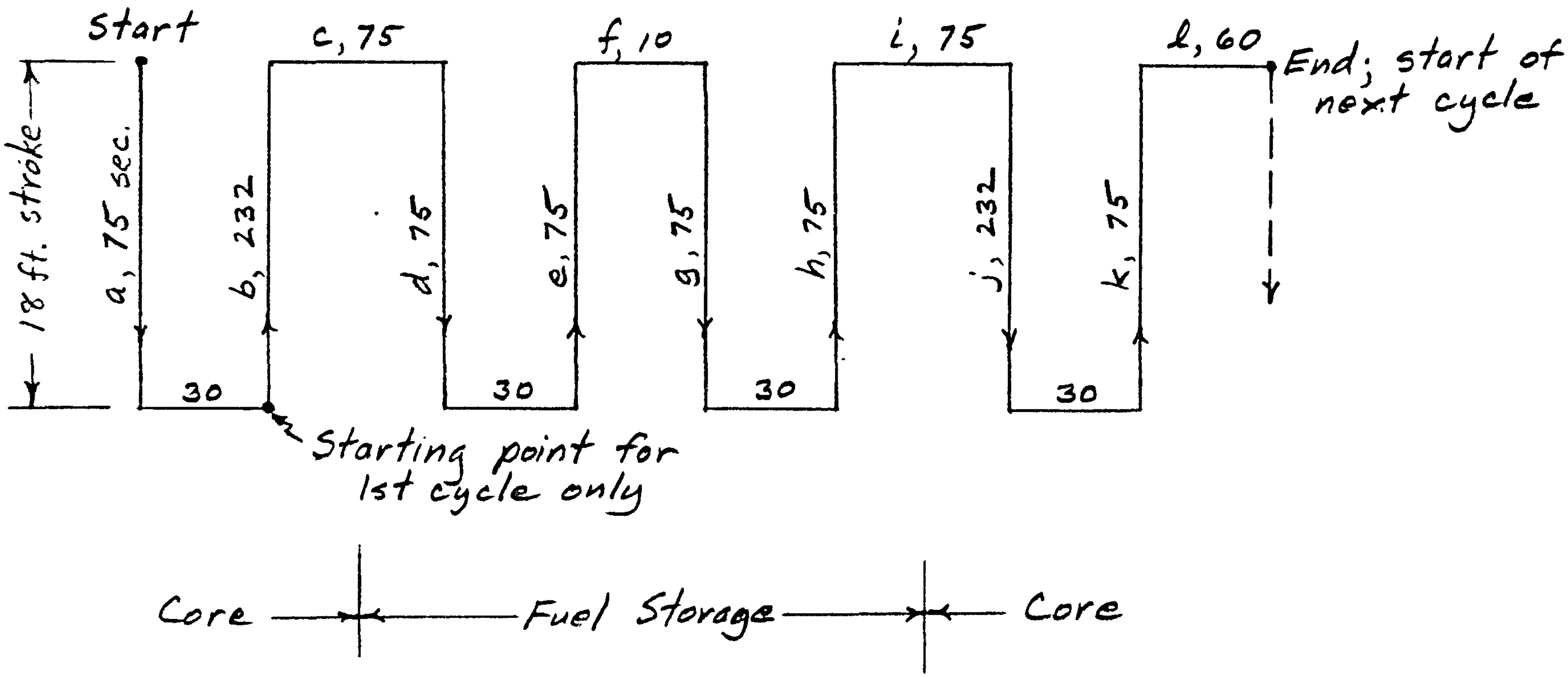
IV. RESULTS

The starting point in the grapple drive stem temperature vs time computation was taken to be the beginning of Step "b" (see Fig. 3), after the grapple drive stem had initially reached equilibrium temperature in the lowered position. Computer runs were made for the first three transfer cycles and for transfer cycles when the system is close to dynamic thermal equilibrium.

Fig. 4 shows the grapple drive stem wall temperature at the beginning of the raised position dwells during the first and third transfer cycles and during the transfer cycles when the system has nearly attained dynamic thermal equilibrium. Also shown in Fig. 4 is the grapple drive stem wall temperature at the start of Step "b" in the first transfer cycle. It is observed that the seals will see stem wall temperatures as high as about 600°F during the first transfer cycle. The stem wall temperture at the seal decreases with succeeding transfer cycles. After a sufficient number of transfer cycles, when dynamic thermal equilibrium is approached, the maximum wall temperature seen by the seals is 325°F for the 18 foot stroke case. For shorter strokes, the stem wall temperature seen by the seals can be determined approximately by shifting the curves in Fig. 4 downward an appropriate distance or, conversely, by shifting the effective elevation of the seals upward. For example, if the stroke is 17.2 feet (the design stroke) instead of 18 feet, the effective elevation of the lower end of the seals would be 110.8 feet instead of 110.0 feet. For this case, it can be seen from Fig. 4 that when the system is approximately at dynamic thermal equilibrium, the maximum stem wall temperature seen by the seals would be 270°F.

