ORNL
COPY

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-578

COPY NO. - 4

DATE - May 23, 1963

RELATIONSHIP BETWEEN PLUNGER TRAVEL AND SHIM ROD MOTION FOR TWO ORR CONTROL ROD BALL LATCH CONFIGURATIONS

J. Foster

ABSTRACT

The initial fraction of an inch of ORR control rod travel is calculated as a function of ball latch plunger travel. Further control rod insertion is independent of the ball latch mechanism. Equations of motion are presented, solved, and plotted for two ball latch configurations, the present ORR latch and redesigned latch presently being fabricated for test in conjunction with a pneumatic actuator. These relationships are required for the interpretation of experimental measurements in the ORR control rod test stand.

The acceleration problem is introduced and its significance pointed out. Acceleration relationships are solved in simplified form and the results plotted to demonstrate the value of the acceleration approach and its importance in ball latch analysis.

NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report. The information is not to be abstracted, reprinted or otherwise given public dissemination without the approval of the ORNL patent branch, Legal and Information Control Department.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Relationship between Plunger Travel and Shim Rod Motion for Two ORR Control Rod Ball Latch Configurations

Release of the ball latch in an ORR control rod mechanism frees the rod to drop into the core. The rod is accelerated by gravity and the supplemental hydraulic forces if the coolant water continues to flow. This memorandum is concerned with the initial fraction of an inch of control rod travel which takes place in two different ball latch designs as the components move from their latched positions to the positions at which the control rod is released to drop. The arrangement of the ball latch components is such that each increment of plunger and ball motion permits the control rod to commence its insertion into the core by some specific corresponding increment of travel. The relationships between ball latch plunger travel and control rod travel presented herein are calculated and not experimental. They are required to permit interpretation of the experimentally measured values for these same quantities. Discrepancies observed between the calculated and experimental results constitute evidence of friction, binding, dimensional variations, or other possible departures from ideal conditions of performance.

Figure 1 represents the ball latch which has been in service in the ORR to date. The two specific configurations for which these analyses have been made are shown in Figs. 2 and 3. Figure 2 represents the significant details of the configuration presently in use at the ORR and pictured in Fig. 1, and Fig. 3 represents the configuration presently being prepared for a test with a pneumatic actuator replacing the magnet which has been used to date in the ORR.

Present Arrangement — Fig. 2

Figure 2 shows the ball latch in the initial or "cocked" position. Ball motion is determined as a function of plunger travel, and the consequent control rod travel is determined as a function of ball motion. For analytical purposes, the full travel must be considered as a series of four sequential ranges of motion. The first range of travel relates

