Technical Report Documentation Page

1. REPORT No.

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

Asphalt Concrete Compaction Studies Using Nuclear Devices

5. REPORT DATE

1967

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

Zube, Ernest

8. PERFORMING ORGANIZATION REPORT No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

State of California
Highway Transportation Agency
Department of Public Works
Division of Highways

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

13. TYPE OF REPORT & PERIOD COVERED

12. SPONSORING AGENCY NAME AND ADDRESS

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

From document:

The purpose of this report is to provide a summary of previous studies of the California Division of HIghways on compaction of asphalt concrete, and also to present a resume of our present work on AC compaction methods including so-called thick lift pavements. In our present study, nuclear equipment is used for determining density or relative compaction during rolling operations. Cores are also obtained from the finished pavement for density comparison.

17. KEYWORDS

18. No. OF PAGES:

26

19. DRI WEBSITE LINK

http://www.dot.ca.gov/hq/research/researchreports/1966-1967/67-35.pdf

20. FILE NAME

67-35.pdf

STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

ASPHALT CONCRETE COMPACTION STUDIES USING NUCLEAR DEVICES

67-35

Engineer

nce
c

MATERIALS & RESEARCH DEPARTMENT

ASPHALT CONCRETE COMPACTION STUDIES
USING NUCLEAR DEVICES**

By

Ernest Zube*

The compaction of asphalt concrete pavements has probably been the subject of more studies and publications than any other facet of the paving operation. There seems to be no doubt in the engineer's mind that proper and adequate compaction is most essential in constructing a stable and durable pavement. In fact, no aggregate and asphalt mixture becomes a pavement until it is properly compacted. Over the years, engineers and others have been conscious and concerned over this very important operation in the construction of any bituminous pavement.

I think we are all aware of recent increases in production. With present day paving operations utilizing bottom dump trucks and higher paver speeds, a 3000 to 4000 ton daily output of AC is not uncommon. As a result of this increased production, it is necessary to develop new and faster test methods to maintain effective control of the paving operation. Also, in spite of today's fairly rigid requirements, there is a continuing need for field test methods to properly administer these specifications.

The purpose of this report is to provide a summary of previous studies of the California Division of Highways on compaction of asphalt concrete, and also to present a resume of our present work on AC compaction methods including so-called thick lift pavements. In our present study, nuclear equipment is used for determining density or relative compaction during rolling operations. Cores are also obtained from the finished pavement for density comparison.

The Division of Highways, Materials and Research Department, in 1958 carried out a study program to develop better field methods and a more satisfactory compaction

*Assistant Materials and Research Engineer, Materials and Research Department, California Division of Highways.
**Presented at the Tenth Annual Highway and Public Works Conference, University of the Pacific, Stockton, California, March 7-9, 1967.

procedure for evaluating the adequacy of rolling operations in the densification of the pavement.[1]

This program covered a period of two years and had as its objective adequate compaction through the medium of specifying types, weights and number of rollers, number of coverages and reasonably rigid temperature requirements for the paving mixture at various stages of the placing and compacting.

Some of the primary factors influencing the compaction of asphalt paving mixtures were found to be:

1. Temperature of the mixture at the various phases of compaction, with emphasis being on an adequately high temperature at the time of initial rolling.

2. Air temperature as it effects mix temperature.

3. Gradation and shape characteristics of aggregates.

4. Asphalt content of the mixture.

5. Weight of rollers and number of coverages.

The Materials and Research Department had prior to 1958 developed a water permeability test, Figure 1, primarily for use in the construction of seal coats.[2] It became apparent that this test could also be utilized in the compaction of asphaltic pavements.

Water permeability tests were performed in conjunction with the various rolling operations to determine the possibility of establishing a definite relationship between permeability and density of the pavement which would provide a simple and rapid method for compaction control. Although permeability is a function of the void

(1) Ernest Zube, "Compaction Studies of Asphalt Concrete Pavement as Related to the Water Permeability Test", Presented at the Highway Research Board Meeting, Washington, D.C., January 1962.
(2) Ernest Zube, "Permeability Test", California Highways and Public Works, July-August 1963.

system in the pavement mass, it is influenced by the extent to which the voids are inner connected. However, it was gratifying to find a dependable relationship between pavement density, void content and permeability, Figure 2. We have consequently established a tentative maximum average permeability of 150 ml per minute for newly compacted AC pavements.

The compaction controls specified in our current standard specifications are based, to a large extent, on the data and experience from this two year study and are essentially as follows:

All initial rolling shall be performed when the temperature of the mixture is above 225°F and the sum of the air temperature plus the temperature of the mixture is between 300°F and 375°F. The initial or breakdown rolling shall consist of one complete coverage with a 2- or 3-axle tandem or 3-wheel roller weighing not less than 12 tons. This is followed by additional rolling consisting of at least three complete coverages with a pneumatic tired roller while the temperature of the mixture is above 150°F. The final rolling shall be performed with an 8-ton 2-axle tandem roller.

The statewide record sampling program, instigated by the Bureau of Public Roads in 1960, provided us with an excellent opportunity to evaluate the adequacy of our specified compaction controls. Relative compaction determinations were performed on hundreds of cores obtained from projects representing many different types of aggregates, different grades and amounts of asphalt and constructed at different seasons of the year.

Although the average relative density for these many and varied projects was 93 percent, analyses of the data on individual projects and the appearance of many of the cores gave ample evidence that our present method for controlling compaction was not providing the desired results in all instances, and that further field studies were required.

An example is shown in Figure 3. This pavement was placed in 3 layers. The base course showed 100% relative compaction, the middle or level course 92.5% and the top surface course showed only 89.5% relative compaction. In most instances, poor compaction can easily be identified by visual inspection of the core.

In another instant where the pavement received only the minimum compaction, and temperatures were below our requirements, the finished surface showed a water permeability of 1000+ ml/min. Additional rolling and increased mix temperature reduced the permeability to about 70 ml/min.

In the early 1960's the Foundation Section of our department purchased nuclear gages for the compaction control of soil embankments. We tried these gages for compaction control of asphaltic concrete. It was found, however, that these soil gages were not suitable for temperatures in excess of 140°F. This, of course, rendered the gages useless for hot mixes as it is obvious that if we are to exercise any positive control over compaction of asphalt pavements, we must be able to measure the density of the mat during the rolling operation.

The Pavement Section of Headquarters Laboratory has recently purchased two of the heat shielded nuclear gages. These new gages can withstand temperatures up to 350°F.

There are two types of nuclear gages, the backscatter type and the direct transmission type. The operating principle of each type for the determination of density of asphalt concrete is as follows:

(a) Backscatter Technique, Figure 4

The asphalt density gage contains a small, radioactive source which emits energetic gamma rays. These rays are scattered by the surface layer of the asphalt concrete back into the special high temperature gamma detectors. The only way radiation can reach the detectors is for it to enter the AC, then be reflected back to the detectors. The amount of detected radiation is correlated with the density of the AC; that is, as the radiation count is increased, the less dense the AC is.