Fig. 3

IVTM Transfer Cycle



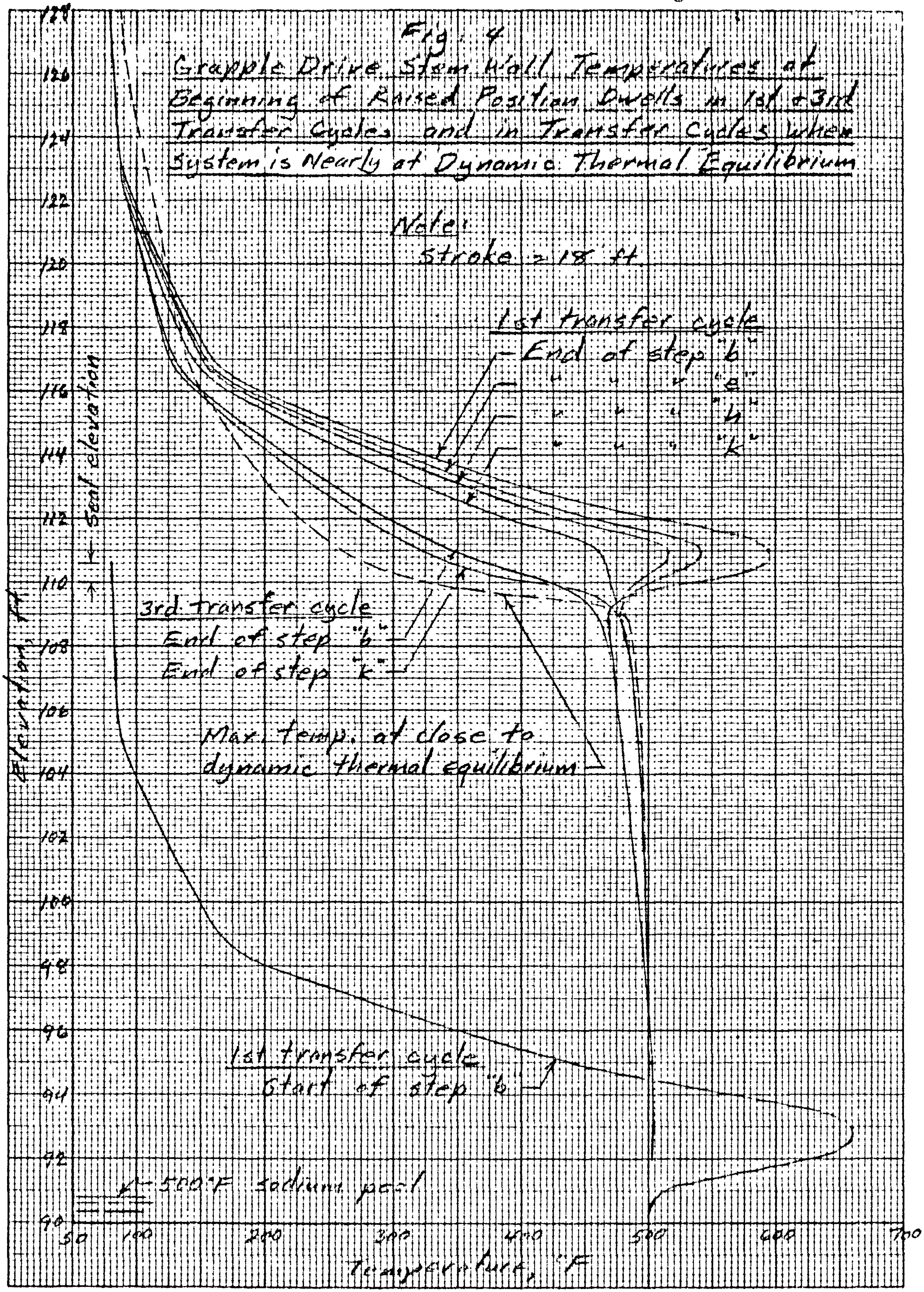


Fig. 4
Grapple Drive Stem Wall Temperatures at Beginning of Raised Position Dwells in 1st + 3rd Transfer Cycles and in Transfer Cycles when System is Nearly at Dynamic Thermal Equilibrium
Note:
Stroke = 18 ft
1st transfer cycle
End of step "b"
" " " "e"
" " " "h"
" " " "k"
3rd transfer cycle
End of step "b"
End of step "k"
Max. temp. at close to dynamic thermal equilibrium
1st transfer cycle
Start of step "b"
500°F sodium pool
Seal elevation
Elevation, ft
Temperature, °F
128
126
124
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
50
100
200
300
400
500
600
700

Fig. 5 shows the temperatures of the structures surrounding the grapple drive stem during the first and third transfer cycles and during subsequent transfer cycles when the system is close to a dynamic thermal equilibrium.

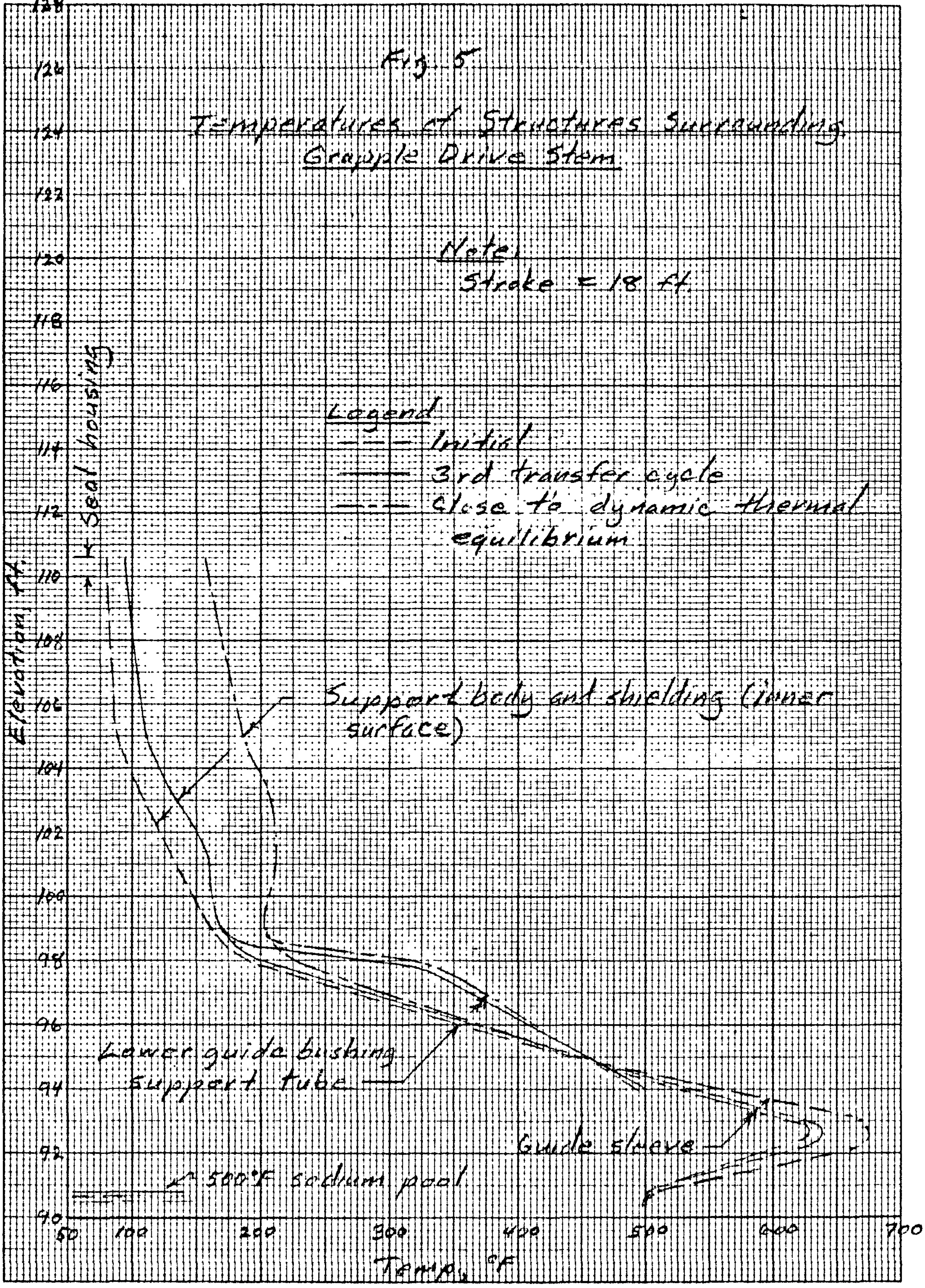
If the maximum permissible stem wall temperature at the seals is 300°F, it can be seen from Fig. 4 that this temperature limitation is not met during the first few transfer cycles, if, initially, the grapple drive stem is at thermal equilibrium in the lowered position. Ways to avoid exceeding the 300°F stem wall temperature limitation at the seals include the following:

1. During the initial lifting of the grapple drive stem in the first transfer cycle, stop the lifting when the stem temperature at the seals approaches 300°F. From the results shown in Fig. 4, this would occur when the stem is about 3-1/2 feet below the raised position, for the 17.2 feet design stroke. If the stem is held in this position for a period of about 40 minutes (see solid curves in Fig. 6), it would cool sufficiently, i.e., to $\leq$ 300°F, so that the lifting can be resumed and completed without the stem wall temperature exceeding 300°F at the seals. Normal transfer operation is followed thereafter.