ORNL-LR-Dwg. 66078
Unclassified

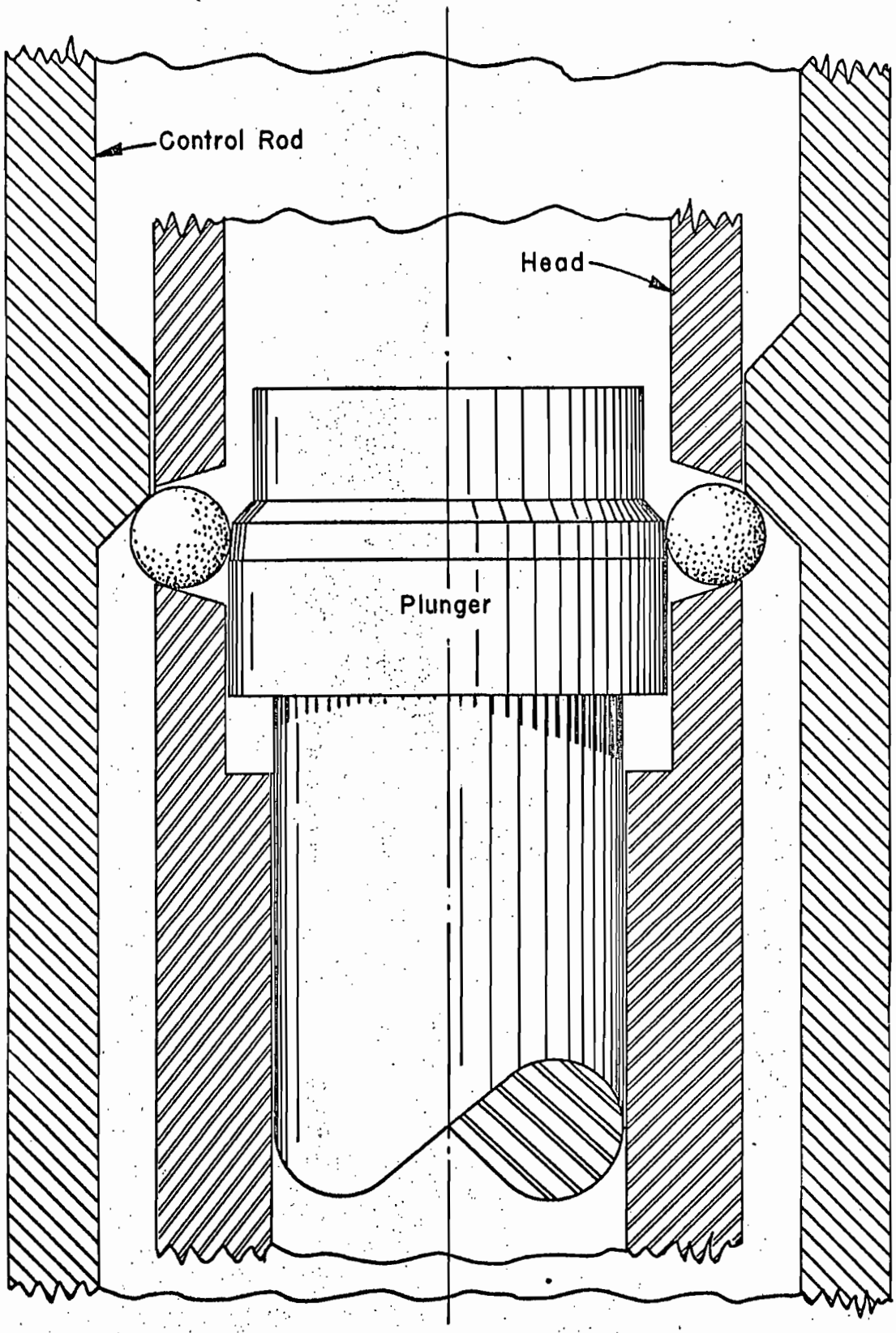

FIGURE 1

ORNL-LR-Dwg. 66079
Unclassified

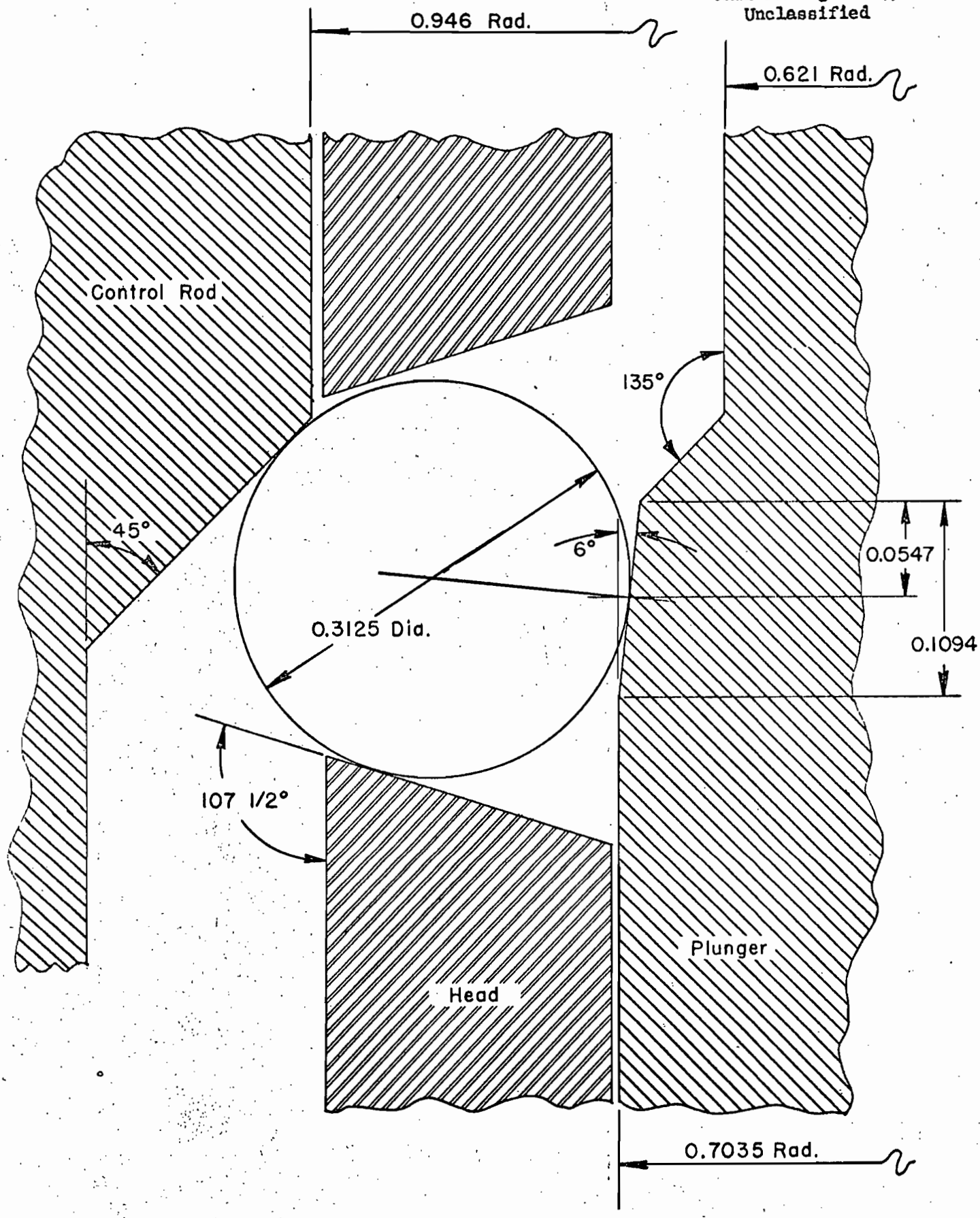

FIGURE 2

control rod motion to plunger travel from the initial plunger position to that position at which the plunger can be lowered no farther without ceasing to remain tangent to the ball at the upper end of the 6-deg plunger surface. The second range of motion continues from this point at which the plunger shoulder formed by the 6-deg and 45-deg surfaces commences to slide over the ball and continues to the point at which the ball has retracted to the position at which it is just commencing to lose tangency to the 45-deg control rod shoulder surface. The third range of motion is for further retraction of the plunger to that point at which the balls just commence to become tangent to the 45-deg surface on the plunger. The fourth range of motion is from this point to the position at which control rod release occurs. These four ranges of motion will be referred to as Ranges 1, 2, 3, and 4.