We have found when using the backscatter gage, that the effective depth for determining the compaction of the material is limited to about 2 inches.

(b) Direct Transmission Technique, Figure 5

The direct transmission technique requires the insertion of the radioactive source (or detector) in the

AC to various selected depths (from 1" to 12"). In this case, a high percentage of the radiation reaches the detectors by transmission substantially along a direct line from the source to the detectors. The direct transmission technique is considerably more accurate than the back-scatter technique for AC pavements more than 2" in thickness.

The direct transmission gage is best suited for the compaction process, whereas the backscatter gage is more effective for completed pavements.

Field studies involving nuclear equipment were made during last year's construction season and are being continued this year. The following compaction procedures are being used:

1. Compaction is carried out according to our present Standard Specification requirements.

2. Additional rolling passes, particularly during the breakdown operation, are made as required.

3. Either all steel or all rubber compaction equipment is utilized.

4. The possibility of using vibratory rollers for the compaction of AC is being explored.

5. The compaction of AC in single lifts up to 5" in thickness is being evaluated.

Typical Field Study

On each contract we usually select from one to three locations, place thermocouples at various depths within the mixture, and record the air temperature.

A typical temperature gradient curve is shown in Figure 6. The temperature at mid-depth in the AC mixture drops from 275°F at the beginning of the break-down rolling to 175°F upon completion of the rolling. This occurs during a time interval of 80 minutes. The air temperature was about 75°F during this operation.

The following three types of rollers were usually used: a 12-ton tandem or 3-wheeler for breakdown, a pneumatic roller for intermediate rolling, and an 8-ton tandem for final rolling.

The first measurement was usually made before the breakdown, followed by measurements after each pass, up to six passes of the breakdown roller, and several passes of the pneumatic roller. From the data obtained, it was concluded that the ultimate density of the new pavement depends upon the number of breakdown passes, providing the temperature of the mix is still above 200°F. At any rate, one coverage, as specified in our present Standard Specification, is not sufficient to obtain the desired compaction. I would like to mention that by one coverage I mean two passes, one forward and one backward in the same path.

The following 3 figures show typical rolling patterns. As shown, up to six passes were made with the breakdown steel roller, also the pneumatic rollers. In some instances, a slight drop in density was indicated after the first or second pass with the pneumatic roller. This is probably due to some slight disturbance of the surface.

Figure 7 shows a comparison of our Standard Specification rolling and additional rolling up to six passes with the breakdown roller. Even with the additional rolling we obtained only about 93% relative compaction. Note that the temperatures are rather low.

Figure 8 shows breakdown with a 12-ton pneumatic followed by steel rolling. Note the steady increase in compaction with the pneumatic breakdown and intermediate steel rolling.

Figure 9 is another comparison of Standard Specification rolling with additional passes with a 12-ton steel breakdown roller. Our normal rolling produced about 93% compaction, whereas the extra rolling increased the density to about 97% of relative compaction.

In our study so far, conventional type rollers have been used with the exception of two test sections where an 8-ton tandem vibratory roller was used.

On one project, consisting of a 3" compacted lift, various combinations of vibratory rolling versus steel wheel rolling were tried. The maximum density obtained by our normal rolling procedure was 137 p.c.f. after the final pass with an 8-ton tandem roller equivalent to 92% relative compaction. The maximum density obtained by the 8-ton vibratory roller was 143 p.c.f. after three complete passes. This is equal to 96% of relative compaction. Prior to the vibratory rolling, the first breakdown pass was made with the vibrator off.

On the other project, complete comparisons between our standard rolling procedure versus the vibratory roller were not obtained due to some unfortunate circumstances which resulted in a considerable difference in the temperatures of the mixes of the two test sections.

We were able, however, to make a comparison on the first pass of the breakdown where the temperature of the mix in the two test sections was comparable. The density of the 4" compacted mat after one pass with the 12-ton steel roller was 130 p.c.f. as compared to 137 p.c.f. after one pass with the 8-ton vibratory steel roller.

Although we have not completed our evaluation of the vibratory roller, the results, so far, indicate vibratory rolling is capable of producing satisfactory densities with fewer passes. Vibratory rollers are used with excellent results extensively in Europe for the compaction of asphalt concretes with single layer depths of up to 12".

Thick Lift Compaction

In our last year's study we were also able to investigate the possibility of compacting AC in thicker lifts than provided in our Standard Specifications. Our present standards limit AC surfacings and bases to maximum compacted layer thicknesses of 2" and 3", respectively.

In August of 1966, a so-called thick lift test section of asphalt concrete, approximately 6000 feet in length, was constructed in the southern part of the state. The section was divided into three subsections for the purpose of making density measurements with nuclear gages where different types of rollers and roller patterns were used, see Figure 10.

The mix was a standard asphalt concrete base course ranging from 4" to 5.5" in compacted thickness and having 1-1/4" maximum size aggregates.

The following data was obtained on each of the three subsections:

1. Temperature measurements

2. Density determinations

3. Water Permeability Tests

4. Profilograph records

5. Obtaining 4" dia. cores

In Subsection "A" (Standard Specification Rolling) the rolling pattern consisted of two coverages by a 12-ton tandem for the breakdown rolling, two coverages by a 9-ton pneumatic during intermediate rolling, with final rolling being done by a steel 12-ton tandem. A density of 133 p.c.f. was obtained after the second pass of the 12-ton breakdown. No appreciable increase in density was evident during the intermediate rolling with the 9-ton pneumatic. A maximum density of 137 p.c.f. was obtained after the final pass with the 12-ton steel tandem.

For Subsection "B" (All Steel) the breakdown rolling consisted of three coverages by a 12-ton steel tandem followed by three intermediate coverages by a 16-ton, 3-axle steel tandem, and final rolling by a 12-ton steel tandem. A density of 134 p.c.f. was obtained on the third pass and a maximum of 141 p.c.f. after three passes with a 16-ton, 3-axle steel tandem.

For Subsection "C" (All Rubber) the breakdown was made with a 16-ton pneumatic tired roller using a 30 psi tire pressure. After two passes the spray bar failed so that it was necessary to make a few coverages with a lighter pneumatic. This was then followed by five coverages with the original 16-ton pneumatic with tire pressures ranging from 60 to 120 psi. The intention was not to use a steel roller on this section; however, some slight rutting caused by the heavy pneumatic made it necessary to finish rolling with an 8-ton steel tandem. A density of 133 p.c.f. appeared to be the maximum which could be obtained with a 16-ton pneumatic roller. When the tire pressure was increased to 120 psi, the nuclear gage indicated that the density was actually somewhat decreased. This may have been caused by the slightly uneven surface caused by the tires and thus creating small air pockets which prevented uniform contact with the AC surface. A density of 138 p.c.f. was obtained by an 8-ton steel tandem used to iron out the ruts caused by the pneumatic.