2. Start transfer operation with the grapple drive stem initially at thermal equilibrium in the raised position.

3. If, during the course of the transfer operation, the grapple drive stem is held in the lowered, or nearly lowered position for an extended period, the temperature of the grapple drive stem would increase and tend to reach the lowered, or nearly lowered, position equilibrium temperature. In this event, it may be necessary to go thru Step 1 again. However, the required dwell time may now be longer inasmuch as the support body will now be hotter. Figure 6 shows that if the temperature of the support body opposite the peak temperature point in the stem is 183°F at the start of the partially raised position dwell, the dwell time required for the peak temperature in the stem wall to drop from 600°F to 300°F will be 60 minutes.

At the upper end of the grapple drive stem, where the grapple finger actuating rod seals are located, the grapple finger actuating rod temperature will always be approximately the same as the temperature of the adjacent grapple drive stem wall. The maximum temperature that this region could reach will be less than the maximum temperature of the seal housing which, from Figure 5, is seen to be about 160°F.



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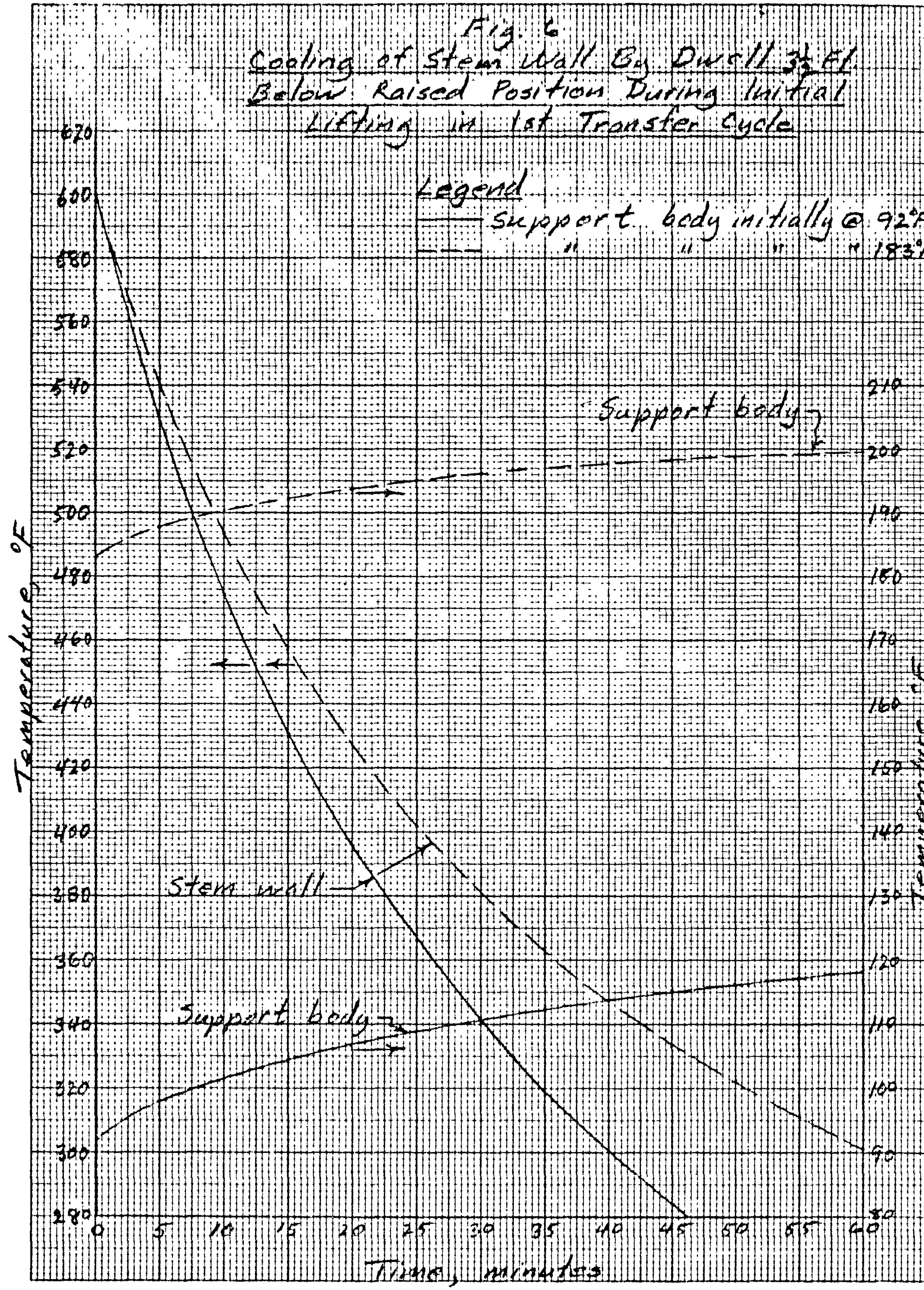
Fig. 6
Cooling of Stem Wall By Dwell 3½ Ft. Below Raised Position During Initial Lifting in 1st Transfer Cycle
Legend
Support body initially @ 92°F
" " " " 183°F.
Support body
Stem wall
Support body
Temperature °F
Temperature, °F
Time, minutes
620
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
210
200
190
180
170
160
150
140
130
120
110
100
90
80
0
5
10
15
20
25
30
35
40
45
50
55
60

V. DISCUSSION

A. SEAL LUBRICANT TEMPERATURE

While it is possible to program the operation of the IVTM so that the grapple drive stem wall temperature at the seals never exceeds 300°F, this does not necessarily mean that the seal lubricant will not be exposed to temperatures higher than 300°F. Any lubricant that is left on the stem surface after the surface slides down past the wiper and scraper would be subject to temperatures up to greater than 600°F if the grapple drive stem is permitted to stay in the lowered position for an extended period.

B. EFFECT OF GRAPPLE SPEED

Each time the grapple drive stem is lowered into the sodium pool and then raised, heat is, in effect, pumped from the sodium pool to the support body and shielding structure through the grapple finger actuating rod and the grapple drive stem, and the temperatures of these components are increased. Hence, increasing the number of strokes per unit time, by increasing the grapple drive stem speed and/or by decreasing the time between strokes, without changing the fraction of total time the grapple drive stem is in the raised or lowered position, will increase the heat pumping rate, and therefore, the maximum grapple drive stem wall temperature at the seals.

C. EFFECT OF CHANGE OF COVER GAS TO HELIUM

If the cover gas is changed from argon to helium, the maximum temperature of the grapple drive stem wall at the seals would be lower inasmuch as the rate of heat transfer from the grapple drive stem to the support body and shielding structure, which is, on the average, colder than the drive stem, would be increased due to the higher thermal conductivity of helium.

VI. CONCLUSIONS

1. The maximum grapple drive stem wall temperature at the grapple drive stem seals will be about 270°F for the assumed transfer cycle when the system is at dynamic thermal equilibrium.