The results of the analysis are expressed in terms of three variables:

d = radial distance from the assembly center line to the center of each ball, in.

s = downward vertical displacement of the control rod measured from the initially cocked position, in.

v = downward vertical displacement of the plunger measured from the initially cocked position, in.

The analytical relationships between these variables are listed below for each of the four ranges of motion.

<u>Range 1</u>:

$v = 0$	to	$v = 0.0547$ in.
$d = 0.8532$	to	$d = 0.8476$ in.
$s = 0$	to	$s = 0.0073$ in.

$$s = 0.13381\ v$$

$$d = 0.85315 - 0.10173\ v$$

Range 2:

$v = 0.0547$ to $v = 0.1044$ in.

$d = 0.8476$ to $d = 0.8355$ in.

$s = 0.0073$ to $s = 0.0232$ in.

$$0.63585\ s^2 - 0.22728\ s + 0.002832 = -v^2 + 0.073190\ v + 0.47960\ sv$$

$$d = 0.85315 - 0.76034\ s$$

Range 3:

$v = 0.1044$ to $v = 0.1633$ in.

$d = 0.8355$ to $d = 0.8026$ in.

$s = 0.0232$ to $s = 0.0816$ in.

$$1.0994\ d^2 - 1.5771\ d + 0.54808 = -v^2 + 0.61118\ v - 0.63060\ dv$$

$$1.0994\ d^2 - 2.1425\ d + 1.0282 = -s^2 + 0.79424\ s - 0.63060\ ds$$

These two equations must be solved for a series of d values covering the stated range and the corresponding values for v and s determined.

Range 4:

$v = 0.1633$ to $v = 0.1802$ in.

$d = 0.8026$ to $d = 0.7897$ in.

$s = 0.0816$ to $s = 0.1481$ in.

$$0.63549\ v^2 + 0.079643\ v - 0.013042 = -s^2 + 0.20984\ s + 0.47943\ sv$$

$$d = 0.92672 - 0.76028\ v$$

The control rod is released at the following values of v, d, and s:

$v = 0.1802$ in.

$d = 0.7897$ in.

$s = 0.1481$ in.

Solution of Equations:

The values of s and v determined by solving the equations over the four ranges are listed in Table I and plotted in Fig. 4.

Redesigned Test Plunger — Fig. 3

The general method of operation for this design is similar to that described for the arrangement in Fig. 2. The absence of the double taper on the plunger reduces to two the number of ranges of motion for which separate analytical expressions are required. The first range of motion is from the initially cocked position to the position at which the ball is about to lose tangency to the 54-deg control rod shoulder surface, and the second range is from this point to the position at which control rod release occurs. These will be referred to as Ranges 1 and 2 respectively. The two sets of analytical relationships are listed below. Nomenclature is consistent with that used previously.

Range 1:

$v = 0$ to $v = 0.0548$ in.

$d = 0.8258$ to $d = 0.7991$ in.

$s = 0$ to $s = 0.0279$ in.

$s = 0.50887\ v$

$d = 0.82582 - 0.48844\ v$

Range 2:

$v = 0.0548$ to $v = 0.2658$ in.

$d = 0.7991$ to $d = 0.6960$ in.

$s = 0.0279$ to $s = 0.2626$ in.

$$0.26229\ v^2 + 0.18568\ v - 0.30801\ sv - 0.010965 = -s^2 + 0.44341\ s - 0.012060$$

