Development of a Nuclear Surface Density Gage for Asphaltic Pavements

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The nuclear method of density determination can be applied successfully to density measurements of bituminous pavement. Test results indicate than an accuracy of 1 percent can be obtained with the P-22 surface density probe used in conjunction with a filter when a maximum of ten 2-min trials are taken and the density does not exceed 130 pcf. This can be reduced to three 2-min trials for an accuracy of 2 percent. An accuracy of better than 2 percent can be obtained with the pavement probe developed in the laboratory using a 3-mc radium-berillium source if two 2-min trials are taken. This accuracy applies over the density range of 110 to 150 pcf.

Density measurements of asphalt pavement will be affected by a change in density of the subgrade when the P-22 surface density probe and filter are used. It is reasonable to expect an error of less than 2 pcf for pavements having a thickness of 3 in. or more and a density range of 110 to 140 pcf on subgrades having the same range in density. Subgrade density does not have a significant effect on the count rate for the pavement density probe.

Surface roughness may produce errors in density measurements up to 2½ pcf. Surface roughness seems to be the most critical factor in density measurements. There is no indication that aggregate gradation has an effect on results obtained by nuclear measurement of density. Changes in count rate due to changes in ambient temperature may require a correction factor when these changes become extreme. It is possible that this could cause an error of up to 5 pcf if not corrected.

• THERE HAS long been a need for improved testing methods and equipment in the field of construction materials. There are several requisites for a good testing method, including (a) rapid results, (b) simplicity of performance, (c) high accuracy, (d) economy, and (e) nondestructiveness. Perhaps the most common objection to present field testing methods is that they do not employ a nondestructive test. This is particularly true in the case of bituminous mixtures whose density and bitumen content must be determined in place. Present methods require that a sample be extracted before investigating its properties. Destructive sampling introduces uncertainties due to sampling techniques and makes it impossible to conduct long-term studies on in-situ materials.

A new testing method involving the use of radioactive materials has been under development for the past ten years and satisfies, to some extent, the previously mentioned requirements. It was the purpose of this investigation to develop a nuclear method of determining asphalt pavement density in place, using a surface density gage.

Although the basic principles governing gamma ray densitrometry have been known for a number of years, most significant applications of these methods have been carried out within the past ten years. This delay can be attributed to two circumstances: radioactive materials did not become available for general use until about 1950, and a considerable amount of time was required to develop rugged and dependable equipment which could be used in the field.

Krueger (1) appears to have made the first use of gamma ray scattering to determine soil density. His work has been followed by that of many researchers, generally employing cobalt 60, cesium 137, or radium-beryllium as gamma ray sources. Belcher, Cuykendall, and Sack (2, 3, 4) refined the nuclear method of density and moisture content measurement to a high degree and in 1952 adapted this method to measurements in thin surface layers.

Surface density gages have generally employed Geiger-Müller tubes for radiation detection. Various methods have been used to measure the radiation picked up by the detectors ranging from dosimeters and survey meters (5, 6) to absolute counting scalers (7, 8).

The theoretical aspects of gamma ray densitrometry and neutron hygrometry are quite complex; only a brief discussion of some of the more important fundamentals will be taken up in this paper.

Nuclear radiations are divided into two classes: those which transmit energy by particle motion and those which transmit energy by wave motion. Neutrons, which are employed in hygrometry, come under the first classification and will not be considered here. Gamma rays, which are employed in densitrometry, come under the second classification, as do X-rays and radio waves. Gamma ray densitrometry is dependent on the absorption and scattering of rays by the material whose density is to be determined. Absorption and scattering may involve three processes: photoelectric effect, Compton effect, and pair production.

In traveling through a given medium, a gamma ray photon may collide with an electron, and depending on the type of collision, will either be absorbed or deflected. If the collision is direct, the photon may impart all of its energy to the electron, ejecting it from the atom. The ejected electron is called a photoelectron and the remaining atom becomes an ion. The original gamma ray is said to have been absorbed by the photoelectric effect. This type of absorption is common at low energy levels (below 0.1 Mev).

If the collision occurs with an electron in one of the outer orbits, the energy transfer may not be complete, resulting in a ray having a lower energy level and a new direction of travel. This process, known as the Compton effect, is the major source of gamma ray absorption and reflection up to an energy level of approximately 0.5 Mev.

Pair production is another contributing factor in gamma ray absorption but is not significant below energy levels in the neighborhood of 2.5 Mev. Most density gages employ radiation sources with energy levels below 1.0 Mev; therefore, pair production will not be discussed here.

Because the degree of absorption and scattering is a function of the number of electrons present in a given material, as is the density of the material, a change in the number of gamma rays entering the detector can be related to a change in density. The highly complex nature of this relationship requires that it be arrived at experimentally.

Various arrangements have been used for depth probes and surface gages. Generally, a depth probe consists of a source and detector unit mounted in such a manner that it may be lowered into an access tube that has been driven into the soil. The unit may contain a pre-amplifier and is connected to a counting unit through a cable. The detector is shielded from the source by a few inches of lead so that the greatest portion of the count is due to gamma rays that have been scattered by the soil.

Much the same arrangement is used for surface gages, the chief difference being that the zone of influence is more nearly a hemisphere than a sphere Mathematical relationships are available to serve as a guide to probe or gage design (9, 10).

LABORATORY INVESTIGATION

A number of asphaltic concrete blocks were prepared in the laboratory to enable the development of calibration curves for the surface density probes These blocks were made up using aggregates obtained from four locations in Arizona. Mixes were designed to obtain a fairly wide range of density, asphalt content, and thickness of blocks.