2. If the transfer operation is started with the grapple drive stem initially at thermal equilibrium in the lowered position, it will be necessary to pre-cool the stem if the maximum permissible temperature of the stem wall at the seals is 300°F. The pre-cooling can be accomplished by stopping the initial lifting of the stem when the stem is about 3-1/2 feet below the full raised position and holding it in this

position for 40 minutes before resuming the transfer operation. No pre-cooling is required if the transfer operation is started with the grapple drive stem initially in the raised position.

3. While it is possible to program the operation of the IVTM so that the grapple drive stem wall temperature at the seals never exceeds 300°F, this does not necessarily mean that the seal lubricant will not be exposed to temperatures higher than 300°F.

4. The maximum temperature that the grapple finger actuating rod seals could be subjected to will be less than 160°F.

5. Increasing the speed of the grapple drive stem will increase the stem wall temperature at the seals.

6. Changing the cover gas from argon to helium will decrease the stem wall temperature at the seals.

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1. Drawing R-N097241007, as of 3-30-73

2. TI-097-220-003, "Reactor Vessel and Vessel Cover Thermal Studies", M. J. Gabler, 12-19-72.

3. RFT-097-241-002, "Fuel Transfer Machine Seal and Guide Bushing Test Requirements", K. Bilibin, 12-13-72.

4. K. Bilibin, Feb. 1973.

5. LAP 69-552(RC), "Manual for the Differential Equation Analyzer Program. (DEAP), Volume I", B. L. McFarland, 10-1-69.

APPENDIX A

HEAT TRANSFER NETWORK

The heat transfer network used is shown in Figures A-1 and A-2.

The vertical distance between nodes was taken as 2 feet. For this vertical distance between nodes, there are 18 nodes in the stem and 18 nodes in the finger-actuating rod. Programming is simplified if the number of nodes in the stem and in the finger-actuating rod is a multiple of 10. Therefore, dummy nodes 41 and 60 were added to the stem and dummy nodes 61 and 80 were added to the finger-actuating rod. These four nodes function only as dummies by virtue of an artificially high thermal resistance inserted between each of these nodes and the respective, adjacent end nodes.

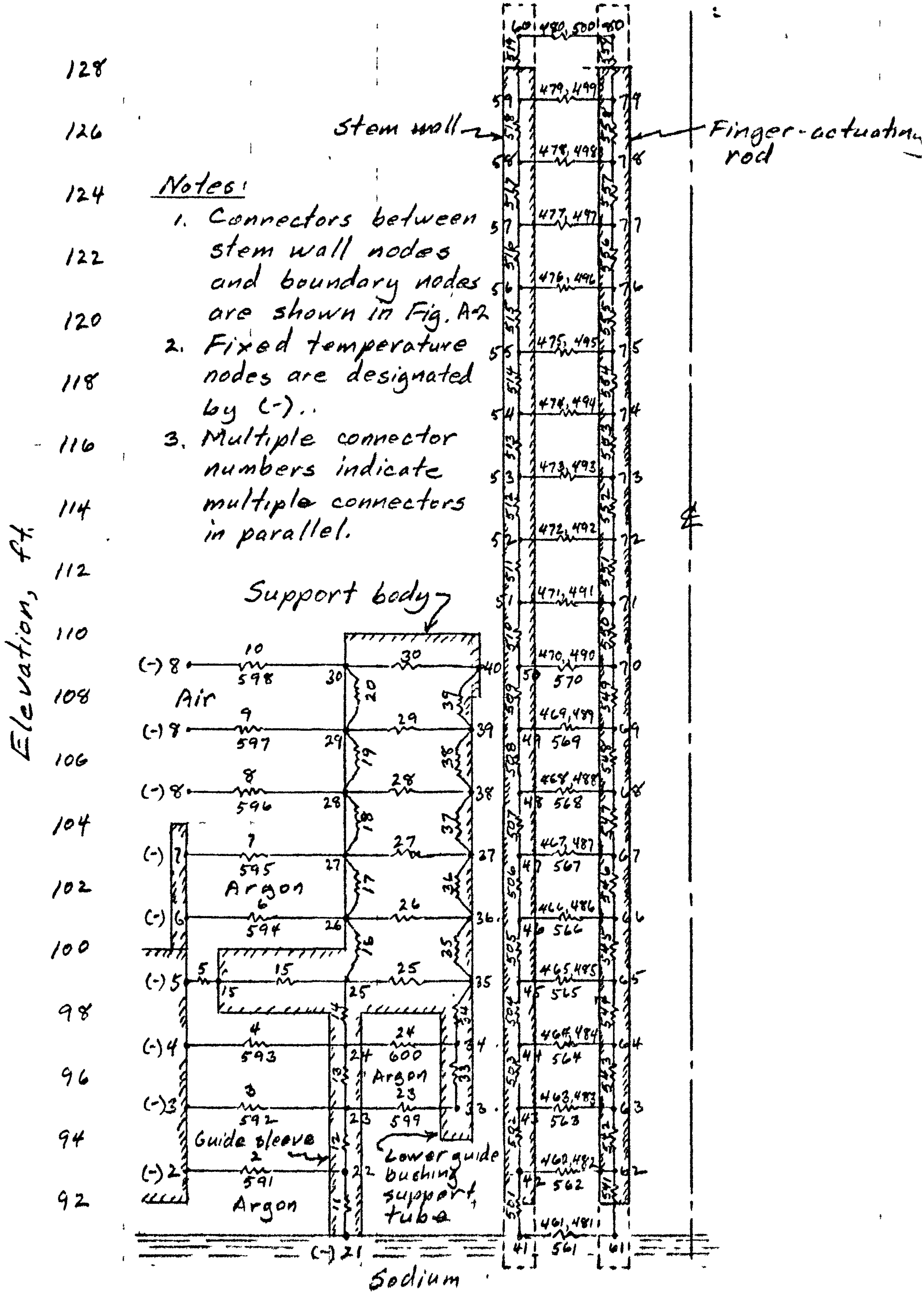
The connectors shown in Fig. A-1 are described in Table A-I. The connectors shown in Fig. A-2 are described in Fig. A-2. Appropriate functions are used in the *030 section of the DEAP input to cancel all connectors other than the appropriate ones for any particular stroke position of the grapple drive stem.

TABLE A-I

DESCRIPTION OF CONNECTORS
SHOWN IN FIGURE A-1

Connectors	Description
Y002-Y007	Conduction thru argon
Y008-Y010	Air Convection
Y011-Y020 Y023-Y030 Y033-Y039	Conduction thru S. S.
Y461-Y480	Conduction thru argon
Y481-Y500	Radiation
Y501-Y519	Conduction thru S. S.
Y541-Y559	Conduction thru S. S.
Y561-Y570	Conduction thru sodium
Y591-Y600	Radiation