$d = 0.82582 - 0.48844\ v$

ORNL-LR-Dwg. 66080
Unclassified

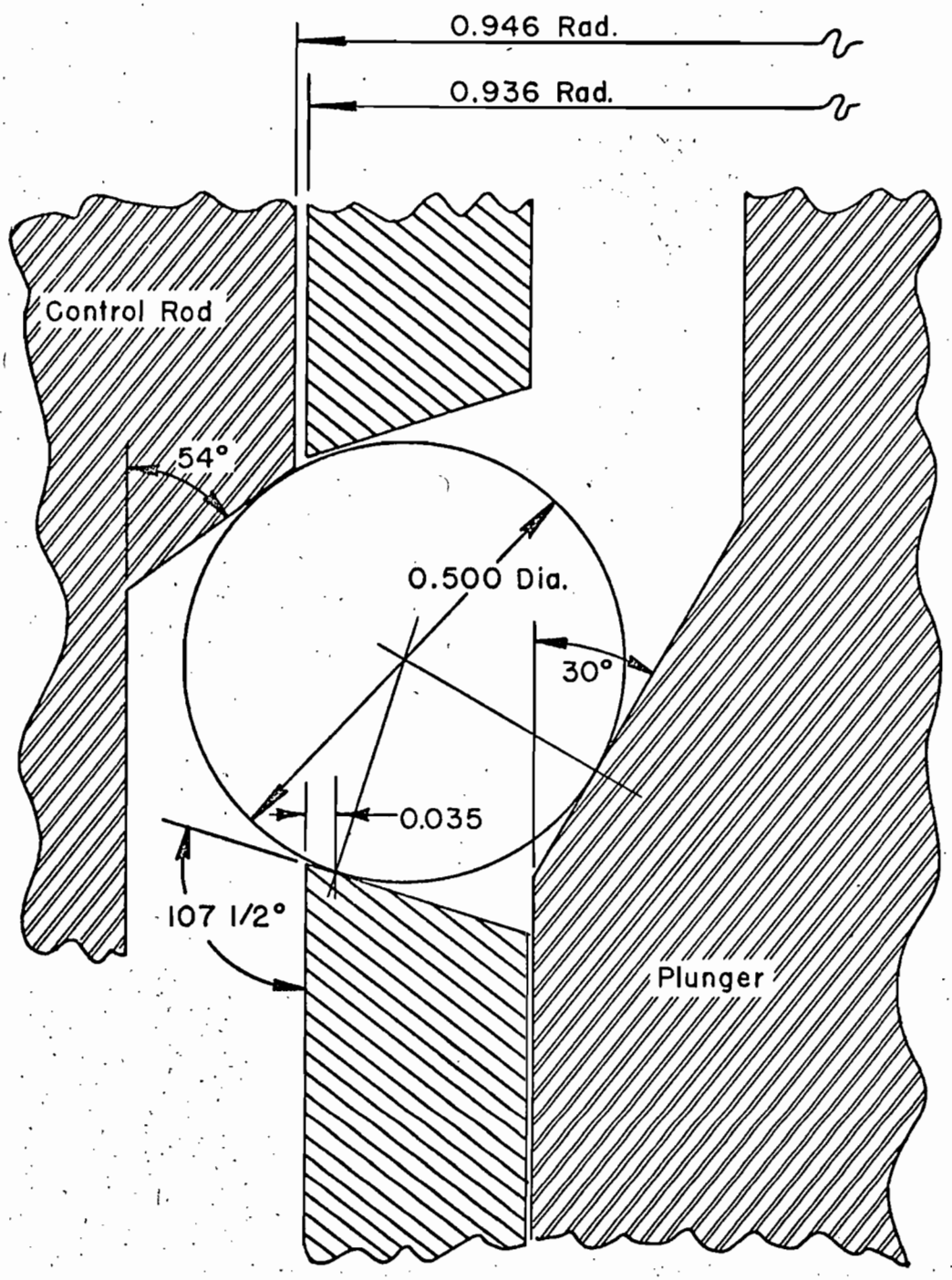

FIGURE 3

TABLE I

Range	Vertical Plunger Travel v — in.	Vertical Control Rod Travel s — in.	Radial Distance to Ball Center Line d — in.
1	0	0	0.853
1	0.010	0.0013	0.852
1	0.020	0.0027	0.851
1	0.030	0.0040	0.850
1	0.040	0.0054	0.849
1	0.050	0.0067	0.848
1	0.0547	0.0073	0.847
2	0.060	0.0081	0.847
2	0.065	0.0091	0.846
2	0.070	0.010	0.845
2	0.075	0.012	0.844
2	0.080	0.013	0.843
2	0.085	0.015	0.842
2	0.090	0.017	0.840
2	0.095	0.019	0.839
2	0.100	0.021	0.837
2	0.104	0.023	0.836
3	0.118	0.030	0.830
3	0.128	0.038	0.825
3	0.137	0.046	0.820
3	0.145	0.055	0.815
3	0.153	0.064	0.810
3	0.163	0.082	0.8026
4	0.167	0.090	0.800
4	0.170	0.097	0.797
4	0.175	0.112	0.794
4	0.178	0.125	0.791
4	0.1802	0.148	0.7897