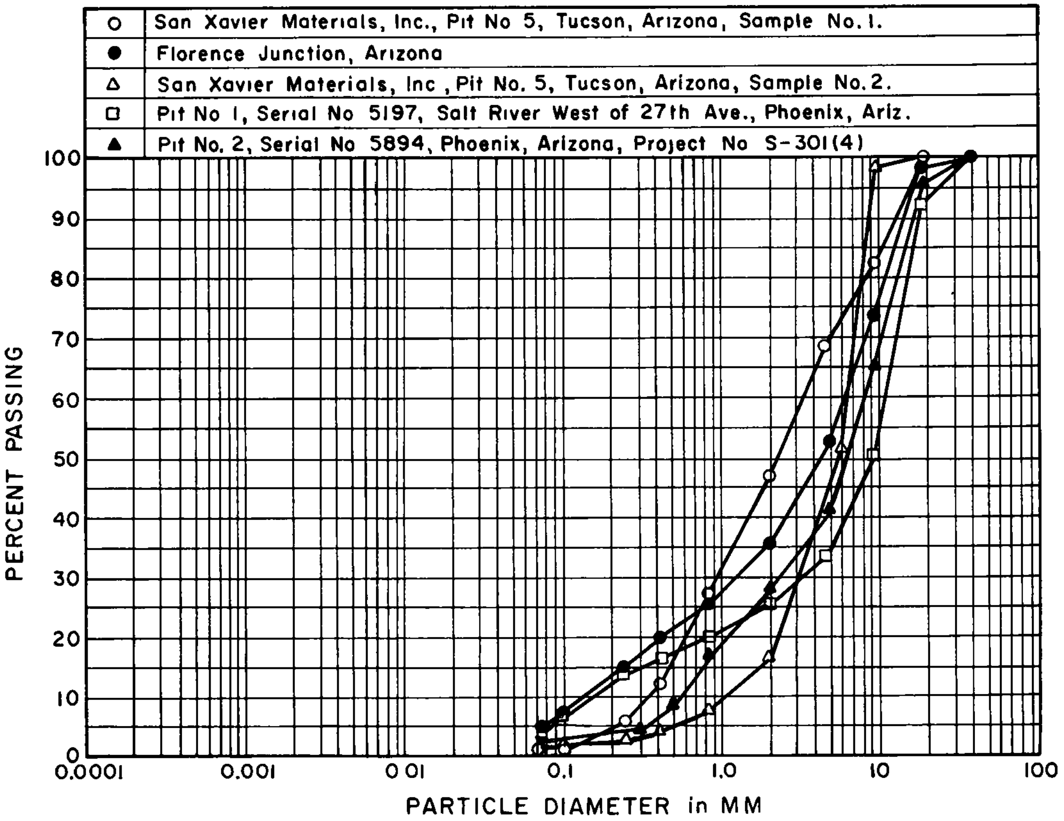

Figure 1. Grain-size distribution of aggregates used in study.

TABLE 1

ORIGINAL PROPERTIES OF CALIBRATION BLOCKS

Block No	Source of Aggregate	Wt of Agg (g)	Wt. of Asph (g)	Total Wt of Block (g)	Thickness of Block (ft)	Asphalt Content (%) Agg. Wt	Asphalt Content (%) Total Wt	Density (pcf)
A-1	Pit 5, sample 1	17,227	1,577	18,804	0 330	9 15	8 39	125 5
A-2	Pit 5, sample 1	16,587	1,296	17,883	0.312	7 81	7 25	126 0
A-3	Pit 5, sample 1	14,324	1,931	16,255	0.263	13 48	11 88	136 1
A-4	Pit 5, sample 1	12,920	716	13,636	0.242	5 54	5.25	124 1
A-5	Pit 5, sample 2	15,953	832	16,785	0.333	5.22	4.96	111.0
A-6	Pit 5, sample 2	15,988	624	16,612	0 321	3.90	3 76	114.0
A-7	Pit 5, sample 2	15,971	770	16,741	0 323	4.82	4 60	114 2
1	Florence Jct.	14,335	886	15,221	0 246	6 18	5.82	136.3
2	Florence Jct	12,716	843	13,559	0 215	6 63	6.22	138.9
3	Florence Jct.	16,001	1,509	17,510	0.261	9 43	8 62	147 8
4	Florence Jct.	15,578	1,182	16,760	0 256	7 59	7 05	144 2
5	Florence Jct.	15,248	605	15,853	0 261	3 97	3 82	133 8
6	Pit 1, ser. 5197	13,014	860	13,874	0 225	6.61	6 20	135 8
7	Pit 1, ser 5197	14,852	1,075	15,927	0.253	7 24	6 75	138.7
8	Pit 2, ser 5849	14,968	752	15,720	0.275	5.02	4 78	125 9
9	Pit 2, ser. 5849	16,509	611	17,120	0 294	3.70	3 57	128 1
10	Pit 2, ser 5849	15,350	899	16,249	0 270	5.86	5.53	132 7
11	Pit 2, ser. 5849	18,765	1,066	19,831	0.344	5.68	5 38	127 1

TABLE 2

FINAL PROPERTIES OF CALIBRATION BLOCKS

Block No.	Aggregate Source	Thickness (ft)	Density (pcf)	General Condition	Surface Condition
A-1	Pit 5, sample 1	0.331	119.3	Very good	Smooth
A-2	Pit 5, sample 1	0.309	125.8	Very good	Smooth
A-3	Pit 5, sample 1	0.278	130.2	Fair	Smooth
A-4	Pit 5, sample 1	0.242	123.1	Very good	Smooth
A-6	Pit 5, sample 2	0.315	114.0	Poor	Fair
A-7	Pit 5, sample 2	0.325	113.8	Very good	Fair
2	Florence Jct.	0.214	138.9	Very good	Smooth
3	Florence Jct.	0.258	147.8	Very good	Smooth
4	Florence Jct.	0.254	144.2	Very good	Smooth
5	Florence Jct.	0.262	133.8	Fair	Fair
6	Pit 1, ser. 5197	0.221	135.8	Good	Rough
7	Pit 1, ser. 5197	0.250	138.7	Good	Rough
8	Pit 2, ser. 5849	0.275	122.8	Good	Rough
9	Pit 2, ser. 5849	0.294	127.2	Fair	Rough
10	Pit 2, ser. 5849	0.270	132.7	Poor	Fair
11	Pit 2, ser. 5849	0.344	127.1	Poor	Fair

Materials Used

To provide a variation in aggregates used in the sample asphalt blocks, four sources were utilized.

San Xavier Materials, Inc., of Tucson, provided two different samples. Sample 1 contained more fine material than sample 2. Neither, however, contained any material larger than $^3/_4$ in. Blocks made of material from sample 2 were unstable because of lack of fines. At an asphalt content of approximately 5 percent, one block was so rich that the sides sloughed away rendering it useless for testing.

The material obtained from Florence Junction was well graded and contained some aggregate larger than $^3/_4$ in. Blocks made from this aggregate had lower void ratios than did blocks of equivalent density made from aggregates from other sources.

Aggregate obtained from Pit 1 in Phoenix had 7.7 percent retained on the $^3/_4$-in. sieve. This aggregate was, however, fairly well-graded. Aggregate obtained from Pit 2 in Phoenix also had good gradation but less material in the $+^3/_4$-in. size. Both these aggregates had sufficient fine material to act as binder.

The specific gravity of the material from Florence Junction and from the two pits in Phoenix was 2.68. The specific gravity of the material obtained from the San Xavier pit was 2.60 to 2.61. Figure 1 shows grain-size distribution curves for the aggregates used.

The asphalt used in making up the calibration blocks was 85 to 100 penetration asphalt cement and was obtained from the American Bitumuls and Asphalt Company of Tucson. The asphalt was tested before use and was found to meet AASHO asphalt specifications.

Molding Technique

The desired density and asphalt content of each block were predetermined. The necessary weight of oven-dried hot aggregate (250 F) was weighed out as was the proper amount of heated asphalt (250 F). Mixing pans and tools, which had previously been placed in an oven and were now hot, were removed. The mixing bowl was placed in the holder of a Hobart mixer having a ½-cu ft capacity. Aggregate was placed in the bowl and about one-half the hot asphalt was added. The asphalt and aggregate were thoroughly mixed until the aggregate was covered as completely as possible. The remainder of the asphalt was added and mixing continued until a uniform appearance was obtained. On completion of mixing, the mix was placed in the mold which also had been preheated.

