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ABSTRACT

An analysis of the grapple stem temperature during operation of the CRBRP (Clinch River Breeder Reactor Plant) IVTM (In-Vessel Transfer Machine) indicates that the maximum stem temperature at the stem seals will be about 300°F if the seals are at design elevation, when the system is at dynamic thermal equilibrium. If the grapple stem is held in the lowered position for more than 10 minutes (in the case of the stem seals at the design elevation), the stem temperature at the seals will exceed 300°F when the stem is raised.

FORM 734-C REV 4-71

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FIGURES

I. INTRODUCTION

The results of an analysis of the grapple drive stem temperatures at the grapple drive stem reciprocating seals during fuel transfer operation of the In-Vessel Transfer Machine (IVTM) for the Clinch River Breeder Reactor Plant (CRBRP) are presented.

II. SYSTEM DESCRIPTION AND ASSUMPTIONS

Fig. 1 shows the in-vessel section of the IVTM. The elevation of the grapple drive stem reciprocating seals was taken to be 20" higher than the design elevation shown in Fig. 1. Correspondingly, the length of the grapple drive stem was taken to be 20" longer than shown in Fig. 1.

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 all steel surfaces = 0.3
5. The temperature distribution in the top head, radiation shields and thermal shields was assumed to remain constant and was taken as that which prevails 10 hours after reactor shutdown (Ref. 1). This temperature distribution is shown in Fig. 2.
6. Grapple drive stem stroke = 223 inches
7. The assumed fuel transfer cycle for the IVTM is shown in Fig. 3. The time required to complete each phase of the cycle is shown in minutes and seconds. The cumulative time to certain phases of the cycle is shown in seconds by the figures in parentheses.
8. The movement (40 1/2" stroke) of the hold-down shafts will have only an insignificant perturbation on the temperature distribution of the system, and can, therefore, be neglected in the analysis.