ORNL-LR-Dwg. 66081
Unclassified

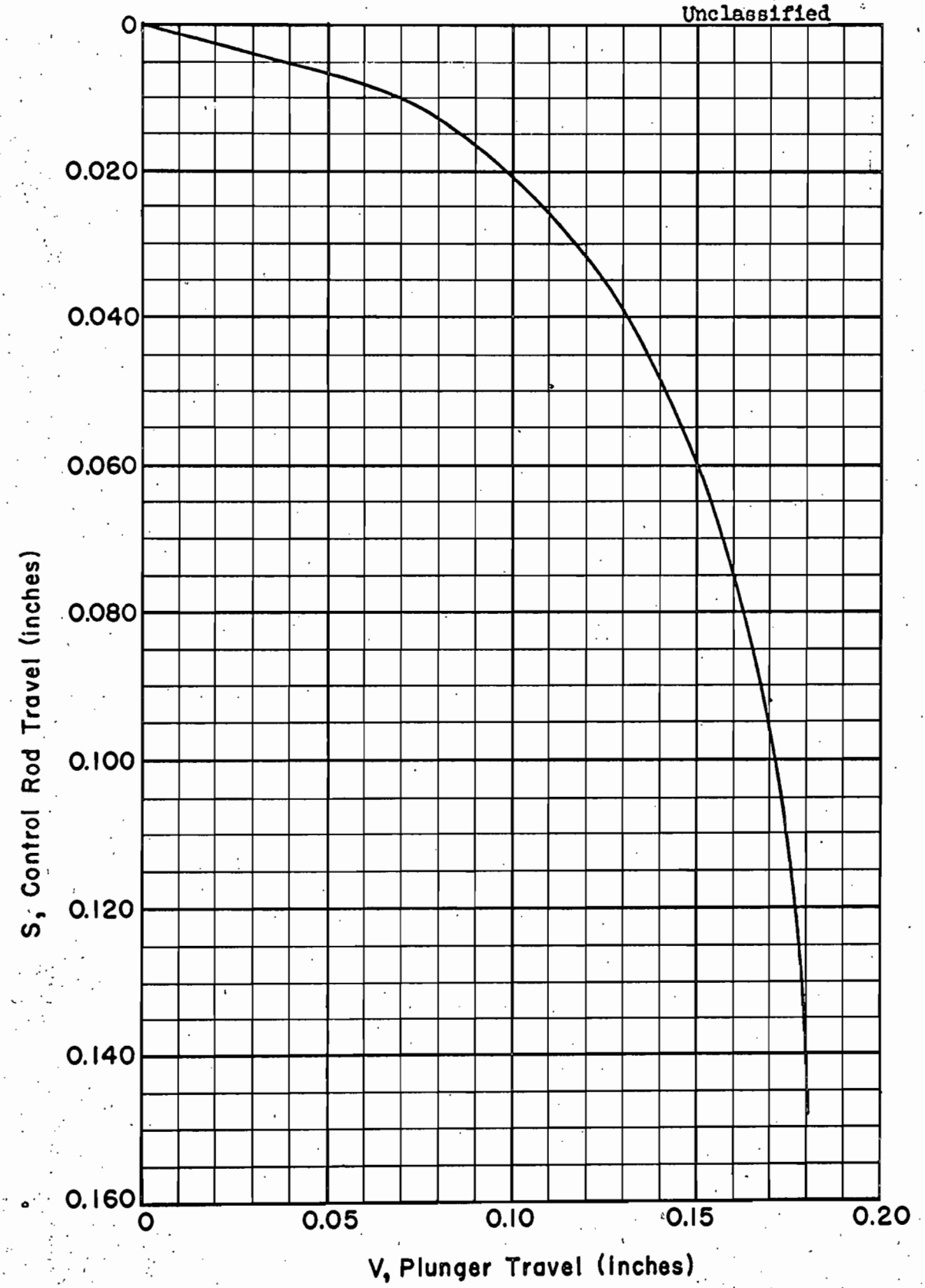

FIG. 4 CONTROL ROD VS. PLUNGER TRAVEL FOR DESIGN SHOWN IN FIG. 2.

Solution of Equations:

The values of s and v determined by solving the equations over the two ranges are listed in Table II and plotted in Fig. 5.

Acceleration Effects during Release

Consider now the question of acceleration of the control rod and of the ball latch plunger. For a given control rod acceleration, there is some acceleration of the plunger for which the balls, following the plunger, would exert no restraining force on the control rod during the release actions shown in Figs. 4 and 5. Consider the specific case of Fig. 4. If the control rod, which has an actual weight of 46 lb and a submerged weight of 32 lb, is subjected to a downward hydraulic force of 258 lb and all frictional and other restraining forces are ignored, the position of the control rod in a free fall can be determined as a function of time by the simple relationship:

$$s = \frac{1}{2} at^2$$

$$a = \frac{290 \times 32.2 \times 12}{46} = 2436 \text{ in./sec}^2$$

Referring to Table I the total control rod travel from the cocked to the released position is 0.148 in. Combining these two equations produces the relationship between time and the distance traveled by the unrestrained control rod:

$$s = 1218\ t^2$$

Corresponding values of s and t appear in Table III for the required range of s values and are plotted in Fig. 6.

The third column in Table III is the plunger travel corresponding to the various control rod positions listed. These values are taken from Fig. 4 and are also plotted in Fig. 6. This curve represents the rate at which the plunger would have to move downward for the assumed control rod free fall condition to obtain. If the plunger does in fact move at this or some greater rate, the release action of the ball latch is executed

TABLE II

Range	Vertical Plunger Travel v – in.	Vertical Control Rod Travel s – in.	Radial Distance to Ball Center Line d – in.
1	0	0	0.826
1	0.010	0.0051	0.823
1	0.020	0.010	0.821
1	0.030	0.015	0.818
1	0.040	0.020	0.816
1	0.050	0.025	0.813
1	0.0548	0.028	0.812
2	0.070	0.036	0.792
2	0.085	0.044	0.784
2	0.100	0.053	0.777
2	0.115	0.062	0.770
2	0.130	0.072	0.762
2	0.145	0.083	0.755
2	0.160	0.094	0.748
2	0.175	0.107	0.740
2	0.190	0.120	0.733
2	0.205	0.135	0.726
2	0.220	0.152	0.718
2	0.235	0.172	0.711
2	0.250	0.199	0.704
2	0.260	0.224	0.699
2	0.2658	0.263	0.696