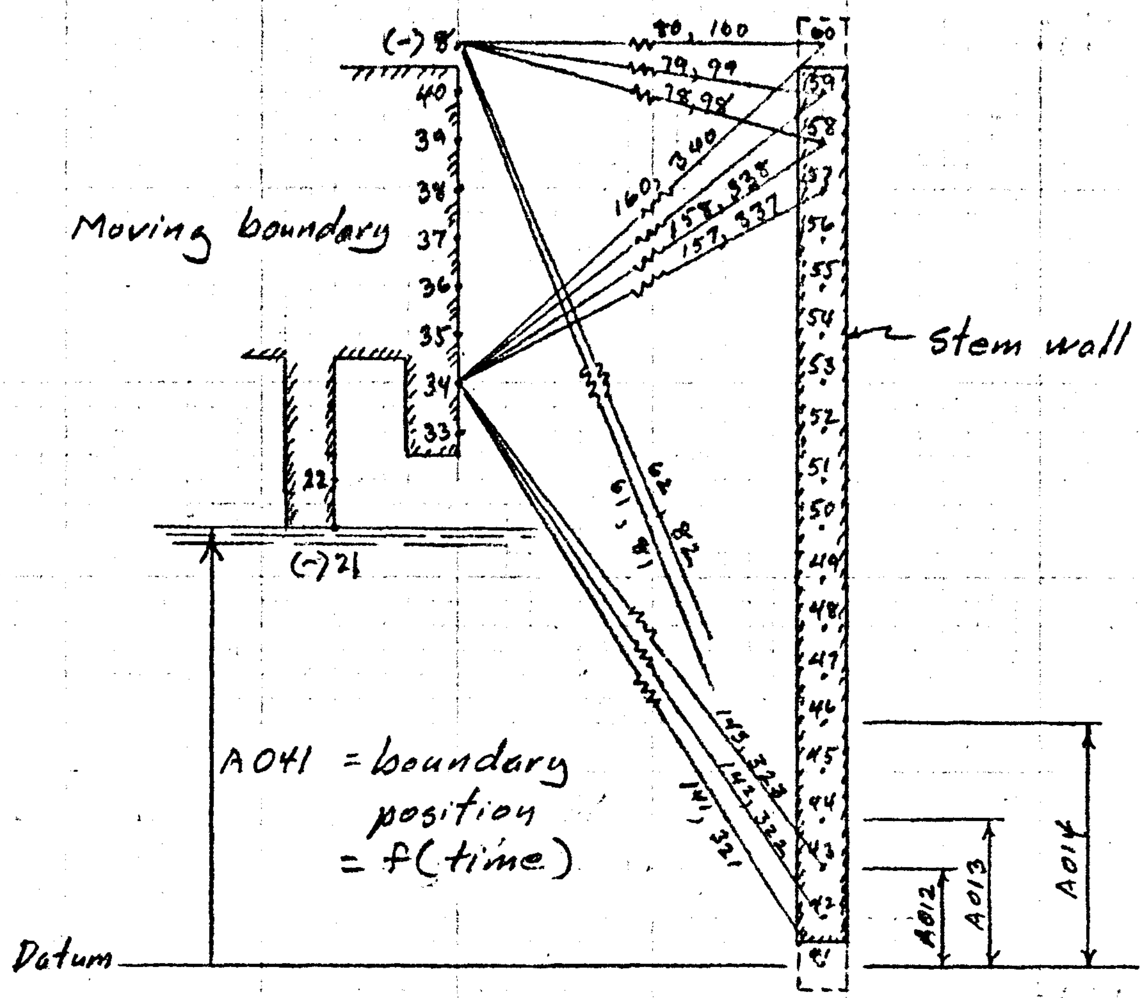
Fig. A-1 Heat Transfer Network



Notes:
1. Connectors between stem wall nodes and boundary nodes are shown in Fig. A-2
2. Fixed temperature nodes are designated by (-).
3. Multiple connector numbers indicate multiple connectors in parallel.

Fig. A.2

Connectors Between Boundary Nodes and Stem Wall Nodes



Boundary Nodes	Connectors		
	Conduction	Convection	Radiation
(-) 8 (Air)		Y061 - Y080	Y081 - Y100
(-) 21 (Sodium)		Y041 - Y060	
		Y521 - Y540	
22	Y101 - Y120		Y281 - Y300
33	Y121 - Y140		Y301 - Y320
34	Y141 - Y160		Y321 - Y340
35	Y161 - Y180		Y341 - Y360
36	Y181 - Y200		Y361 - Y380
37	Y201 - Y220		Y381 - Y400
38	Y221 - Y240		Y401 - Y420
39	Y241 - Y260		Y421 - Y440
40	Y261 - Y280		Y441 - Y460

APPENDIX B

CALCULATION OF GRAPPLE DRIVE STEM TEMPERATURE IN IVTM SEAL & BUSHING TEST

I. INTRODUCTION

In order to check the validity of the method of calculation used to calculate the temperature of the IVTM grapple drive stem, this method of calculation was applied to the IVTM Seal & Bushing Test configuration and cycle. The calculated results are compared with experimental data.

II. SYSTEM DESCRIPTION & ASSUMPTIONS

Fig. B-1 shows a schematic representation of the IVTM Seal and Bushing Test configuration. The grapple drive stem travels 60 inches at a speed of 15 feet/min. The dwell time is 105 seconds in the raised position and 120 seconds in the lowered position.

The thickness of the stem wall is not known with certainty. It is not less than 1/4" and may be greater. In the calculations, the stem wall thickness was assumed to be 1/4". The diameter of the 12" long stainless steel slugs stocked in the stem is presumably 3-1/4". For this set of dimensions, the annular gap between the stem wall and the slugs is 1/8"

III. RESULTS

Calculations were made for the case in which the seal housing was neither heated nor insulated. Computer runs were made for the first eight cycles, with the grapple drive stem initially at thermal equilibrium in the lowered position.

Fig. B-2 shows the stem wall temperature at the beginning of the raised position dwell in the first, second, fourth and eighth cycles. It is seen that at least up thru the fourth cycle, the stem wall is cooled more rapidly in the vicinity of about 64 inches below the upper end of the stem than elsewhere. This is the wall region that is at the same elevation as the seal housing when the stem is in the raised position. The reason why the stem wall is cooled more rapidly in this region, is that the seal housing is quite cool initially, the thermal impedance between the seal housing and the stem wall is relatively small due to the small clearance (0.013") between the seal housing and the stem wall, and the stem is in the raised position a significant fraction (40%) of the total cycle time.

Fig. B-3 shows the stem wall and slug temperatures at the end of the raised position dwell in the fourth and eighth cycles. It is seen that the slug temperature at the seal housing elevation is virtually unperturbed as compared with the stem wall temperature. This is due to the