Fig. 1
In-Vessel Section of IVTM

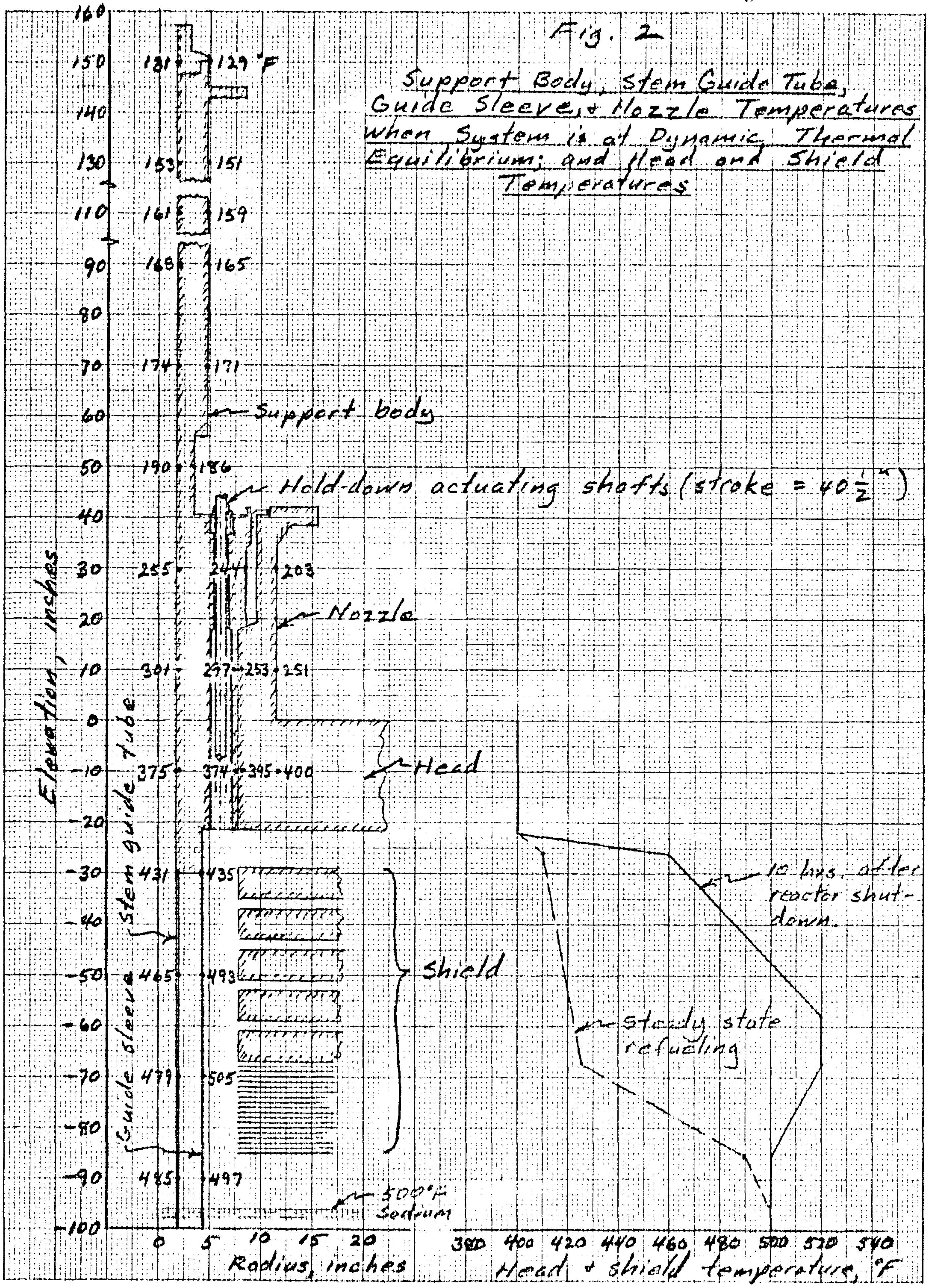
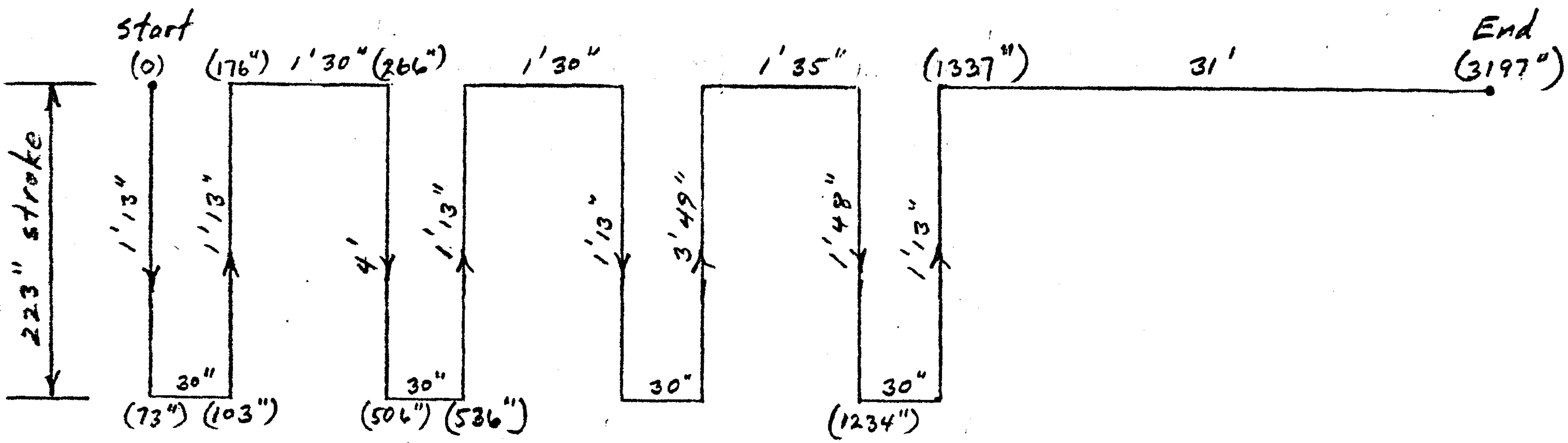