ORNL-LR-Dwg. 66082
Unclassified

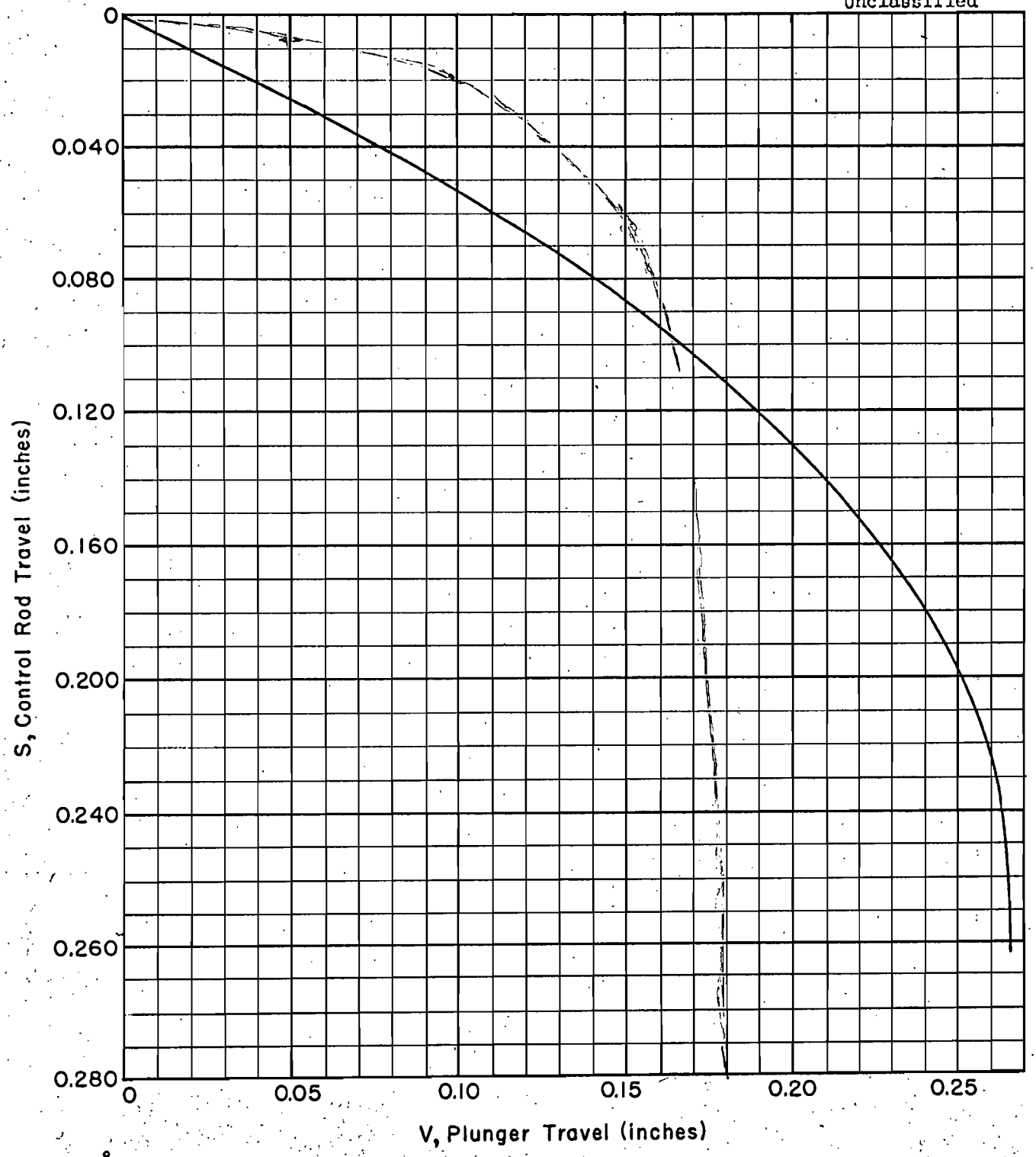

FIG. 5 CONTROL ROD VS. PLUNGER TRAVEL SHOWN IN FIG. 3.