The mold used in making up the calibration blocks was constructed of ⅓-in. aluminum stock with steel clamping devices. Inside dimensions of the assembled mold were 9½ by 15⅛ in. This gave the molded blocks a surface area (in plan view) of 1 sq ft. The aluminum sides and ends were removable with both top and bottom of the mold open. When the sides and ends of the mold had been assembled and clamped, the mold was placed on a ¼-in. steel base plate. Asphalt mix was then placed in the mold and tamped into the corners with a ½-in. rod. The top of the mix was leveled off and a

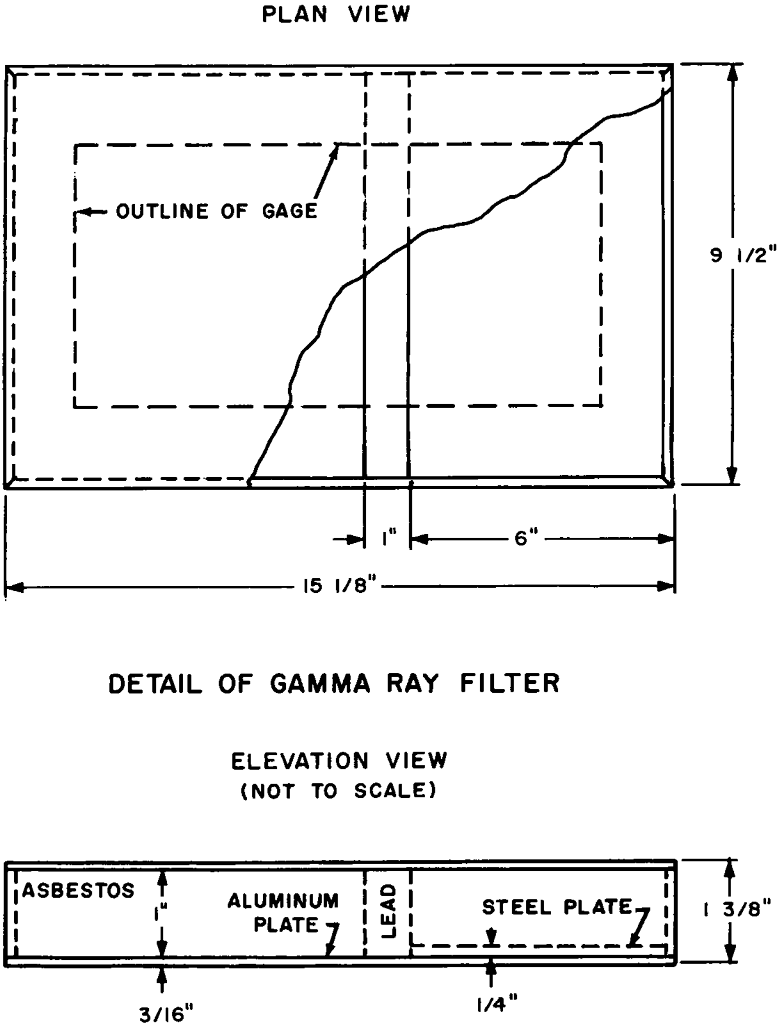

Figure 2. Detail of gamma ray filter used with C-N P-22 surface density probe.

1-in steel loading plate, the exact size of the mold, was placed on top of the mix. The mold was then placed in a compression machine having a 300,000-lb load capacity and loaded to obtain a predetermined density. The density was checked by measuring the thickness of the material while it was being loaded. Load was maintained for approximately 1 hr, at which time the load was released and the mold was removed from the testing machine. The loading plate was then lifted from the mold, and block and mold were allowed to cool. When the block had cooled the mold clamps were removed and the aluminum side plates and ends were heated with a torch and removed. Block and base plate were then turned over so that the base plate faced up. The base plate was heated and removed.

Each test block was weighed and the thickness was measured at each of the four corners. Density and void ratio of the blocks were then computed. Losses in weight due to mixing and molding were accounted for.

A total of eighteen blocks were molded, ranging in density from 111.0 to 147.8 pcf, and in asphalt content from 3.70 to 13.48 percent (based on weight of aggregate). Block thickness ranged from 0.237 to 0.542 ft. Thicknesses achieved were designed to cover the usual range for pavements. Initial and final properties of the blocks are given in Tables 1 and 2, respectively.

Density Measurements

First attempts to develop a calibration curve for the Nuclear-Chicago surface density probe were not successful because of excessive gamma ray penetration. It was found that the density of the material on which the blocks were placed (subgrade) made an appreciable difference in the total recorded count, particularly for those blocks

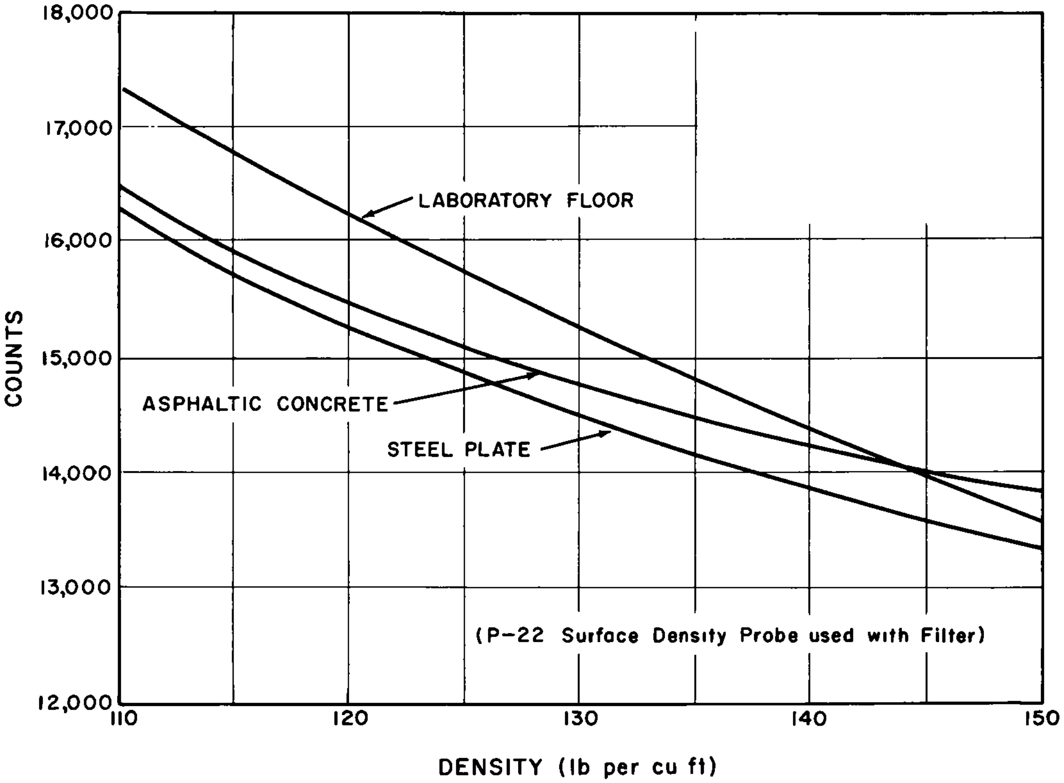

Figure 3. Calibration curves of density vs counts for test blocks placed on type of base indicated.

having a thickness of less than 4 in. It was decided that an air gap between the gage and the block might overcome this difficulty. However, the resultant trials gave counts that deviated greatly and this approach to the problem was abandoned. The next step was to construct a sandwich-type filter of aluminum and steel plates bonded to asbestos sheets, the aluminum and steel serving the purpose of a gamma ray shield and the asbestos sheets serving as a thermal insulator for the probe. Although it was possible to reduce the gamma ray penetration, this filter was abandoned because of reduced sensitivity. The slope of the calibration curve became so flat that a large change in density resulted in a very small change in count. The filter shown in Figure 2 was finally devised. With this filter the required reduction in gamma ray penetration was achieved without too great a corresponding reduction in sensitivity. The sensitivity achieved was reasonable, particularly at lower densities.