One difficulty we have experienced when using pneumatic rollers for the breakdown, especially on thick lift sections, is that the pneumatic roller cannot come within 8" of the edge of the pavement without breaking down or flattening the edge. In other words, 16" of a 12' lane will be somewhat less compacted. However, this can probably be overcome by modifying the rolling procedure, such as using a steel wheel roller for the edge breakdown.

The maximum laboratory test density using the California kneading compactor averaged 150.5 p.c.f. The relative field compaction for the three test sections was:

A. 91% (Std. Spec.)

B. 94% (All Steel)

C. 92% (All Rubber)

The water permeability of the various sections was also determined. The tests were made approximately one hour after the final rolling and were repeated at the same locations after a period of four days. The four-day results did not show any significant difference between the three sections.

Profilograph readings were taken on the three test sections after completion of final rolling, with the following profile index results:

Section A	37 inches/mile
Section B	14.5 " "
Section C	25 " "

The results show the base layer to be quite rough; this may have been the result of the first attempt by the crew to place the thicker lift.

After placing the final lift of the AC, the profile index results were reduced to a level indicating a normal smooth riding pavement.

Section A	(Normal Rolling)	3.1	inches/mile	
Section B	(All Steel Rolling)	3.7	"	"
Section C	(All Rubber Rolling)	3.0	"	"

On a small 1" to 6" thick wedge section constructed in 1965, the highest density was obtained on the section between 3-1/2" and 4" in thickness.

Table A shows the density comparison between nuclear gage readings and actual cores obtained from the finished pavement for twelve projects. The average density of the cores was 141 p.c.f. as compared to 140 p.c.f. for the nuclear density readings.

CONCLUSIONS

Temperature

1. The temperature of the mix is one of the most important factors in obtaining a well-compacted pavement.

2. The temperature of the mix at the time of breakdown rolling should not be less than 250°F. This is a 25° increase over our present requirement.

3. Our present temperature requirement of 150°F for the intermediate rolling by pneumatic rollers should be increased to about 180°F.

4. The importance of maintaining the proper temperature of the mix must be stressed to paving inspectors. Inspectors should be encouraged to reject loads when the temperature of the mix is not within the specified parameters.

5. Our present combination air and mix temperature range appears to be satisfactory.

Comparison of Compaction Equipment

1. There appears to be no significant difference in densities obtained by the various types of equipment used; i.e., all steel versus all rubber versus a combination of steel and rubber, in compacting a thick lift section. This opinion, however, is based on one test section only, in Orange County.

2. I do not want to convey the impression that we are against pneumatic rolling. On many jobs, a slight increase usually occurred after the first or second pass of the pneumatic roller. I definitely believe that pneumatic rolling is an essential part of the compaction procedure.

Effects of Additional Rolling

1. Our specification for the types of compaction equipment to be used is satisfactory. However, one coverage which we now specify for breakdown rolling is not sufficient for proper compaction. The number of coverages should be increased to at least three. These additional coverages together with better temperature control should provide, in most instances, the desired 95% relative compaction.

2. It appears that it is not so much the type of roller, but the number of coverages which has the most significant effect on density providing the temperature of the pavement is above 175°F when compaction is completed.

Compaction Control

1. The water permeability test can be used as an aid in compaction of bituminous surfaces. If the average permeability is in excess of 150 ml/min, additional rolling, particularly with the pneumatic roller, should be ordered. The pneumatic rolling will add but little to the density of the pavement, but it will provide a sealing action of the surface and thus retard the entrance of air and water into the new pavement.

2. The nuclear density gage can be used as a compaction control test for establishing the compaction procedure, such as minimum number of roller passes. This would require only the purchase of a few gages by each District. Once the rolling pattern is established at the start of the job, only occasional checking with the nuclear gage should be necessary.

3. Or: Our present standard specification requirements should be changed to provide an end result by specifying a minimum relative compaction, such as 95% minimum, based on laboratory-compacted specimen. The nuclear gage would be used in the field to assure that this requirement was met. This would necessitate the purchase of a larger number of gages by the Districts as this method would require the almost continual use of nuclear gages at each job site.

4. By analyzing our compaction data from the 1966 and the coming 1967 construction season, we are going to recommend a definite compaction method, which will probably be similar to our present one, except for increases in compaction temperature and number of roller passes. No increase in mixing temperature appears to be necessary. We also hope to be able to recommend an increased maximum permissible thickness of compacted mixture.

5. Increased compaction of our asphalt pavements will provide better resistance to water action and fatigue. It will also decrease the voids and the rate of hardening of the asphalt, thus insuring a longer service life and a more durable asphalt pavement.

- - - - - - - - - - -

Some of the data presented in this report was collected on a research project financed jointly by the California Division of Highways and the U. S. Bureau of Public Roads. The opinions, conclusions, and findings of this report are those of the author and not necessarily those of the California Division of Highways or the Bureau of Public Roads.

TABLE A

Contract	Average Density of Cores (P.C.F.)	Density by Nuclear Gage (P.C.F.)	Max. Lab Density (P.C.F.)	% Relative Compaction (Nuclear Gage)	Variance Between Cores & Nuclear Densities (P.C.F.)
A	145	144	151	95	1.0
B	137	137	147	93	0
C	147	146	149	98*	1.0
D	140	137	151	91	2.0
E	136	137	151	91	1.0
F	136	135	147	92	1.0
G	137	139	146	95*	2.0
H	139	138	147	94	1.0
I	140	138	151	92	2.0
J	144	142	153	94	2.0
K	146	144	151	95	2.0
L	149	148	156	95	1.0
Average	141	140	150	94 93**	1.5

*Three additional passes by breakdown roller (12 ton tandem)