ORNL-LR-Dwg. 66083
Unclassified

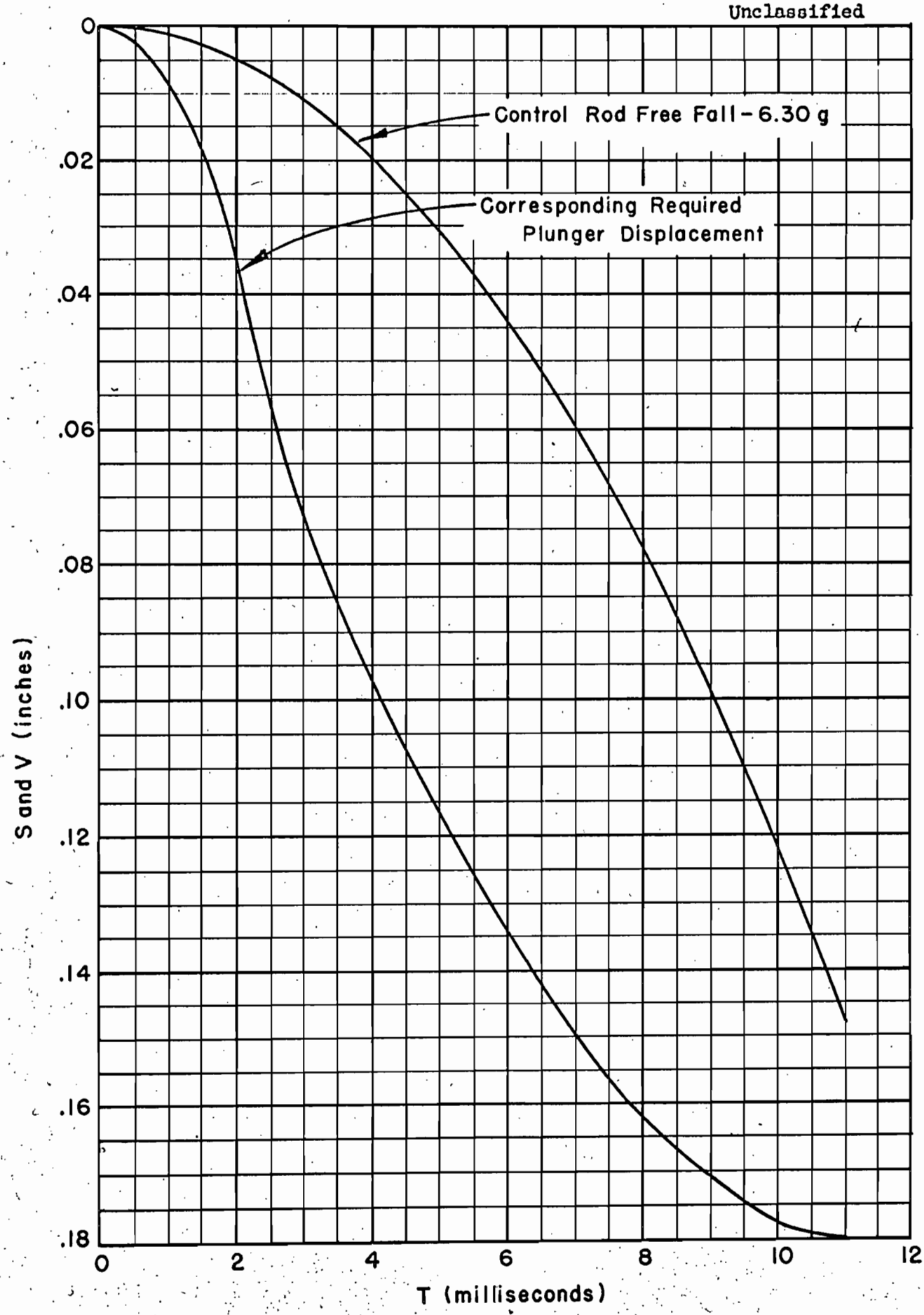

FIG. 6

TABLE III

Vertical Control Rod Travel s – in.	Travel Time (6.30 g Free Fall) t – sec	Corresponding Plunger Travel v – in.
0	0	0
0.001	0.00091	0.007
0.005	0.00203	0.036
0.010	0.00287	0.069
0.025	0.00453	0.108
0.050	0.00641	0.141
0.075	0.00785	0.160
0.100	0.00906	0.171
0.125	0.0101	0.178
0.148	0.0110	0.180

without the balls being subjected to a compressive load between the control rod and plunger. If, on the other hand, the plunger is found to move at a rate less than that indicated by Fig. 6, the control rod rides down on the balls and imparts a load to them until they are fully retracted.

The plunger displacement as a function of time is calculated for release spring forces of 55 and 70 lb and for plunger assembly weights of 6 and 8 lb as indicated below. The actual weight of the plunger assembly in the present ORR mechanism is approximately 8 lb. For the purpose of these simplified calculations, the release spring force is assumed constant over the 0.180-in. stroke. The release spring force in the presently used ORR assembly is about 70 lb in the cocked position, and this reduces to about 50 lb during the course of the initial 0.180 in. of plunger travel.

$$v = \frac{1}{2} at^2$$

$$\frac{a}{12} = \frac{F}{m} = \frac{(P + w)}{w} g$$

$$v = \frac{12\,(P + w)\,gt^2}{2w}$$

where

- a = plunger assembly acceleration, in./sec^2
- F = force (P + w), lb
- g = acceleration of gravity, ft/sec^2
- m = mass of plunger assembly, lb-sec^2/ft
- P = spring force, lb
- t = time, sec
- v = plunger travel measured from cocked position, in.
- w = plunger assembly weight, lb

The range of s values of interest is again from s = 0 to s = 0.148 in. which corresponds to values of v from 0 to 0.180 in. Solutions for the stated cases are listed in Table IV and plotted in Fig. 7.

TABLE IV

Plunger Travel v – in.	Plunger Travel Time, sec			
	P = 55 lb		P = 70 lb	
	w = 6 lb	w = 8 lb	w = 6 lb	w = 8 lb
0	0	0	0	0
0.025	0.00357	0.00405	0.00320	0.00364
0.050	0.00505	0.00573	0.00452	0.00515
0.075	0.00618	0.00702	0.00554	0.00631
0.100	0.00714	0.00811	0.00639	0.00729
0.125	0.00798	0.00906	0.00715	0.00815
0.150	0.00874	0.00993	0.00783	0.00892
0.175	0.00944	0.0107	0.00846	0.00964
0.180	0.00957	0.0109	0.00858	0.00978