After a satisfactory filter had been developed, density trials were conducted on each block. Twenty trials of approximately 2 min each were made on each block and a standard count was also recorded for each day the density probe was used. (Actual count time was 1.992 min per trial. In subsequent references, it is to be understood that a 2-min trial means 1.992 min.) Three different bases were used under each block so that the effect of the subgrade under an asphaltic base course could be roughly predicted. Bases used were a 1-in. steel plate, the laboratory floor, and two asphaltic concrete blocks (Block 2 on Block 1). This resulted in average base densities of 489, 45 (approximately), and 138 (approximately) pcf. Figure 3 shows calibration curves for the three different bases.

Curves of best fit were arrived at by the method of least squares and are expressed mathematically in the form $Y = bX^m + C$, where Y is the total count and X is the

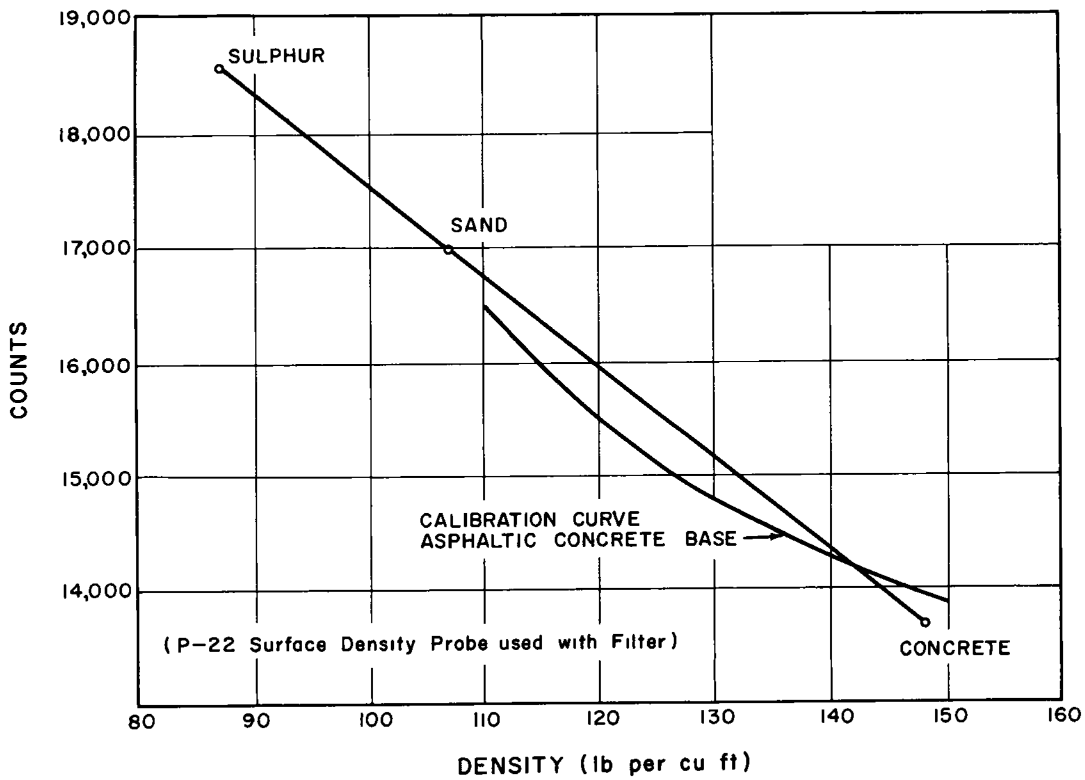

Figure 4. Results of calibration tests for sulphur, sand, and concrete compared with results from asphaltic concrete test blocks placed on asphaltic concrete base.

corresponding density. This method of fitting is quite sensitive to choice of C, therefore, the relationship between counts on the laboratory floor and density was arrived at by successive choices of constants. Deviations of actual densities from the computed densities are included in the solutions of the equations.

In addition to the asphaltic concrete blocks, three other materials were used to relate total count and density Sulphur, sand, and concrete were used, having densities of 87.3, 107.3, and 148.3 pcf, respectively. These points resulted in the straight line shown in Figure 4. The calibration curve for the blocks on the asphaltic concrete base