**For test sections rolled under our present specifications, the average relative compaction is equal to 93%.

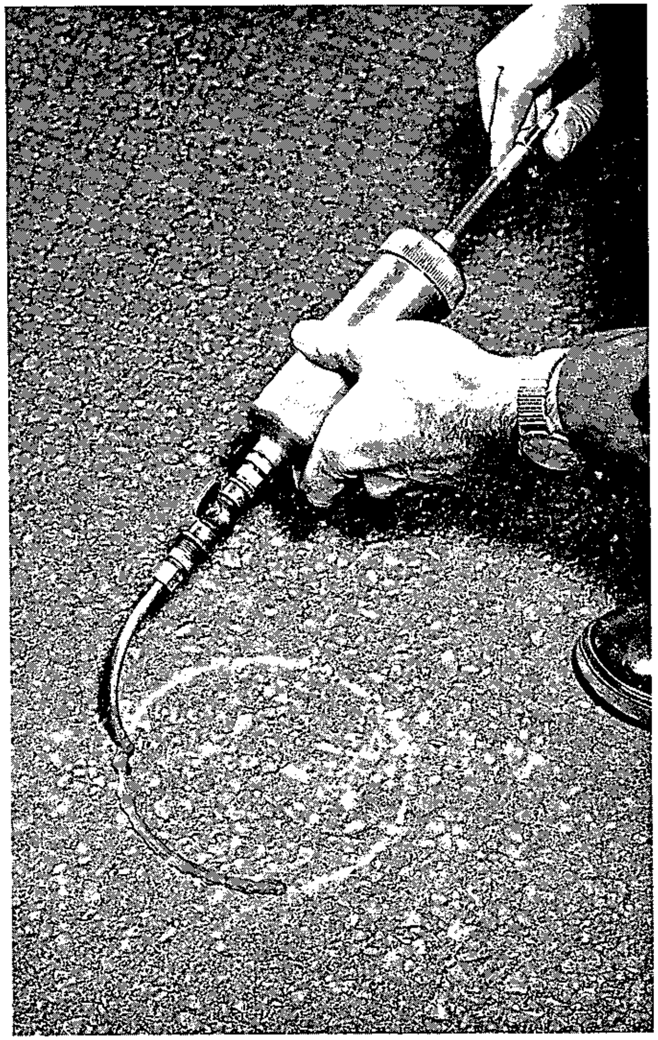


Figure 1A
Forming grease ring

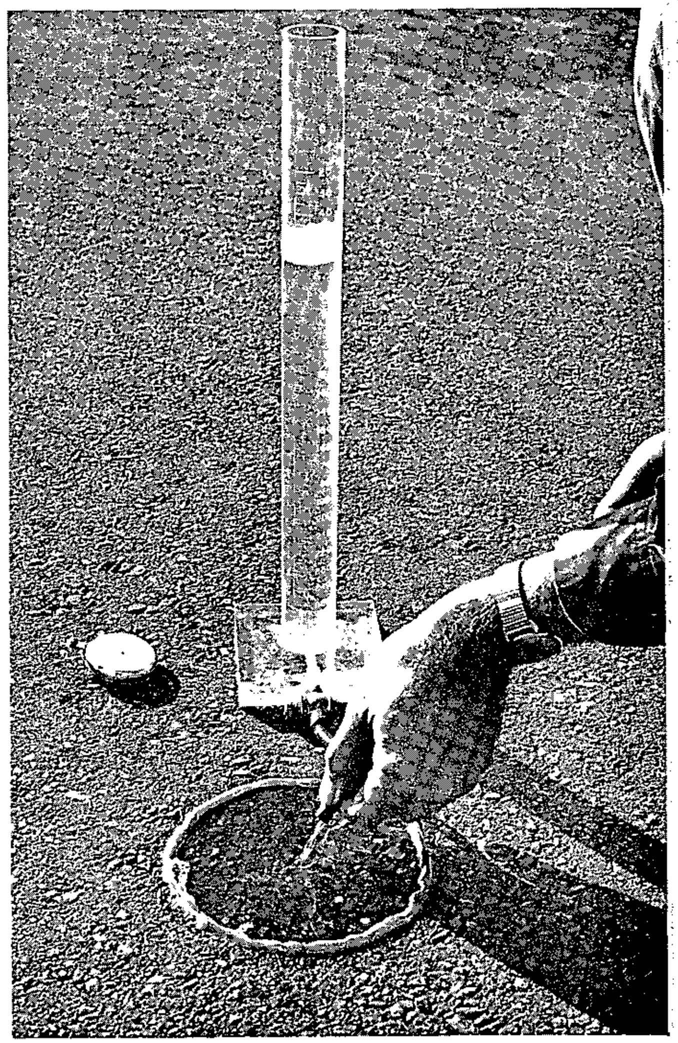


Figure 1B
Applying water solution