Fig. 2
Support Body, Stem Guide Tube, Guide Sleeve, + Nozzle Temperatures when System is at Dynamic Thermal Equilibrium; and Head and Shield Temperatures
Support body
Hold-down actuating shafts (stroke = 40 1/2")
Nozzle
Head
Shield
Stem guide tube
Guide sleeve
500°F Sodium
10 hrs. after reactor shut-down.
Steady state refueling
Elevation, inches
Radius, inches
Head + shield temperature, °F
181
129°F
153
151
161
159
168
165
174
171
190
186
255
244
203
301
297
253
251
375
374
395
400
431
435
465
493
479
505
485
497
160
150
140
130
110
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
0
5
10
15
20
380
400
420
440
460
480
500
520
540

Fig. 3

Fuel Transfer Cycle for IVTM



III. METHOD OF CALCULATION

Computer program DEAP (Ref. 2) was used. To simulate the grapple drive stem motion, the moving boundary concept was employed in the formulation of the heat transfer network. (A description of this method of solution is given in Appendix A of Ref. 3.)

IV. RESULTS

Fig. 4 shows the temperature distribution of the grapple drive stem when it completes its upward stroke, at a speed of 15 ft/min, after it had been in the lowered position long enough to have reached thermal equilibrium. It is seen that during this upward stroke, the temperature of the grapple drive stem sliding past the seals will range from 80°F to 500°F. If it is desired to limit the maximum temperature of the grapple drive stem at the seals to 300°F, it can be accomplished by stopping the upward stroke when the temperature of the grapple drive stem at the seals reaches 300°F, and holding the stem at this position long enough for it to cool sufficiently before completing the upward stroke. It can be seen from Fig. 4 that the temperature of the grapple drive stem at the seals will reach 300°F when the stem is raised to 72 inches below the raised position. On the basis of results obtained in Ref. 3 for an IVTM and support body having slightly different dimensions, the stem will have to be held in this position for about an hour for it to cool enough to permit completion of the upward stroke without the temperature of the grapple drive stem exceeding 300°F at the seals. From this point on, the fuel transfer cycle shown in Fig. 3 can be followed without the temperature of the grapple drive stem exceeding 300°F at the seals.

Fig. 5 shows the maximum temperature of the grapple drive stem in the raised position and Fig. 2 shows the temperature distribution in structures surrounding the grapple drive stem, after enough fuel transfer cycles have been completed for the system to have reached dynamic thermal equilibrium. It is seen in Fig. 5 that the maximum stem temperature seen by the seals is less than 300°F, and in Fig. 2 that the temperatures of the seal housings in the upper end of the nozzle will be less than 250°F. It is also seen from the temperature distribution shown in Fig. 2 that the temperature of the hold-down actuating shafts, which have a stroke of 40 1/2", could exceed 300°F at the seals when these shafts approach or reach the raised position.