Fig. B-1
IVTM Seal & Bushing Test Configuration

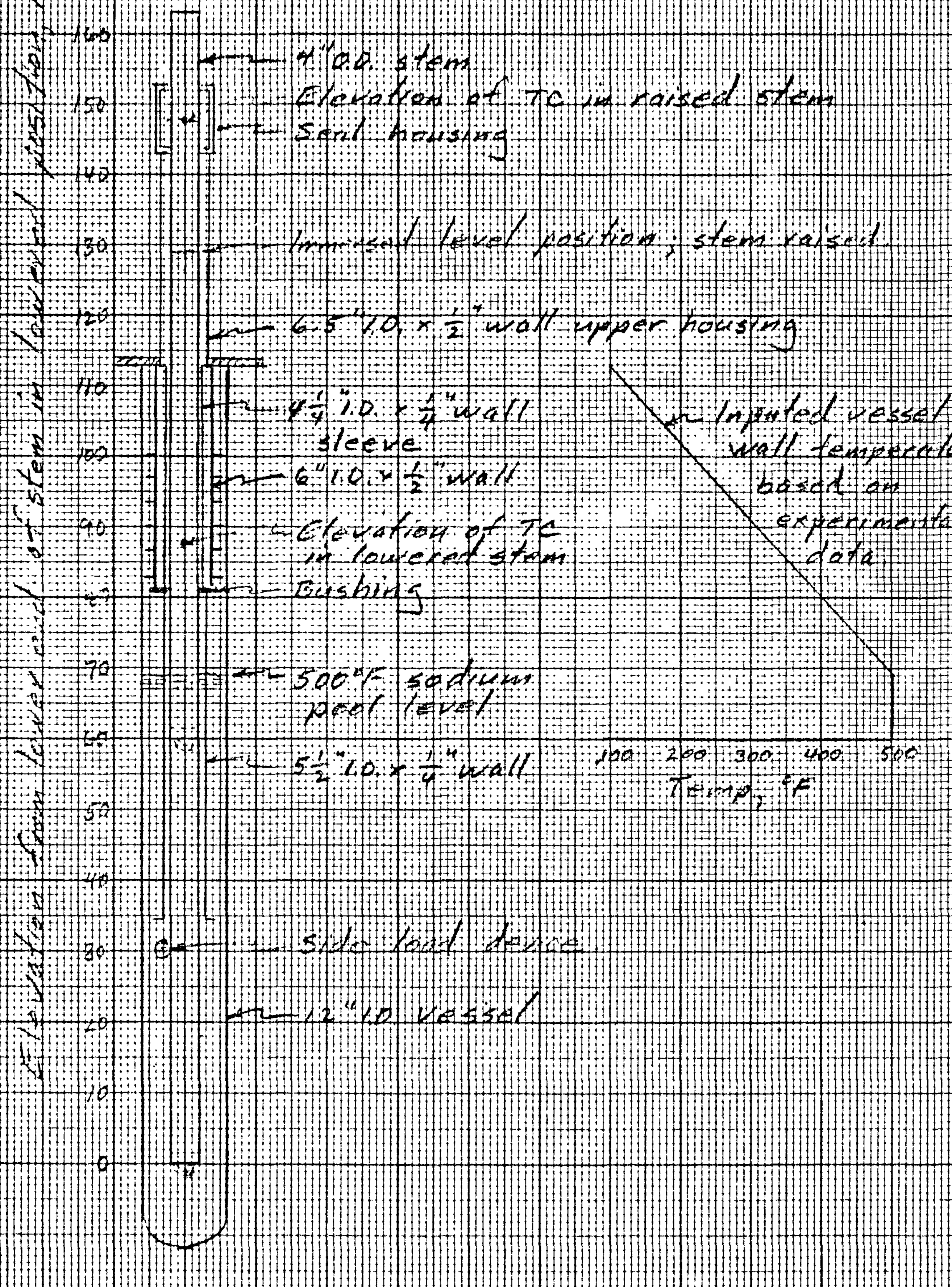
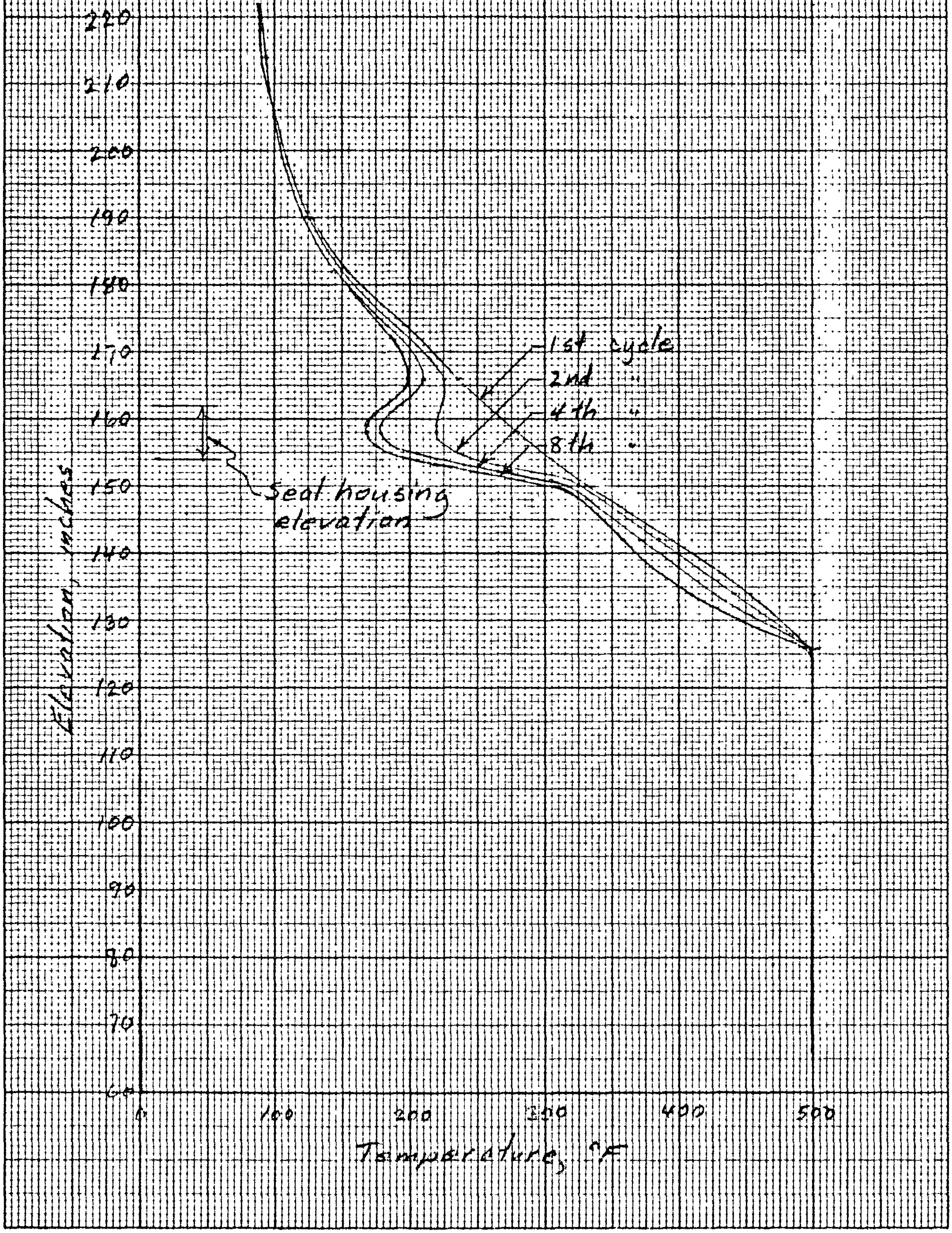