to pavement surface

Performing Permeability Test

FIGURE 2

PERMEABILITY-RELATIVE COMPACTION RELATION FOR TEN DIFFERENT PROJECTS

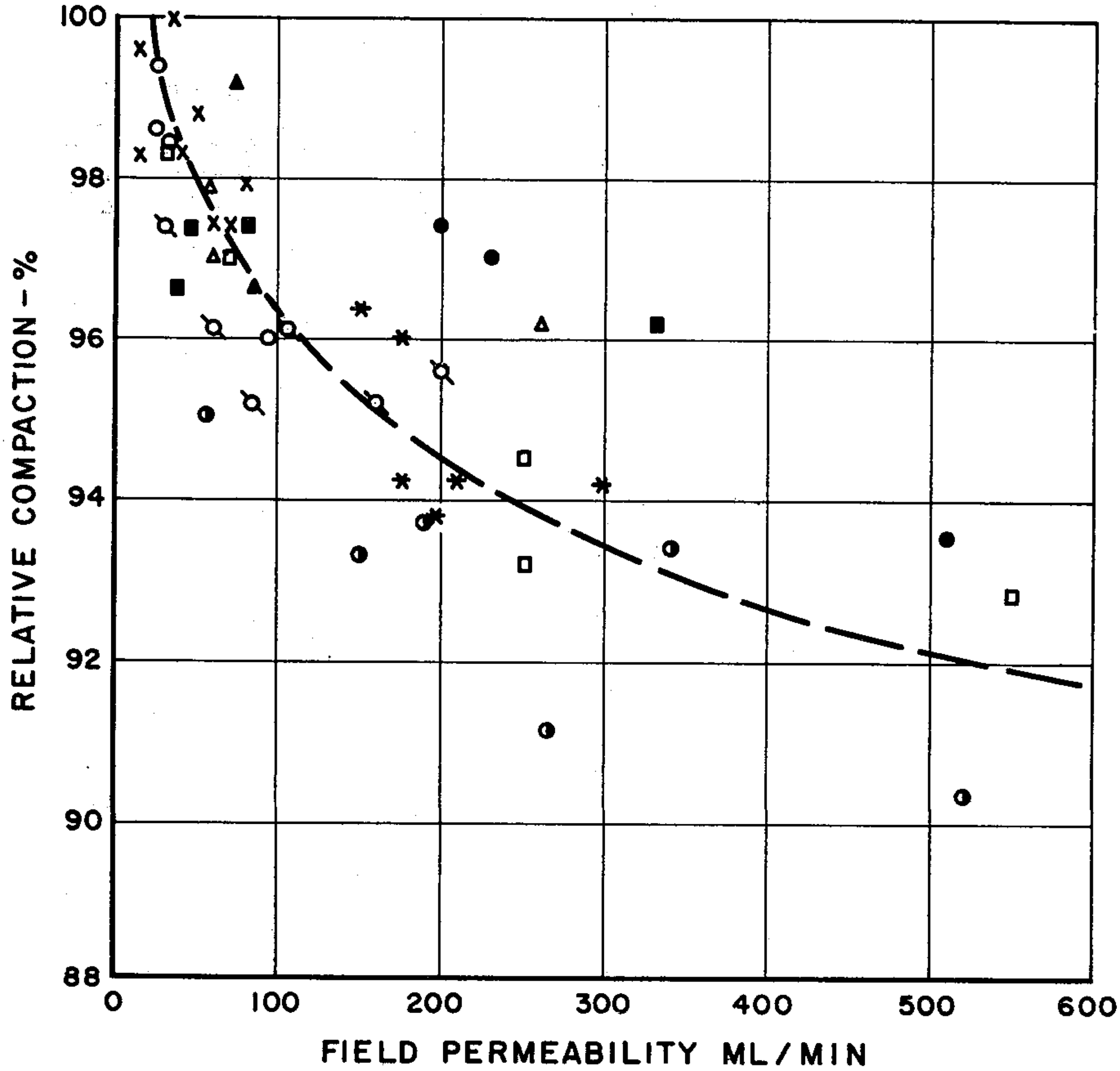


FIGURE 3

COURSE	FIELD COMP. S.G.	LAB. COMP. S.G.	RELATIVE COMP.-%