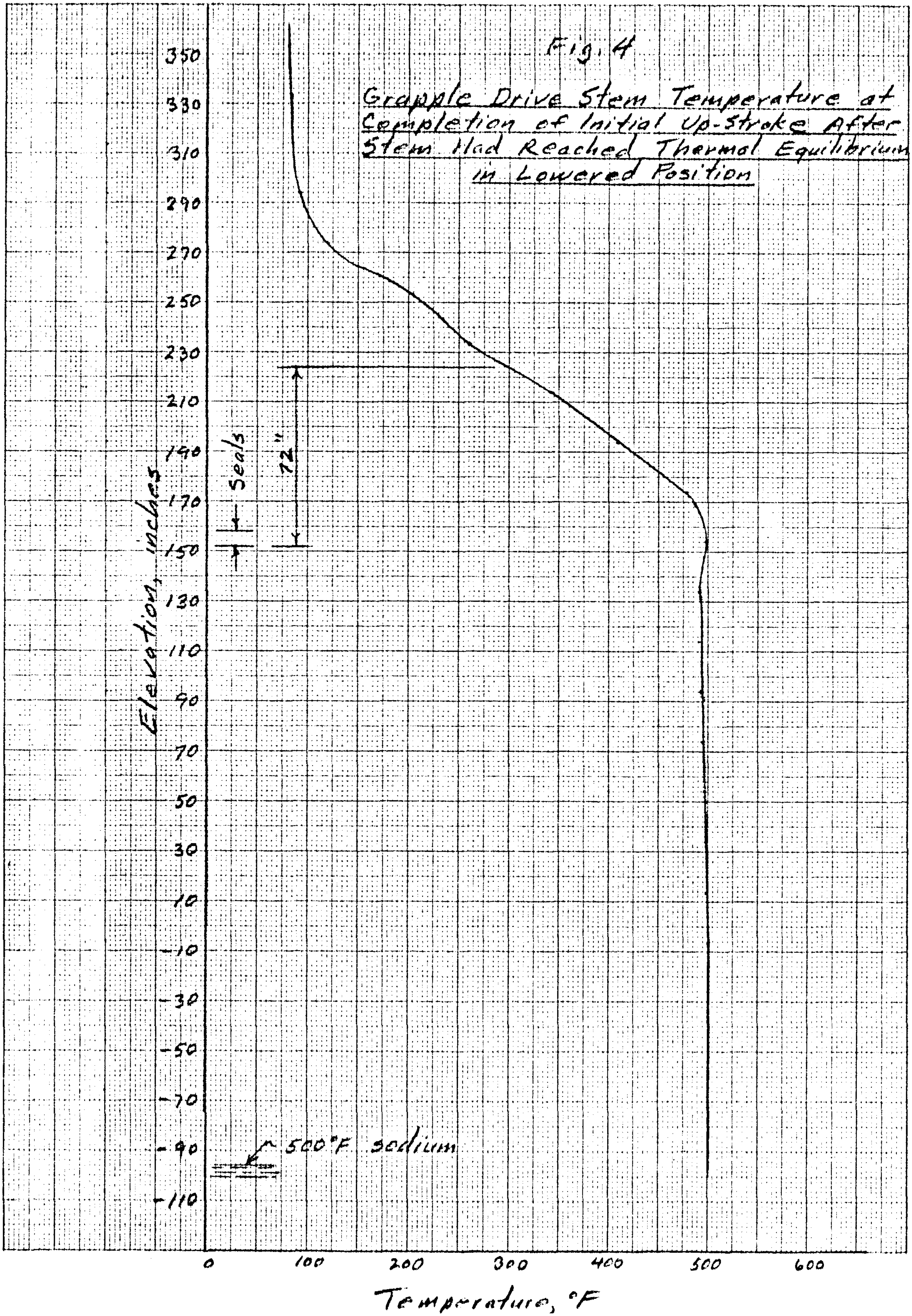


Fig. 4
Grapple Drive Stem Temperature at Completion of Initial Up-Stroke After Stem Had Reached Thermal Equilibrium in Lowered Position
Elevation, inches
350
330
310
290
270
250
230
210
190
170
150
130
110
90
70
50
30
10
-10
-30
-50
-70
-90
-110
Seals
72"
500°F sodium
0
100
200
300
400
500
600
Temperature, °F