ORNL-LR-Dwg. 66084
Unclassified

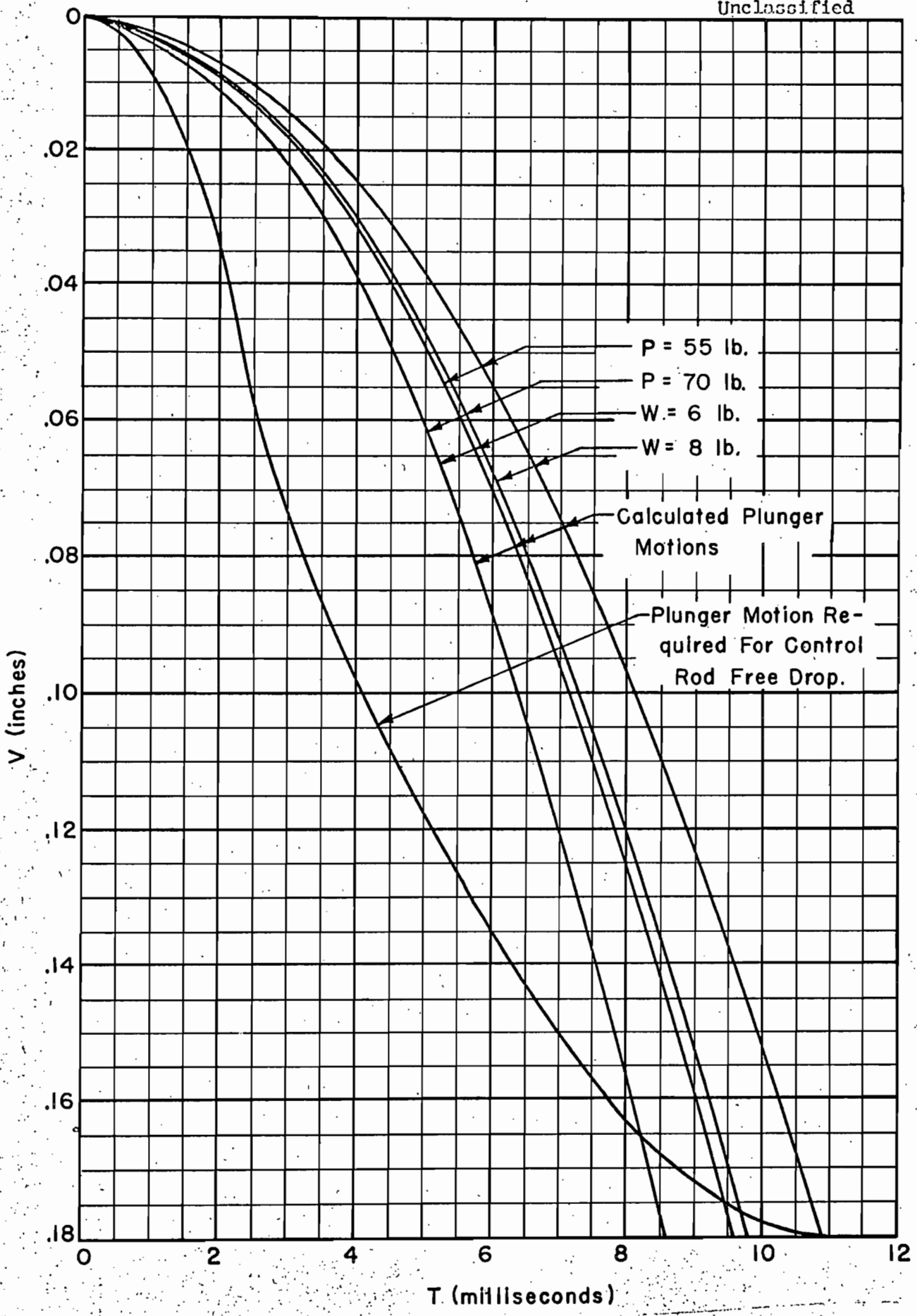

FIGURE 7

Reference to Fig. 7 indicates clearly that the acceleration of the plunger assembly is not great enough to "snatch" the balls out from under the control rod and permit a control rod free fall during ball latch release. The fact that the acceleration of the plunger assembly may equal or exceed that of the control rod must not lead to confusion. The compensating fact is shown in Fig. 4, namely, that through most of the release action the plunger assembly travel is several times the corresponding control rod displacement.

A similar position and acceleration analysis can be made for the configuration shown in Fig. 5. It must be remembered that the acceleration analysis presented herein is simplified and indicates velocities and accelerations for the plunger and especially for the control rod which exceed those to be expected in actual practice. The accelerating forces used must be reduced by the various opposing frictional and hydraulic forces to make more refined quantitative determinations.

Summary and Conclusions

Analytical expressions relating ball latch plunger travel to control rod travel are presented and solved for two ball latch configurations, the present ORR latch and a different latch being built for test. Results are presented graphically as Figs. 4 and 5. These considerations relate only to the initial fraction of an inch of control rod insertion which occurs during release action in the ball latch.

The test stand which has been constructed to test these mechanisms is being instrumented to measure the rate of travel of the control rod over its entire stroke. These analytically determined relationships are required for interpretation of the experimental results.

The brief effort devoted to acceleration is preliminary rather than exhaustive. It indicates an avenue of approach which affords additional and vital insight into the behavior of the ball latch mechanism. This insight is particularly important in studying latch components which exhibit unusual wear or deformation, a task which is frequently confused by the alternate possible explanations of damage which could have occurred during

either cocking or scramming of the mechanism. The acceleration calculations are based upon simplifying assumptions which are stated. They indicate an approach which, to yield accurate results, must be refined to account for decelerating forces imposed by mechanical friction and hydraulic resistance.

Distribution

1-3. DTIE, AEC
4. M. J. Skinner
5-6. Central Research Library
7. Document Reference Section