SURFACE	2.13	2.38	89.5
LEVEL	2.20	2.38	92.5
BASE	2.40	2.40	100

FIGURE 4

TECHNIQUE EMPLOYED FOR MEASURING DENSITY OF ASPHALT CONCRETE

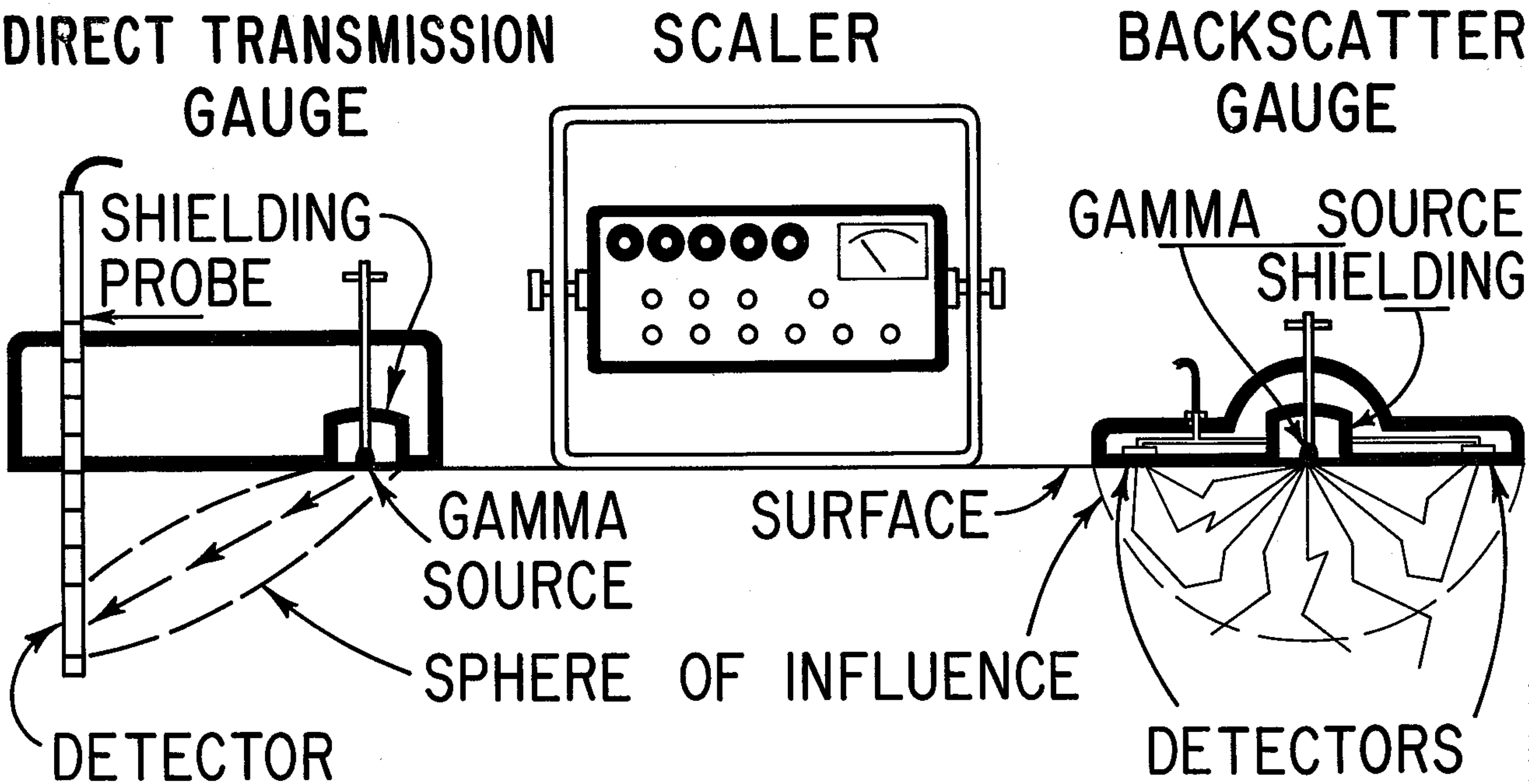
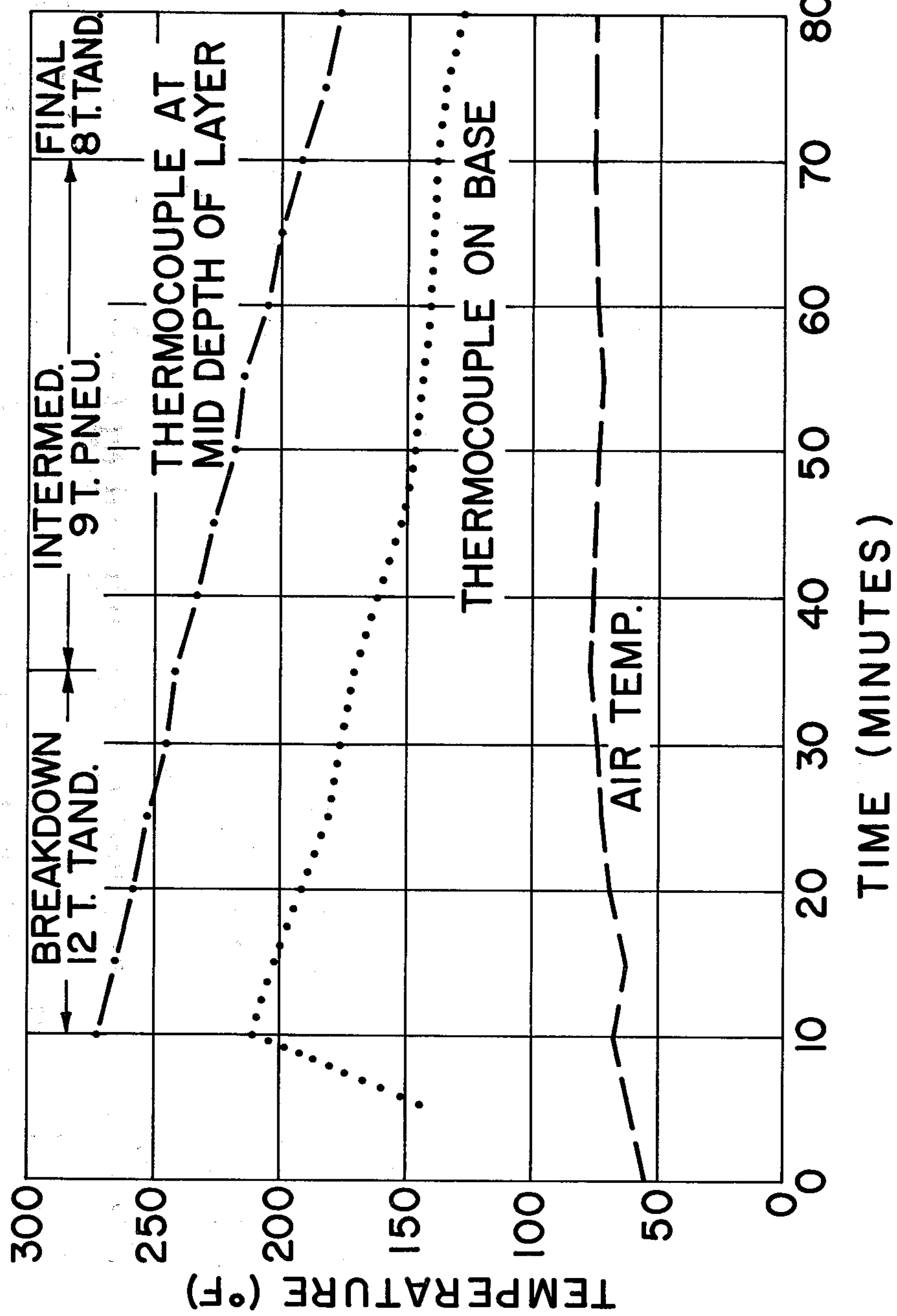
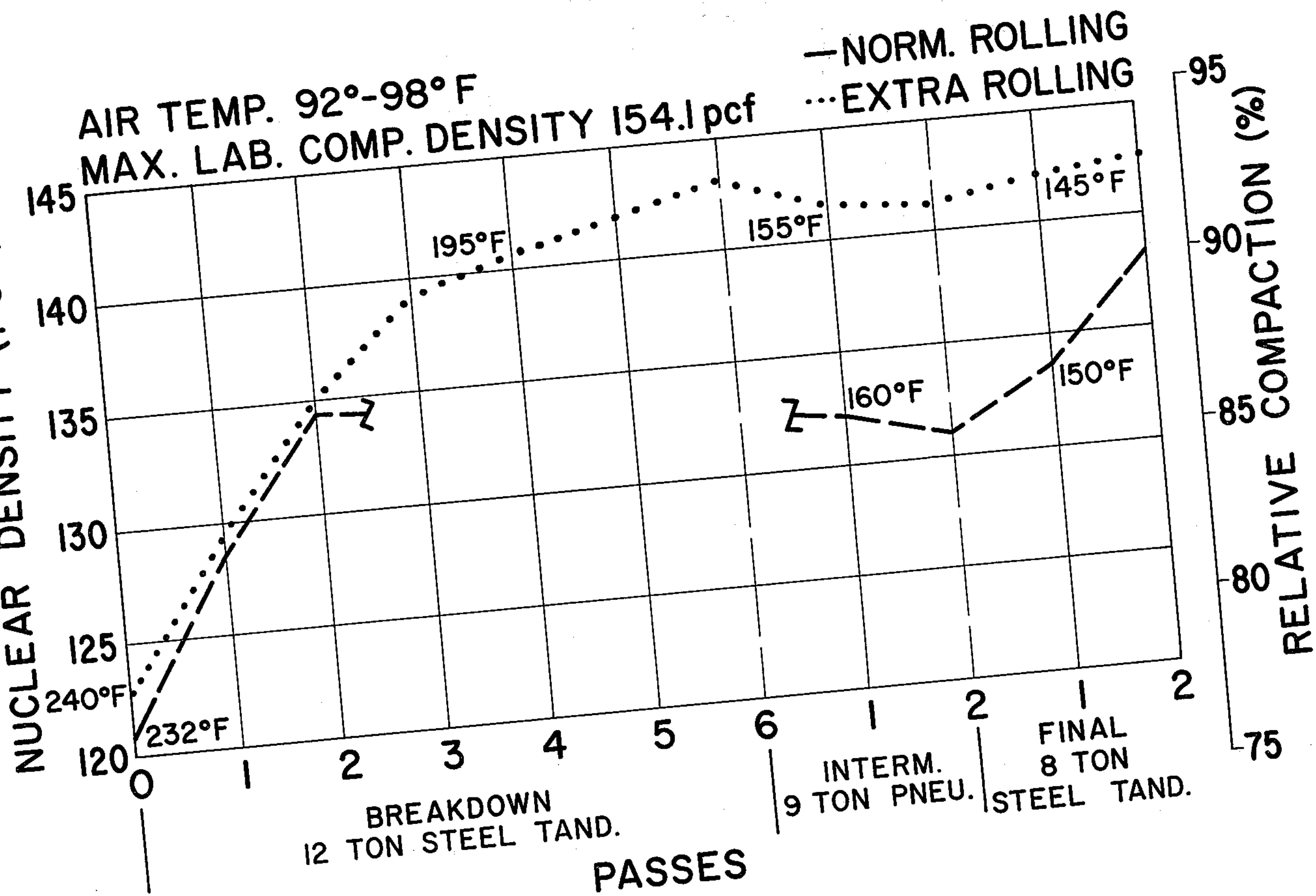