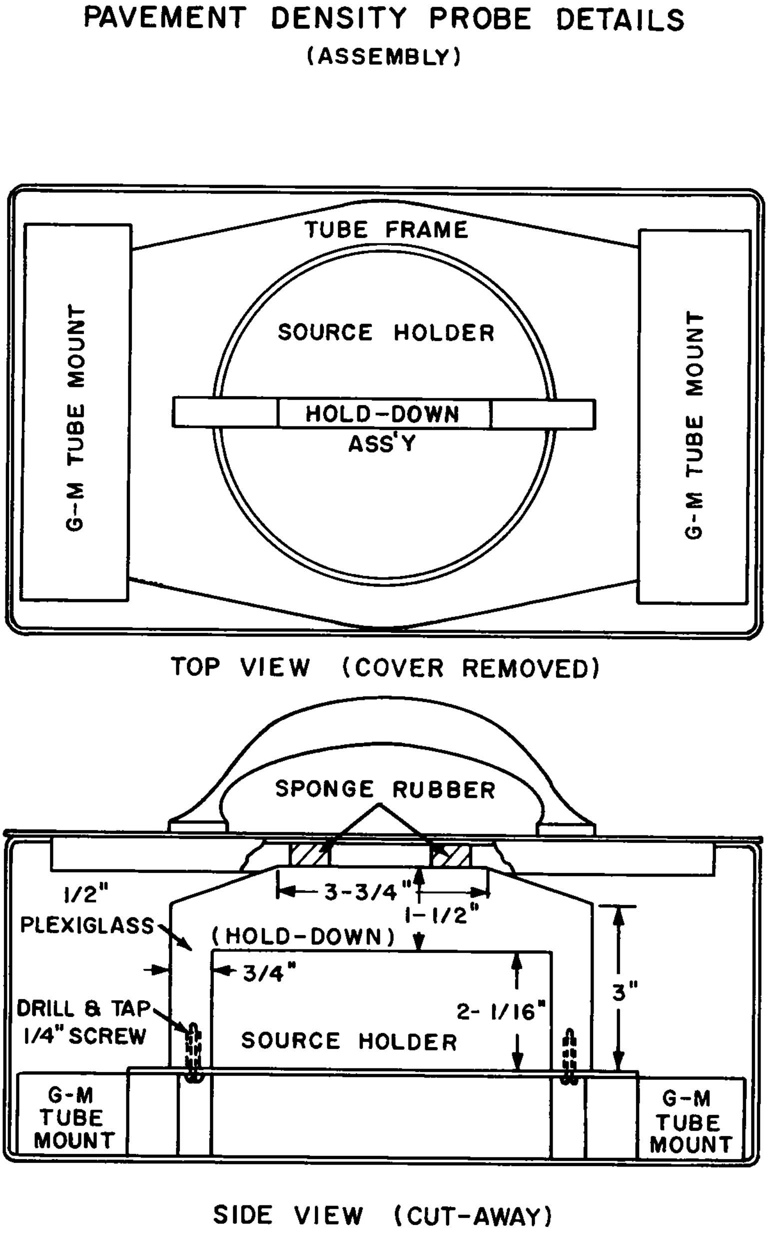

Figure 5. Top and side views of surface density gage developed for use on pavements only.

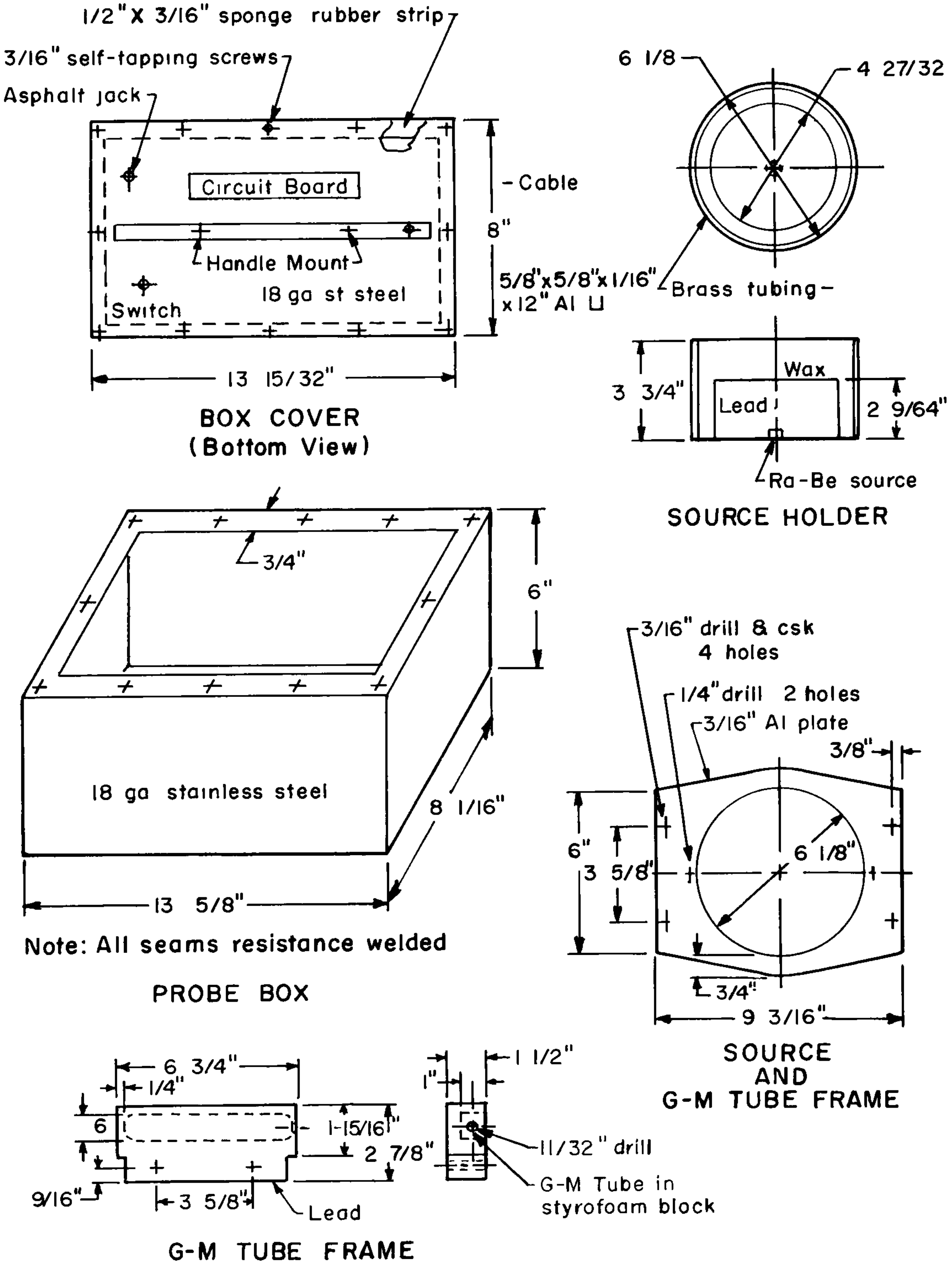

Figure 6. Components of surface density gage developed for use on pavements.
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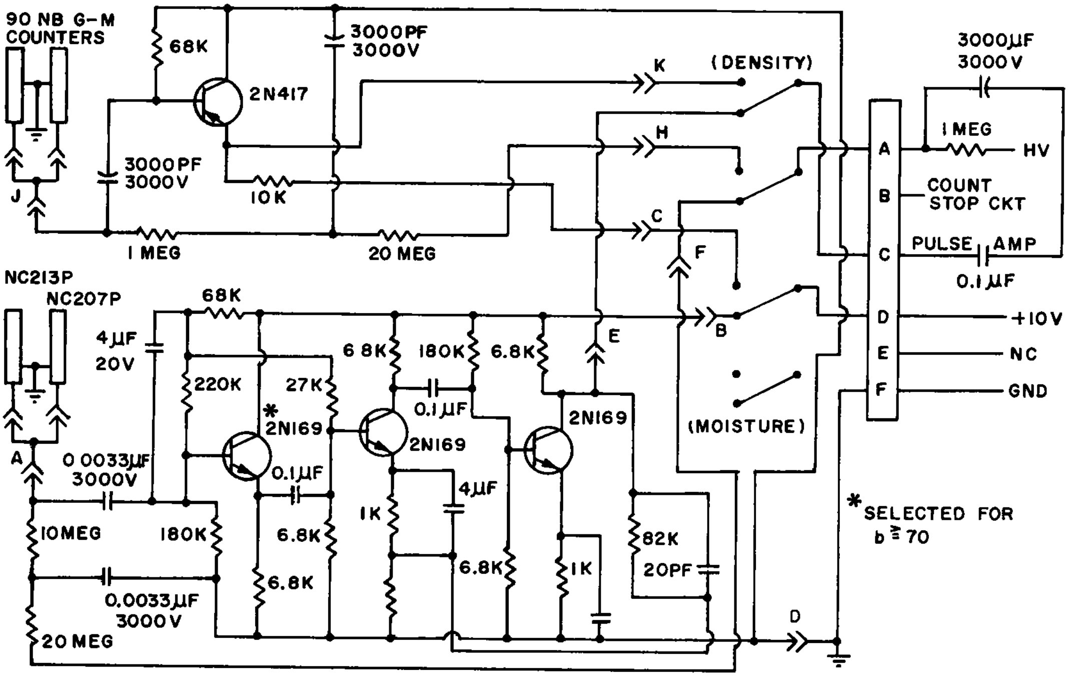
is superimposed on the straight line for comparison. All four of these measurement series were made using the gamma ray filter.