Fig. B-2
Stem Wall Temperature at Beginning of Raised Position Dwell



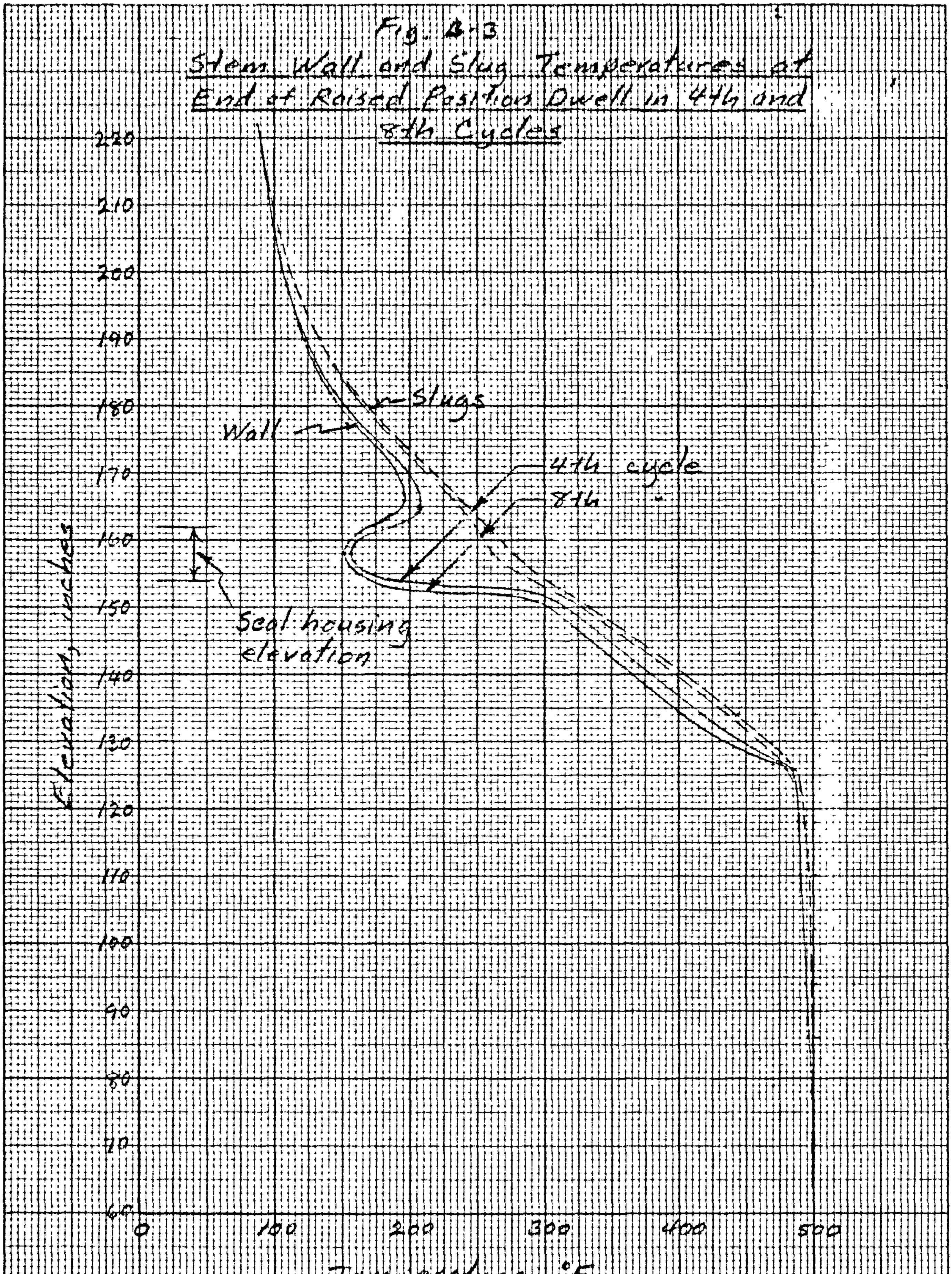


Fig. A-3
Stem Wall and Slug Temperatures at End of Raised Position Dwell in 4th and 8th Cycles
Slugs
Wall
4th cycle
8th
Seal housing elevation
Elevation, inches
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
0
100
200
300
400
500
Temperature, °F

relatively high thermal impedance (1/8" air gap) between the stem wall and the slugs.

Fig. B-4 shows the increase in seal housing temperature with number of cycles. The measured seal housing temperature after many cycles is in the range of 115°F to 120°F.

Fig. B-5 shows a plot of the temperatures of the stem wall at the seal housing elevation when at the raised position (i.e., at the T/C location) vs number of cycles. It is seen that the stem wall temperatures decrease with number of cycles up to the eighth cycle. At the eighth cycle, the stem wall temperature curves have just about flattened out. Inasmuch as the seal housing temperature is still rising at the eighth cycle (see Fig. B-4) at least the raised dwell curves in Fig. B-5 should start rising after the eighth cycle. If the equilibrium seal housing temperature is taken to be 120°F (which is 13°F higher than the seal housing temperature at the eighth cycle), the raised dwell curves would ultimately rise to about 13°F above what they are at the eighth cycle. Accordingly, the temperature of the stem wall at the seal housing elevation when at the raised position, will be 167 + 13 = 180°F at the start of the raised dwell and 150 + 13 = 163°F at the end of the raised dwell. The measured stem wall temperature at this elevation was 205°F regardless of whether it was at the start or end of the raised dwell.

IV. DISCUSSION

Possible reasons for these differences between measured and predicted stem wall temperatures include the following:

1. The stem wall thickness may be greater than 1/4"*. If so, the stem wall temperature at the T/C location would be depressed less, due to (a) greater heat transfer from the slugs, by virture of the decreased air gap between the wall and the slugs, and (b) greater heat flow in the longitudinal direction in the stem wall. A greater wall thickness would also decrease the change in wall temperature during the raised dwell, inasmuch as the heat capacity will be greater.

2. The T/C in the stem was probably seeing a temperature intermediate between the stem wall temperature and the higher slug temperature. This is likely inasmuch as the T/C sheath in the vicinity of the junction was located in a slot in the slug and was probably in contact with the slug.

*Subsequent to the performance of these calculation, it was found that the stem wall thickness is 3/8" and that the slugs fitted quite snugly inside the stem tube.