FIGURE 6

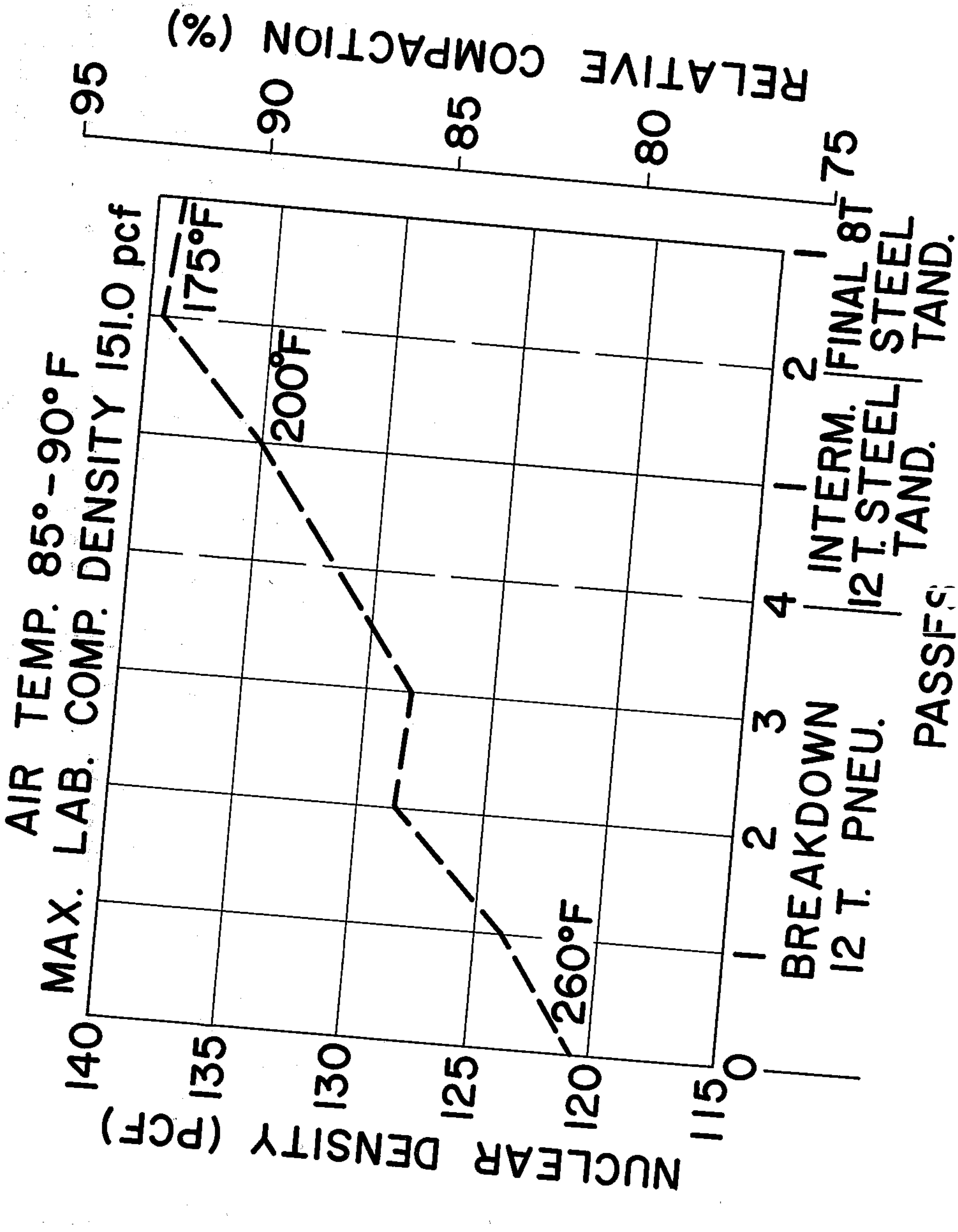

BREAKDOWN
12 T. TAND.
INTERMED.
9 T. PNEU.
FINAL
8T. TAND.
THERMOCOUPLE AT
MID DEPTH OF LAYER
THERMOCOUPLE ON BASE
AIR TEMP.
TIME (MINUTES)
TEMPERATURE (°F)
0
10
20
30
40
50
60
70
80
300
250
200
150
100
50
0



AIR TEMP. 92°-98° F
MAX. LAB. COMP. DENSITY 154.1 pcf
— NORM. ROLLING
··· EXTRA ROLLING
NUCLEAR DENSITY (PCF)
145
140
135
130
125
120
RELATIVE COMPACTION (%)
95
90
85
80
75
240°F
232°F
195°F
155°F
160°F
150°F
145°F
0
1
2
3
4
5
6
1
2
1
2
BREAKDOWN
12 TON STEEL TAND.
INTERM.
9 TON PNEU.
FINAL
8 TON
STEEL TAND.
PASSES

FIGURE 7

FIGURE 8



MAX. LAB. COMP. DENSITY 151.0 pcf
AIR TEMP. 85°-90°F
RELATIVE COMPACTION (%)
95
90
85
80
75
NUCLEAR DENSITY (PCF)
140
135
130
125
120
115
175°F
200°F
260°F
0
1
2
3
4
1
2
1
BREAKDOWN
12 T. PNEU.
INTERM.
12 T. STEEL TAND.
FINAL 8T STEEL TAND.