Although reasonable results were obtained with the Nuclear-Chicago P-22 surface density probe used in conjunction with the filter shown in Figure 2, it was decided to develop a more sensitive surface density gage for use on pavements only. A 3-mc radium-beryllium source was selected because it has a long half-life (1, 620 years) and a low gamma ray energy level (0. 188 Mev). Details of this probe are shown in Figures 5 and 6 and the electronic circuit is shown in Figure 7

Dimensions and shielding were arrived at by a trial-and-error procedure. The source shielding was proportioned to meet minimum requirements for protection of personnel. This required both gamma ray and neutron shielding because radium-beryllium is a fast-neutron emitter. Radiation field strengths are shown in Figure 8.

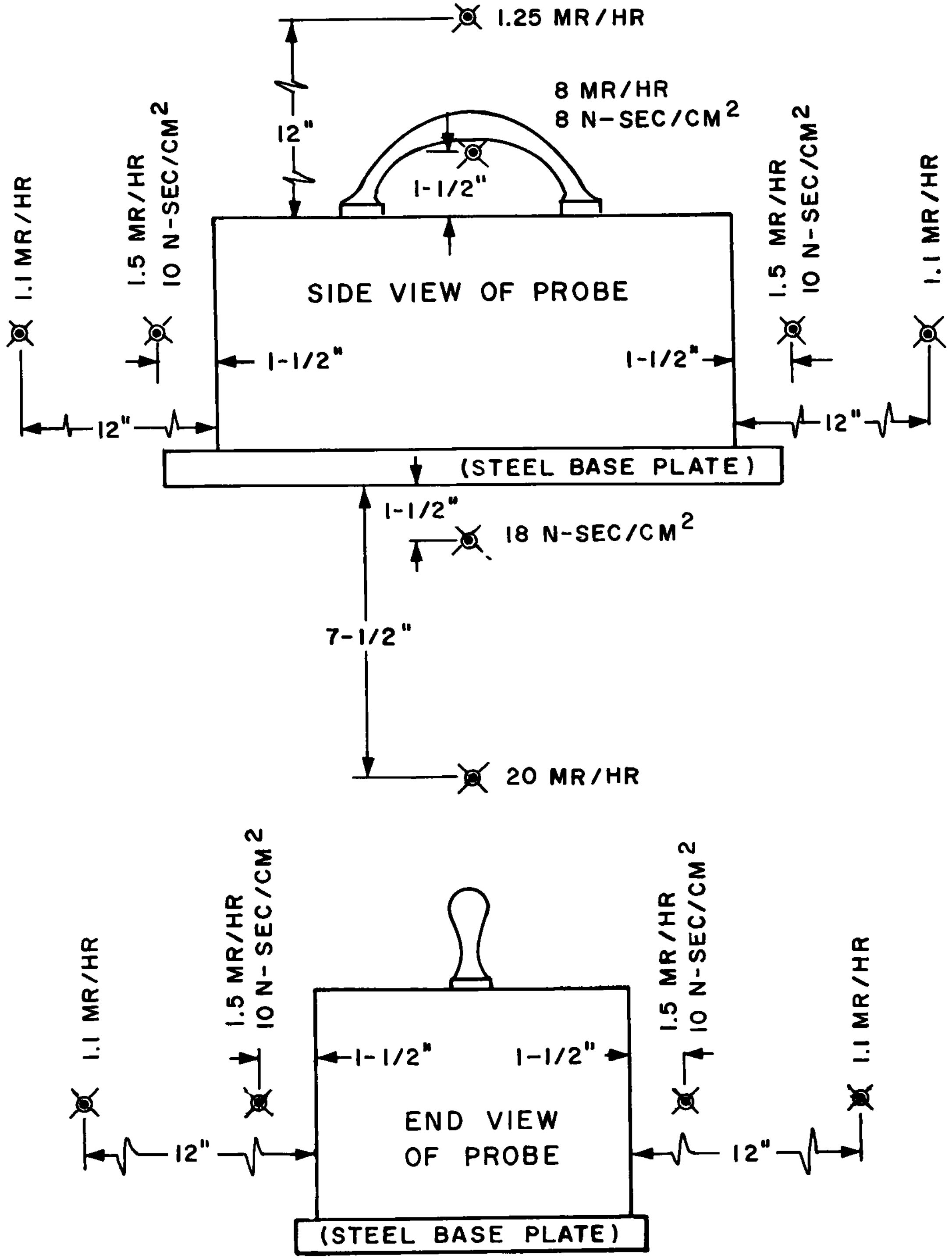
The detector tube shielding and position relative to the source were proportioned to increase the slope of the calibration curve and hence the sensitivity of the gage. This required that the shielding be heavy enough to reduce the count rate and at the same time be light enough to make the probe portable. The distance from the source to the detector tubes was adjusted to make the slope of the calibration curve as large as possible without materially increasing the count rate.

Because the Geiger-Müller tubes are somewhat affected by high temperatures, it was decided to insulate them by mounting in a block of cellulose insulation. However, due to its hydrophyllic nature, this material was discarded in favor of styrofoam. The Geiger-Müller tubes gave spurious counts as the moisture content of the cellulose insulation changed and also triggered at various voltages. Styrofoam seemed to perform quite well at temperatures up to 260 F. The probe should not be subjected to temperatures above this level because the styrofoam becomes unstable. A high temperature wax (N, N'-ethylenebis-stearamide) having a melting point of 280 F was used to provide neutron shielding. Total weight of the probe with base plate is 50 lb.



ELECTRONIC CIRCUIT
PAVEMENT DENSITY PROBE

Figure 7. Electronic circuitry developed for surface density gage for use on pavements.



RADIATION FIELD STRENGTHS

Figure 8. Results of measurements of radiation field strengths indicated at distances from pavement density probe.

To determine the effect of subgrade density on this gage, the test specimens were placed on Block A-7 and Block 3, having densities of 113.8 and 147.8 pcf, respectively. Each run was made up of ten 2-min trials for a total counting time of 20 min. Block A-7 was placed on Block A-6 for the lowest-density subgrade and Block 3 was placed on Block 4 for the highest-density subgrade. Figure 9 shows the results of the tests.