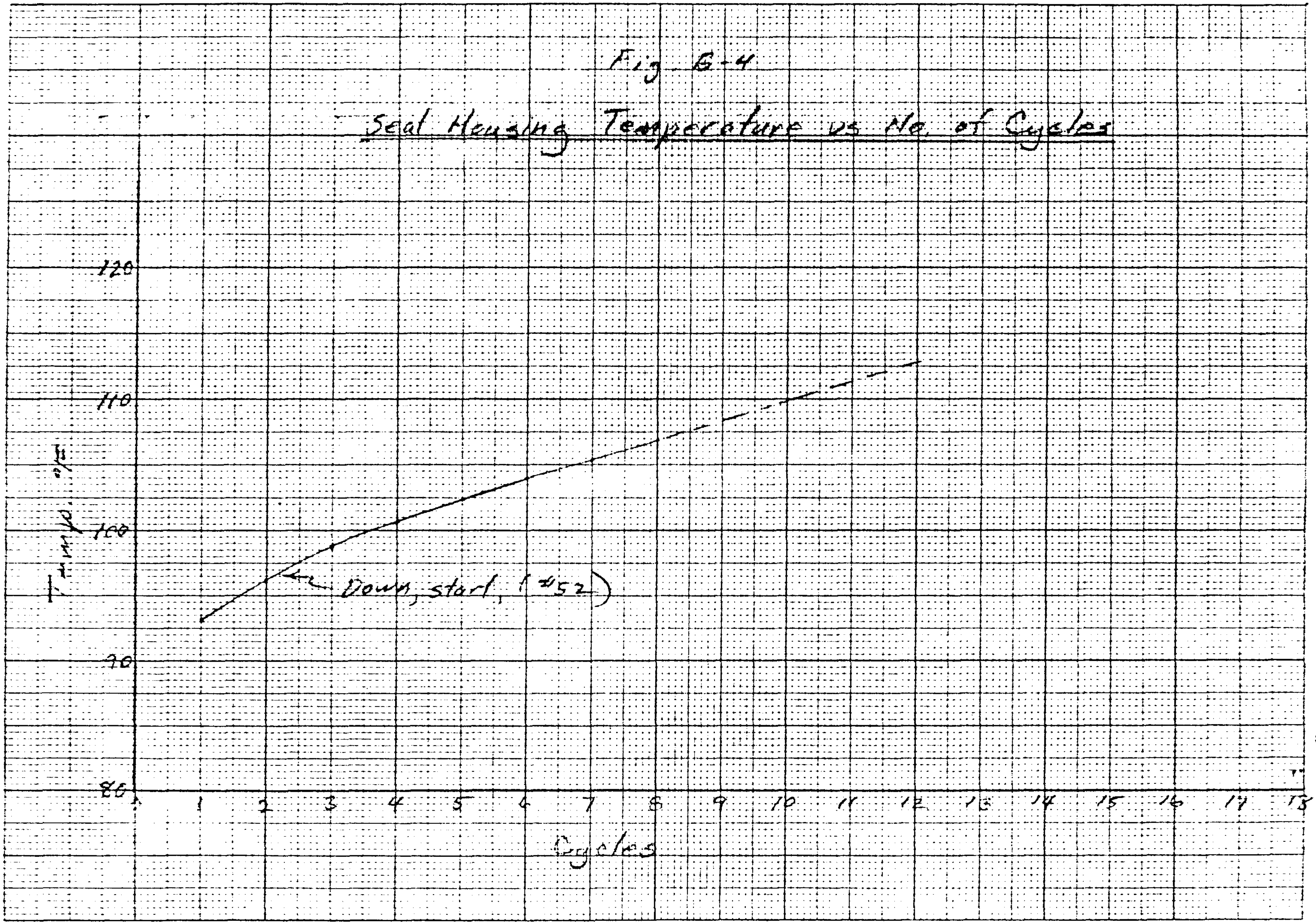


Fig. E-4
Seal Housing Temperature vs No. of Cycles
120
110
100
90
80
Temp °F
Down, start, (#52)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Cycles

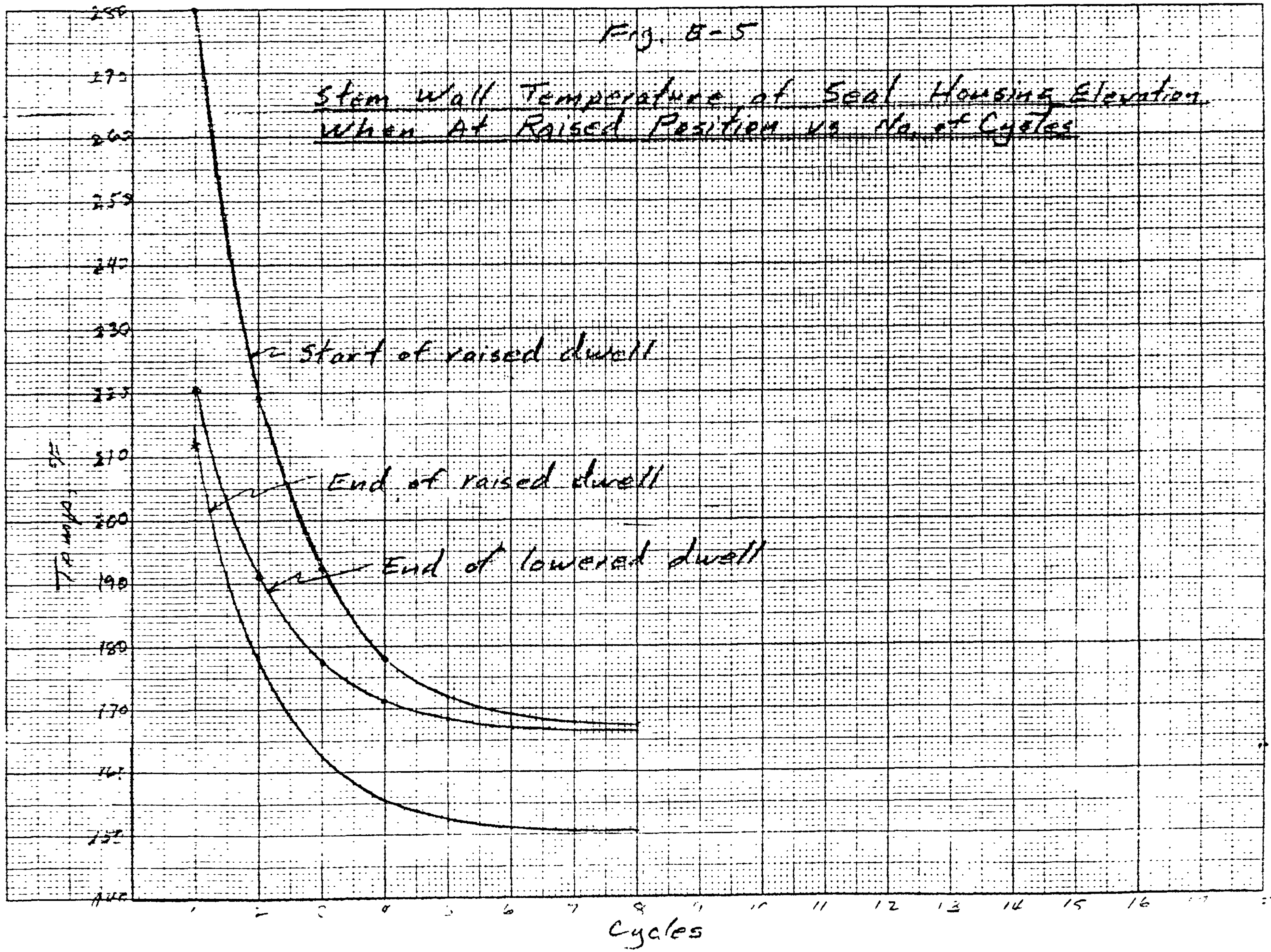


Fig. B-5
Stem Wall Temperature at Seal Housing Elevation When At Raised Position vs No. of Cycles
Start of raised dwell
End of raised dwell
End of lowered dwell
Temp °F
Cycles

V. CONCLUSIONS

The calculated results for the stem wall temperatures in the IVTM Seal and Bushing Test indicate that probably reasonably good agreement between the calculated and measured temperatures would have been obtained if the correct stem wall thickness had been used in the calculation. It is, therefore, concluded that the method of calculation used will produce valid results.