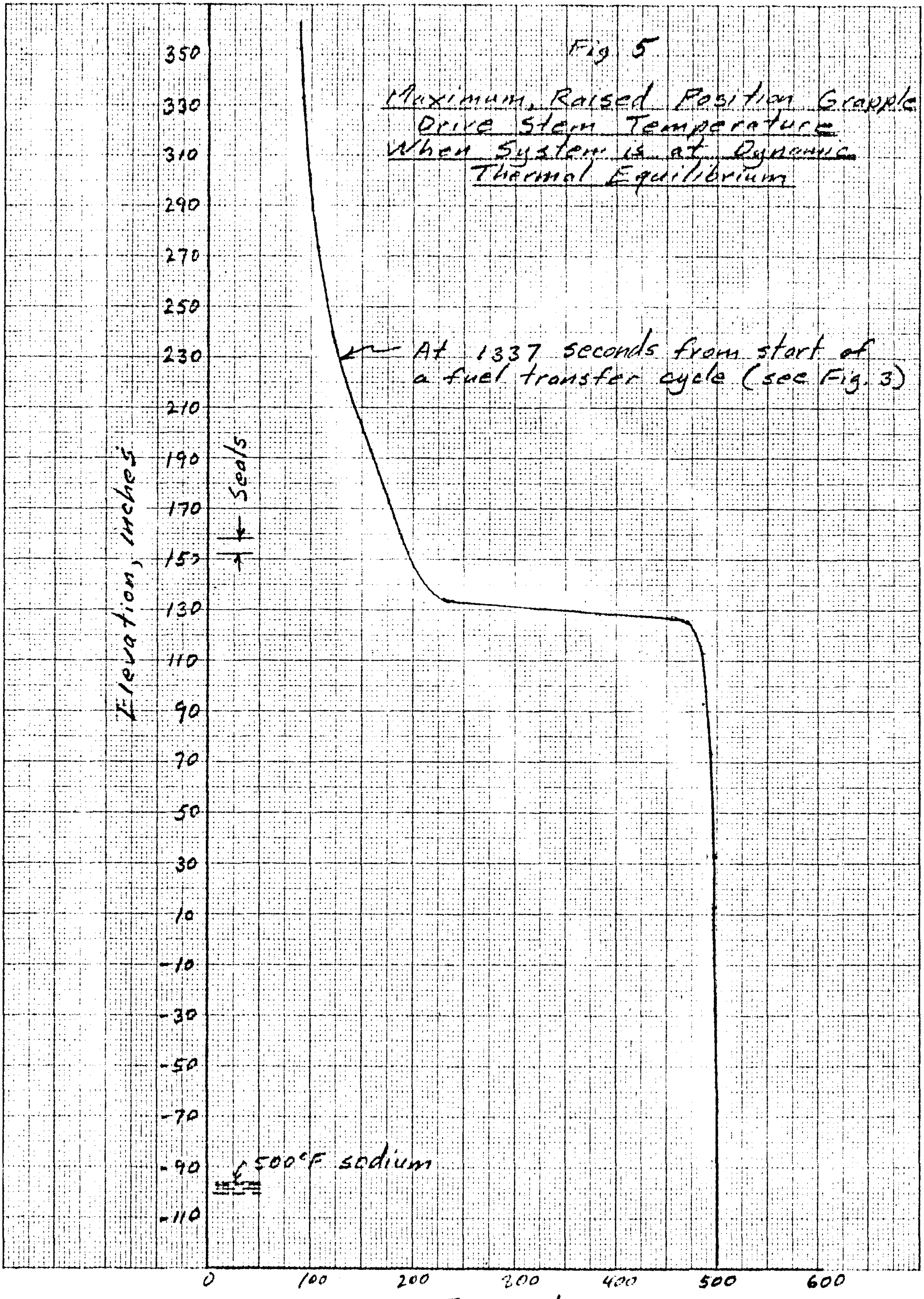


Fig. 5
Maximum Raised Position Grapple Drive Stem Temperature When System is at Dynamic Thermal Equilibrium
At 1337 seconds from start of a fuel transfer cycle (see Fig. 3)
Seals
500°F sodium
Elevation, inches
Temperature, °F.
350
330
310
290
270
250
230
210
190
170
150
130
110
90
70
50
30
10
-10
-30
-50
-70
-90
-110
0
100
200
300
400
500
600