Of those calibration blocks yielding the greatest change in count for the two subgrades, only Blocks A-1 and 4 were in very good condition with smooth surfaces. Of those blocks yielding essentially the same count for the two subgrades, five were in very good condition with smooth surfaces. Because it is difficult to separate the various factors affecting the accuracy of the count rate, attention will be restricted to those calibration blocks in very good condition with smooth surfaces. Considering extremes in the density range, both Blocks 3 and A-7 seemed to be unaffected by subgrade density. Block A-1, however, does show a deviation corresponding to about 3 pcf for the two subgrades. It is believed that the fact that the points for this block fall below the calibration curve (shown dashed) may be due to errors in determining the final density of the block.

While there seems to be little indication that subgrade density has an appreciable effect on count rate, there is a rather good indication that surface roughness or texture may have a decided influence. Referring to Figure 9, Blocks A-1, A-6, 4, 5, 6, 7, 10, and 11 all had changes in count rate of more than 200 for the two subgrades. Only two of these blocks, A-1 and 4, were in very good condition with smooth surfaces. The remainder were in good to poor condition with fair to rough surfaces. Blocks A-2, A-3, A-4, A-7, 2, 3, and 9 all had changes in count rate of less than 160 for the two subgrades. Five of these blocks were in very good condition with smooth surfaces and two were in fair condition with smooth to rough surfaces.

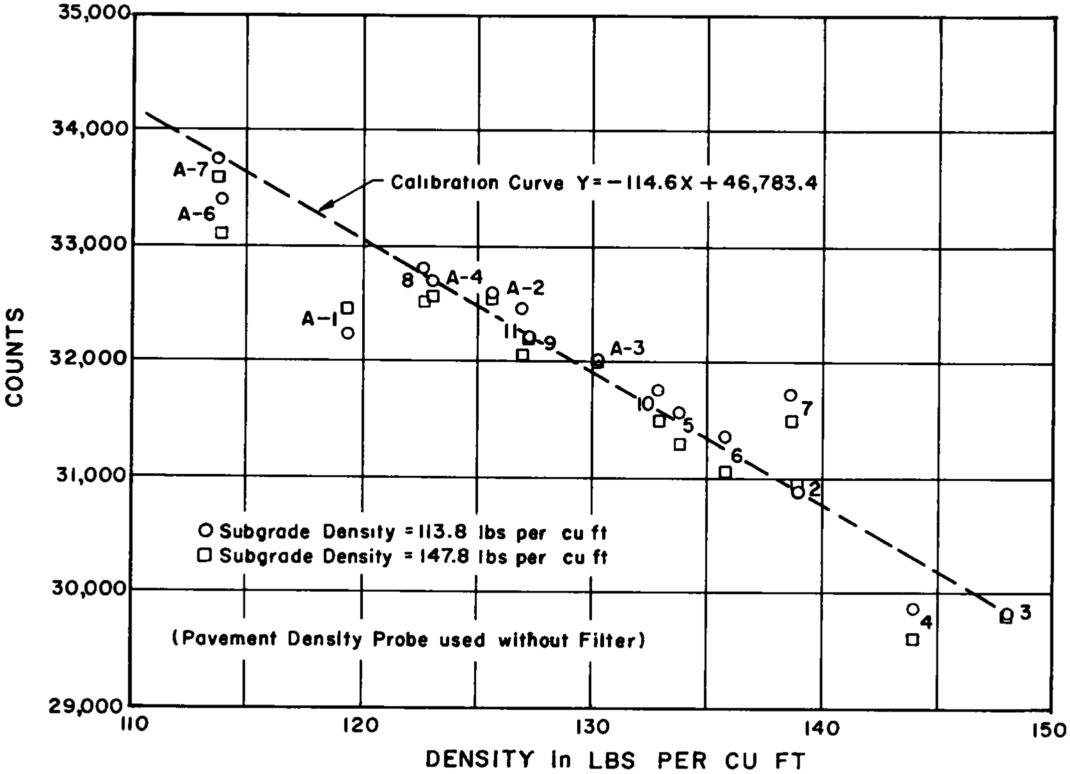


Figure 9. Correlation between density and count rate for asphaltic concrete test blocks when tested on high and low density subgrades.

Figure 10 shows the calibration curve for the pavement density surface gage. The curve of best fit, in this case a straight line, was arrived at by the method of least squares and includes all of the measurements made.

RESULTS

Accuracy

Test results indicated that an accuracy of 1 percent can be obtained with the Nuclear-Chicago P-22 surface density probe used in conjunction with a properly designed gamma ray filter when a maximum of ten 2-min trials are taken and the pavement density does not exceed 130 to 140 pcf. This number of 2-min trials can be reduced to three for an accuracy of 2 percent. These accuracies can be obtained consistently at normal room temperatures in the laboratory; however, at elevated pavement temperatures corrections may be required. Changes in count rate due to changes in ambient temperature may result which will require a correction factor when these changes become extreme. It is possible that such extreme temperature changes could cause errors of as much as 5 pcf if not corrected. A summary of count data for the P-22 surface density probe is given in Table 3.

Improved sensitivity of the pavement density surface gage developed in the University of Arizona laboratory, by elimination of the gamma ray filter, allows the number of 2-min trials to be reduced to five for an accuracy of 1 percent over a wider density range. The 3-mc radium-beryllium source is satisfactory for density measurements of thin surface layers and has the added advantage of a long half-life. This probe will

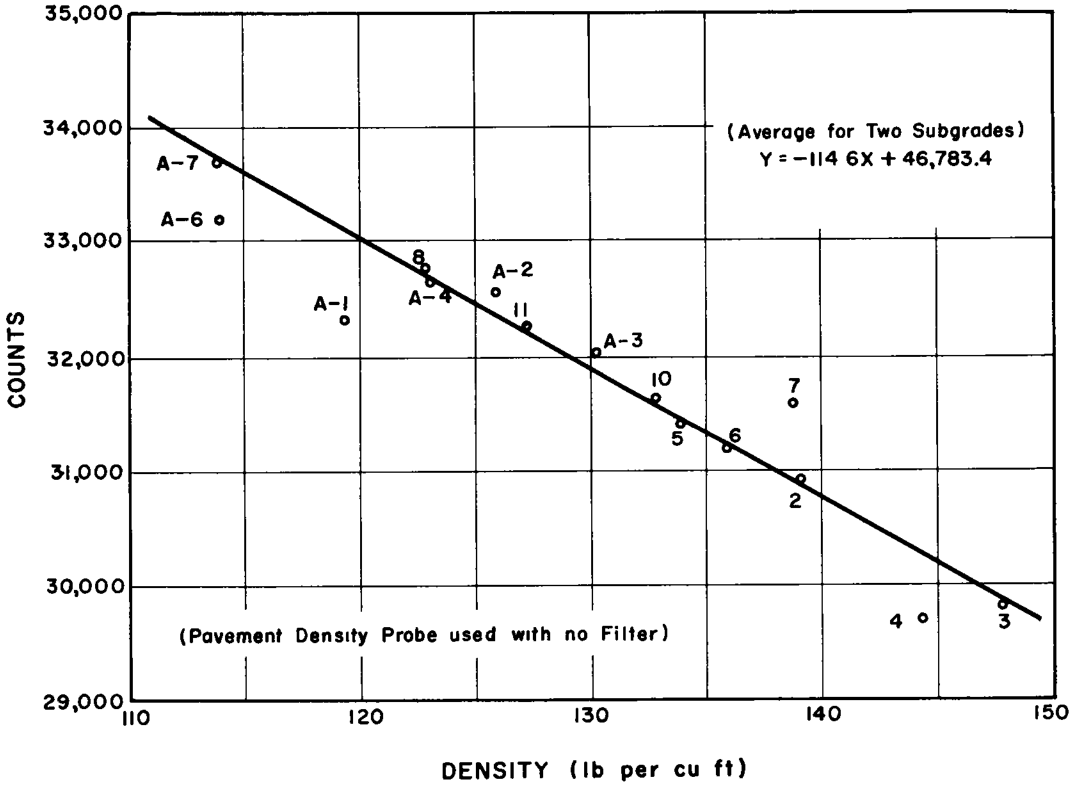


Figure 10. Calibration curve for pavement density surface gage.