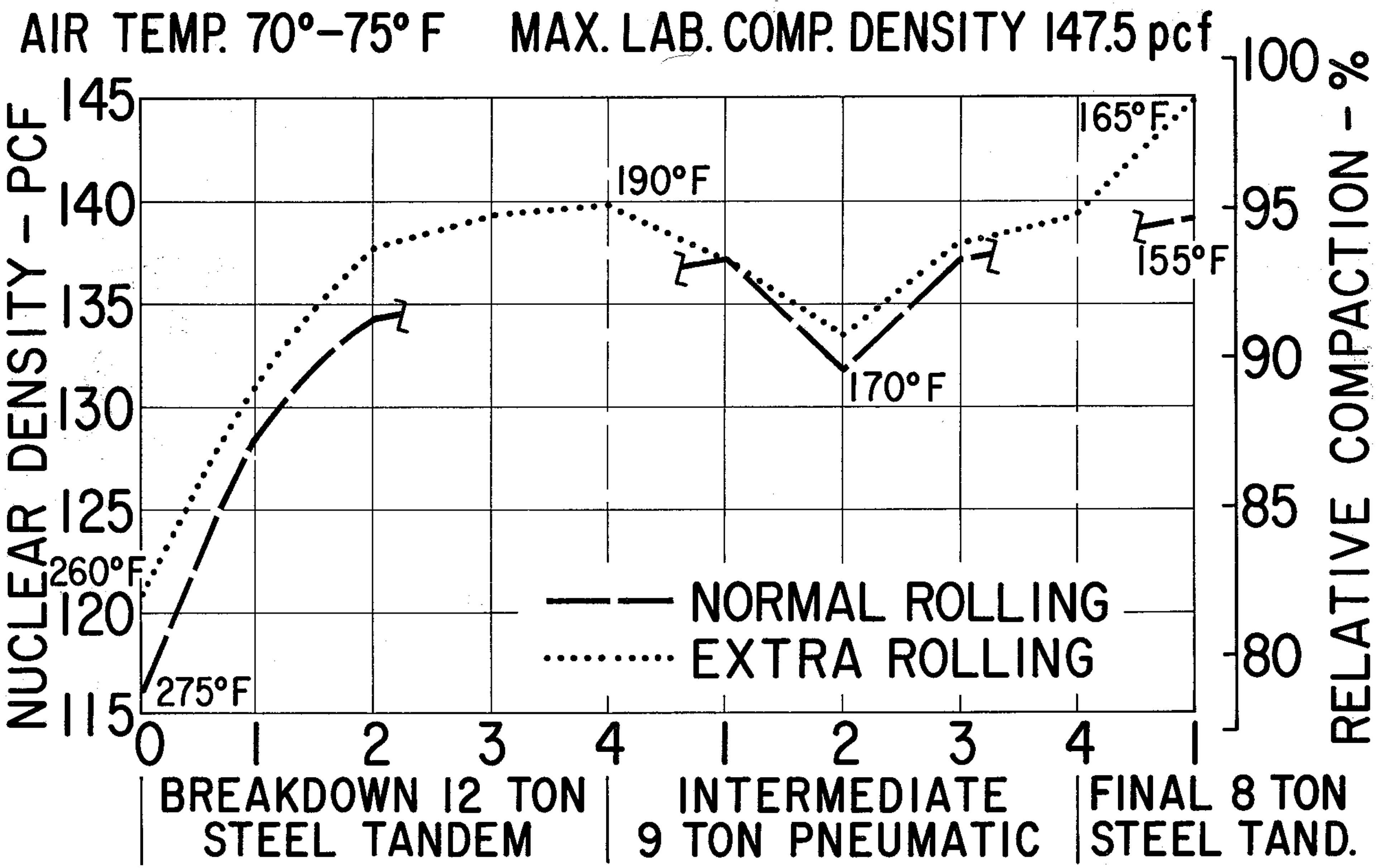
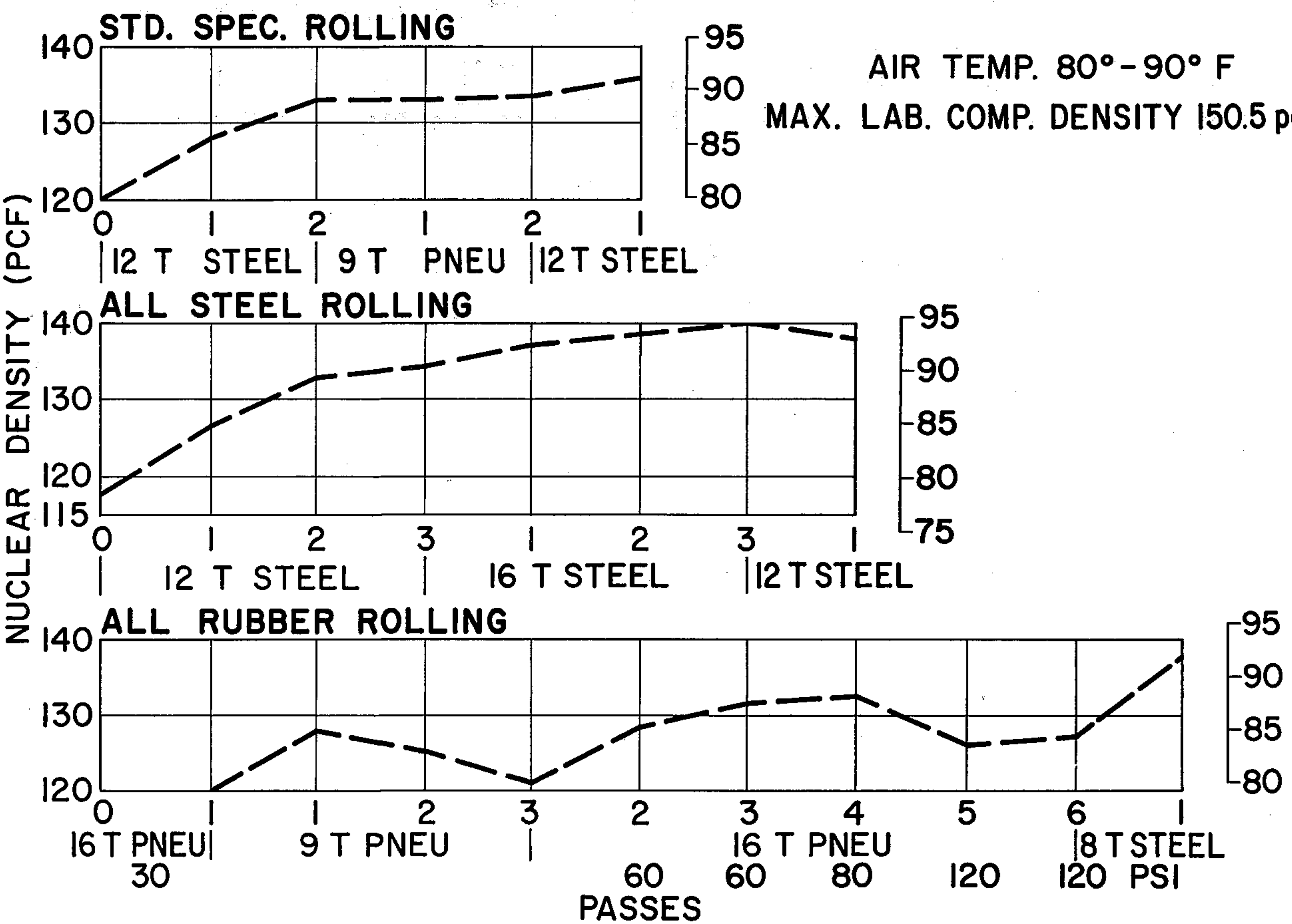

AIR TEMP. 70°-75° F
MAX. LAB. COMP. DENSITY 147.5 pcf
NUCLEAR DENSITY - PCF
145
140
135
130
125
120
115
RELATIVE COMPACTION - %
100
95
90
85
80
275°F
260°F
190°F
170°F
165°F
155°F
NORMAL ROLLING
EXTRA ROLLING
0 1 2 3 4 1 2 3 4 1
BREAKDOWN 12 TON STEEL TANDEM
INTERMEDIATE 9 TON PNEUMATIC
FINAL 8 TON STEEL TAND.

FIGURE 9

FIGURE 10


STD. SPEC. ROLLING
AIR TEMP. 80°-90° F
MAX. LAB. COMP. DENSITY 150.5 pcf
12 T STEEL
9 T PNEU
12 T STEEL
ALL STEEL ROLLING
12 T STEEL
16 T STEEL
12 T STEEL
ALL RUBBER ROLLING
16 T PNEU 30
9 T PNEU
16 T PNEU
60 60 80 120
18 T STEEL
120 PSI
PASSES
NUCLEAR DENSITY (PCF)
RELATIVE COMPACTION (%)