Fig. 6 shows the change in temperature with time of the grapple stem, support body, and stem guide tube, if the stem is held in the lowered position during a fuel transfer cycle after the system had reached dynamic thermal equilibrium. Specifically, zero (0) minute in Fig. 6 corresponds to 1234 seconds in the fuel transfer cycle (see Fig. 3), i.e., when the stem has just reached the lowered position. It is seen that if the drive stem is held in the lowered position for a period of about 18 minutes or longer, the seals will see a stem temperature of 300°F or higher when the stem is raised. It is also seen that the stem guide tube cools much more rapidly than the support body. This is primarily due to the fact that the stem guide tube has a much lower heat capacity than the support body.

V. DISCUSSION

A. Grapple Stem Seals

The effect of the elevation of the grapple stem seals is shown in the following tabulation:

	Design Elevation	20" Above Design Elevation
1. Maximum stem temperature at seals when system is operating at dynamic thermal equilibrium. (From Fig. 5)	~ 300°F	195°F
2. Length of time stem can remain in lowered position without stem temperature exceeding 300°F at seals when stem is raised at 15 ft/min. (From Fig. 6)	10 min.	18 min.

If the grapple stem is held in the lowered position for periods longer than those shown in the above tabulation, it will be necessary to stop the grapple stem after it has been partially raised to permit it to cool for a short period before completing the up-stroke. The required cooling period will vary from a few minutes if the stem is held in the lowered position just in excess of the periods shown in the above tabulation to about an hour if the stem is held in the lowered position long enough to have reached thermal equilibrium.