TABLE 3

SUMMARY OF COUNT DATA FOR NUCLEAR CHICAGO P-22 SURFACE DENSITY PROBE WITH GAMMA RAY FILTER

Block No.	Base	Number of Trials	Mean Count	Mean Deviation	Standard Deviation
A-1	Asphalt	20	15,052	96	121
A-2	Asphalt	20	14,818	84	125
A-3	Asphalt	20	14,463	103	120
A-4	Asphalt	20	15,150	114	135
A-5	Asphalt	20	16,736	98	118
A-6	Asphalt	20	15,940	96	121
A-7	Asphalt	20	15,992	146	181
3	Asphalt	20	14,136	91	117
4	Asphalt	20	14,023	136	163
5	Asphalt	20	14,218	91	110
6	Asphalt	20	14,366	100	119
7	Asphalt	20	14,341	105	124
8	Asphalt	20	15,371	107	130
A-1	Steel	20	15,004	82	115
A-2	Steel	20	14,694	83	100
A-3	Steel	20	14,270	93	115
A-4	Steel	20	14,932	77	100
A-6	Steel	20	15,967	141	166
A-7	Steel	20	15,949	129	145
3	Steel	20	13,302	117	143
4	Steel	20	13,453	115	133
5	Steel	20	13,925	94	109
6	Steel	20	14,122	104	123
7	Steel	20	13,960	134	159
8	Steel	20	14,796	113	149
A-1	Floor	20	15,637	115	152
A-2	Floor	20	15,201	98	130
A-3	Floor	20	14,793	112	131
A-4	Floor	20	15,844	83	101
A-6	Floor	20	16,784	101	120
A-7	Floor	20	16,658	79	99
3	Floor	20	13,793	89	112
4	Floor	20	13,782	85	119
5	Floor	20	14,509	130	152
6	Floor	20	15,268	84	107
7	Floor	20	14,821	105	134
8	Floor	20	15,630	113	138
Concrete block	-	20	13,683	121	144
Sand	-	20	16,969	131	160
Sulphur	-	20	18,577	113	141

not require calibration corrections due to changes in activity of the source. The electronic circuit in this probe is slightly sensitive to the ambient temperature which may cause the count rate to change. Experience has shown that this problem can be eliminated by taking a standard count under field conditions and correcting the readings to the calibration curve by the amount of change in the standard count. A summary of count data for the Arizona pavement density probe is given in Table 4.

TABLE 4

SUMMARY OF COUNT DATA FOR ARIZONA PAVEMENT DENSITY PROBE WITHOUT GAMMA RAY FILTER

Block No.	Base (Block No.)	Number of Trials	Mean Count	Mean Deviation	Standard Deviation
2	A-7	10	30,866	172	227
2	3	10	30,947	106	148
3	A-7	10	29,834	95	141
3	4	10	29,804	173	195
4	A-7	10	29,854	134	157
4	3	10	29,581	106	135
5	A-7	10	31,537	188	241
5	3	10	31,315	128	153
6	A-7	10	31,304	117	159
6	3	10	31,025	218	230
7	A-7	10	31,704	169	209
7	3	10	31,477	151	187
8	A-7	10	32,948	145	169
8	3	10	32,569	164	212
9	A-7	10	32,261	118	143
9	3	10	32,231	139	162
10	A-7	10	31,736	141	161
10	3	10	31,513	118	142
11	A-7	10	32,400	201	228
11	3	10	32,027	113	135
A-1	A-7	10	32,227	150	182
A-1	3	10	32,431	123	157
A-2	A-7	10	32,582	149	201
A-2	3	10	32,556	135	188
A-3	A-7	10	32,028	123	172
A-3	3	10	32,013	101	121
A-4	A-7	10	32,742	113	125
A-4	3	10	32,586	139	172
A-6	A-7	10	33,377	140	174
A-6	3	10	33,070	120	148
A-7	A-6	10	33,757	154	164
A-7	3	10	33,638	212	273

Effect of Subgrade

Using the Nuclear-Chicago surface density probe with gamma ray filter, density measurements of asphalt pavements will be affected by a change in density of the subgrade, the amount depending on the thickness and density of the pavement. It is difficult to draw any sound conclusions as to the relationship between the indicated density and the true density for a pavement of variable thickness and density which is supported by a subgrade of variable density. Theoretical relationships have been established (9), but they depend on the assumption that only homogeneous materials are involved. This assumption is unrealistic for asphalt pavements and aggregate bases. Investigation indicates that it is reasonable to expect an error of less than 2 pcf for pavements having a thickness of 3 in. or more and a density range of 110 to 140 pcf on subgrades having about the same density range.

Test results indicate that the pavement density probe developed in the University of Arizona laboratory will be virtually unaffected by subgrade or subbase density for asphalt pavements 3 in. or more in thickness.

Effect of Surface Roughness

Although there seems to be little indication that subgrade densities affect the count rate when the Arizona pavement density probe is used; there is a rather good correlation between surface roughness or texture and count rate. It would seem that the surface condition is far more important in obtaining consistent results than is the subgrade density. At any rate, because calibration curve has a fairly steep slope, it is reasonable to expect an error of less than 2½ pcf due to surface roughness.

Effect of Aggregate Gradation

There is no indication that aggregate gradation has an effect on results obtained by nuclear measurement of density. However, because surface roughness or texture depends to a high degree on the amount of fines available in the mix, in this sense gradation will affect density measurement. Sources of aggregates are given in Table 1 and 2. Gradations of the aggregates are shown in Figure 1.

CONCLUSIONS

1. Accurate in-place density determinations can be made in the laboratory by nuclear methods for asphaltic concrete blocks 3 in. or more in thickness.
2. Commercially available nuclear surface density probes can be used satisfactorily for density determination of asphalt pavements provided a suitable gamma ray filter is used.
3. Proper design of a nuclear surface density probe for determination of density of thin surface layers eliminates the need of a gamma ray filter and provides improved sensitivity and accuracy.
4. Surface roughness or texture of the pavement is the principal factor limiting accuracy of pavement density measurement by nuclear methods. Other factors, such as aggregate gradation and subgrade density, are of lesser importance.

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