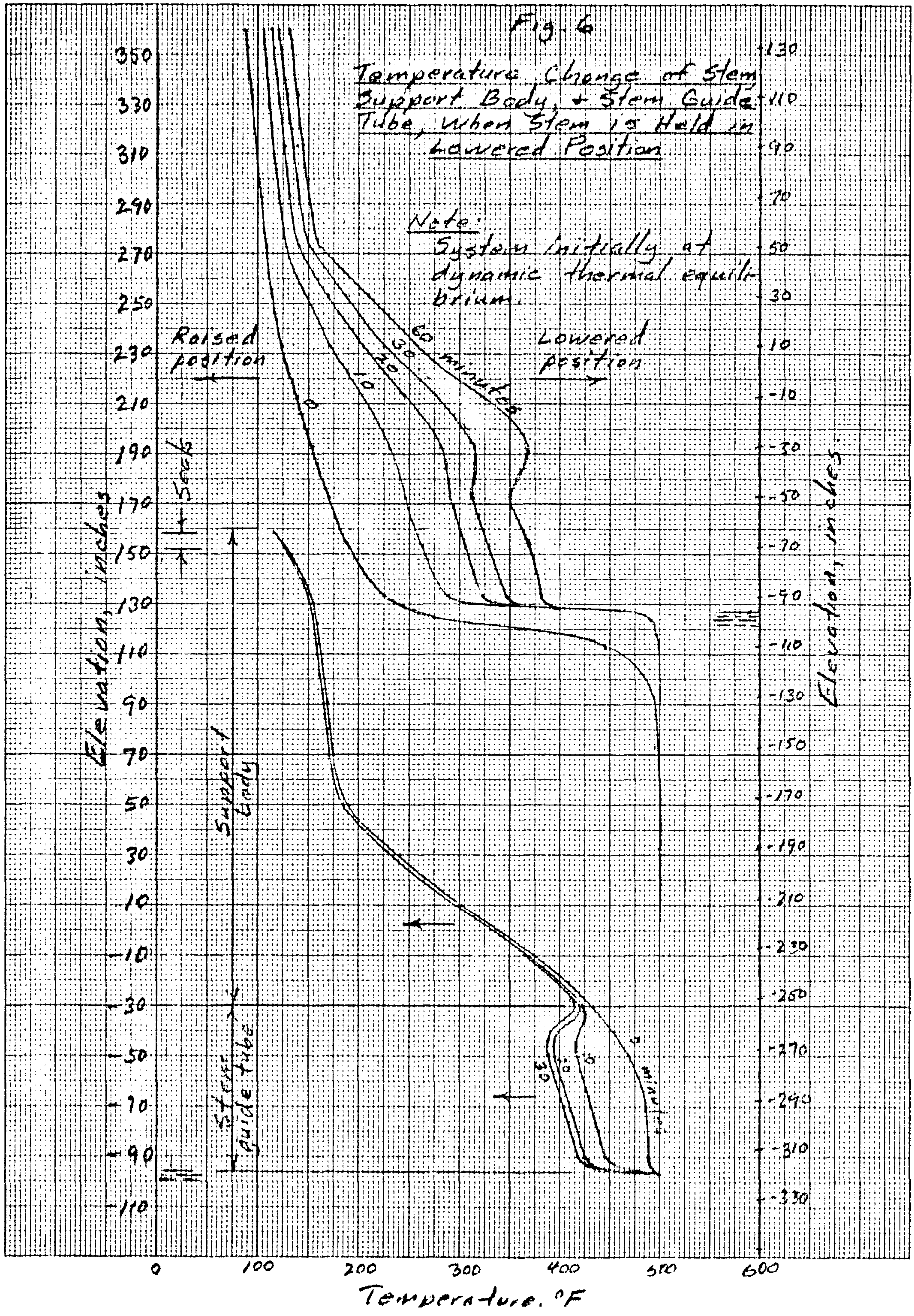


Fig. 6
Temperature Change of Stem Support Body, + Stem Guide Tube, When Stem is Held in Lowered Position
Note:
System initially at dynamic thermal equilibrium.
Raised position
Lowered position
60 minutes
30
20
10
0
Seal
Support body
Steel guide tube
Elevation, inches
Temperature, °F
0
100
200
300
400
500
600
350
330
310
290
270
250
230
210
190
170
150
130
110
90
70
50
30
10
-10
-30
-50
-70
-90
-110
130
110
90
70
50
30
10
-10
-30
-50
-70
-90
-110
-130
-150
-170
-190
-210
-230
-250
-270
-290
-310
-330

The length of time that the grapple stem can be held in the lowered position without the stem temperature exceeding 300°F at the seals when the stem is raised can be increased by (1) increasing the heat capacity of the stem, (2) decreasing the heating rate of the stem when in the lowered position, and/or (3) increasing the cooling rate of the stem when in the raised position.

Increasing the heat capacity of the stem will decrease the rate of temperature rise of the stem inasmuch as for the same amount of heat transferred to the stem, the increase in stem temperature will be less. For example, if the heat capacity of the stem is doubled, the time that the grapple stem can be held in the lowered position before it increases to the same temperature as before would be approximately doubled. However, by the same token, increasing the heat capacity of the stem will also increase the time required to cool the stem when the stem needs to be cooled.

Decreasing the heating rate of the stem when in the lowered position, which decreases the operating temperature of the stem as well as the rate of temperature rise of stem during the time it is in the lowered position, can be effected by

1. Providing, in the region below the top head, additional thermal radiation shields between the stem and the top shield. At present, there are in effect, two thermal radiation shields, i.e., the stem guide tube and the guide sleeve. If two additional concentric tubes were provided, the heating rate of the stem would be almost halved inasmuch as most of the heat transfer from the top shield to the stem in this region is by thermal radiation.

2. Providing either forced cooling or an annular gas gap in the lower part (from elevation 0 to -30 inches) of the support body.

Increasing the cooling rate of the grapple stem when in the raised position, which will lower the operating temperature of the stem, can be effected by

1. In the upper part of the support body, i.e., at elevation above 130 inches, (a) decreasing the annular gap between the stem and the support body, (b) increasing the emissivity of the support body, and/or (c) providing forced cooling of the support body.

2. Using a cover gas having a higher thermal conductivity, such as helium. This would also be desirable from the standpoint of sodium frost considerations inasmuch as use of helium would increase the temperature of the support body above the top head and, therefore, reduce the length of the section of the support body which would be at below the freezing point of sodium. A drawback to using helium as the cover gas is that it would increase the heating rate of the stem when the stem is in the lowered position.

B. Seals in Nozzle Region

The only seals located in the nozzle region that would be subject to temperatures higher than 300°F are the seals for the hold-down actuating shafts. These seals would be subjected to a shaft temperature of greater than 300°F when the hold-down actuating shafts are raised after being in the lowered position for a prolonged period. During normal transfer operation, the maximum shaft temperature at the seals will probably be less than 300°F. It can be seen from the temperatures shown in Fig. 2 that the possibility of these seals seeing a shaft temperature greater than 300°F would be eliminated if the seals were located about 10 inches higher.

C. Seal Lubricant Temperature

While it is possible to program the operation of the IVTM so that the grapple stem temperature at the seals never exceeds 300°F, this does not mean that the seal lubricant will not be exposed to temperatures higher than 300°F. Lubricant remaining on the stem surface after the surface slides down past the wiper and scraper would be subjected to temperatures in excess of 300°F if the grapple stem is permitted to stay in the lowered position for an extended period. This would accelerate the thermal degradation of the lubricant (Ref. 4), the consequence of which may be increased consumption of lubricant and increased frequency of seal housing cleaning.

D. Sodium Frost

It is seen in Fig. 6 that the support body above the elevation of 40 inches is below the freezing point of sodium. Hence, the inside surface of this section of the support body is subject to sodium frost deposits. Calculations indicate that in 30 years, this surface would accumulate about 0.06" (≃ half the annulus gap) of frost from the sodium vaporizing from the wetted stem surface. It was assumed in the calculations that the number of transfer cycles per year is 115, and the bulk density of the frost is 10 lb/ft^3.

VI. CONCLUSIONS

1. The maximum grapple stem temperature at the grapple stem seals will be about 300°F if the seals are at design elevation and 195°F if the seals are 20" above design elevation, when the system is operating at dynamic thermal equilibrium.

2. If the grapple stem is held in the lowered position for longer than 10 minutes in the case of the seals at the design elevation and longer than 18 minutes in the case of the seals located 20" higher than the design elevation, the stem temperature at the seals will exceed 300°F when the stem is raised. In these instances, exposure of the seals to stem temperatures greater than 300°F can be avoided by raising the stem part of the way and letting the stem cool for a period of time before completing the up-stroke.

3. The only seals located in the nozzle region that may be subject to temperatures higher than 300°F are the seals for the hold-down shafts. The possibility of these seals seeing a shaft temperature greater than 300°F would be eliminated if these seals were located about 10 inches higher.

4. While it is possible to operate the IVTM so that the seals are not subjected to temperatures greater than 300°F, this does not mean that the seal lubricant will not be exposed to temperatures greater than 300°F.

5. Sodium frost deposition in the 1/8" annular gap between the grapple stem and the support body is calculated to be about one-half of the gap in 30 years, and, therefore, should not cause any operational problems.

6. Use of helium as the cover gas will increase the cooling rate of the grapple stem when the stem is in the raised position, but will also increase the heating rate of the stem when it is in the lowered position. Inasmuch as the grapple stem is normally in the raised position longer than in the lowered position, the operating temperature of the stem would be lowered.

VII. REFERENCES

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