# Nuclear Asphalt Content Determination at the Job Site

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Quick asphalt content determinations immediately after the asphalt surface course has been placed are necessary for quality control of the amount of asphalt cement in the hot mix. Modern hot plants capable of producing 200 tons or more per hour turn out significant quantities of asphalt concrete between the time a sample to be tested for asphalt content is obtained and the test results are reported.

Correlation with the reflux extraction tests and plant checks is reported in this paper, as well as the procedure involved when using the neutron probe. Asphalts used were 85/100 and 120/150 penetration grade from three different suppliers. Aggregates used came from six different sources. Projects on which this new method was tried ranged in location over a 200-mile area of southeastern Colorado.

Although this new method has not been adopted as standard procedure in Colorado, it is being used as a quick field check on asphalt content in CDH District Two with good results.

•IN AN EFFORT to achieve better control testing of asphalt, District Two of the Colorado Department of Highways has conducted a research program using the Troxler Nuclear Moisture and Density equipment to measure specific gravity and asphalt content. This paper covers the research to date on asphalt content determinations.

The principle of the nuclear test of asphalt content is the same as the nuclear test of moisture in soils. The hydrogen content in the asphalt, like the hydrogen content of water, is the main cause of thermalization of the neutron.

## EQUIPMENT

The only additional piece of equipment used with the Troxler surface moisture gage, Model 104-115, is an experimental test chamber. This unit is designed to contain that portion of the neutron field of the surface moisture gage that is not used in the measurement of the sample.

The sample is contained in a 1-gal container, $6\frac{5}{8}$ in. in diameter and $7\frac{1}{2}$ in. in height. The weight of the sample is 15 lb for grading "C" material having 30 to 60 percent passing the No. 4 sieve, and 13 lb for grading "D" material having 15 to 80 percent passing the No. 10 sieve.

## TESTING

The sample of asphalt is taken from the roadway directly behind the asphalt paving machine. It is then placed in a shallow mixing pan and the temperature is checked. The temperature of the material should be between 200 F and 230 F when put into the 1-gal container. At this temperature the material may be scooped into the container without any compactive effort, and leveled off to the top of the container at the desired weight. A transite lid, $\frac{1}{4}$ in. thick by $6\frac{3}{4}$ in. in diameter, with the outer edge recessed $1\frac{1}{16}$ in. so that the lid can be centered into the container, is fitted onto the container,

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Figure 1. Aggregate materials for master standards.

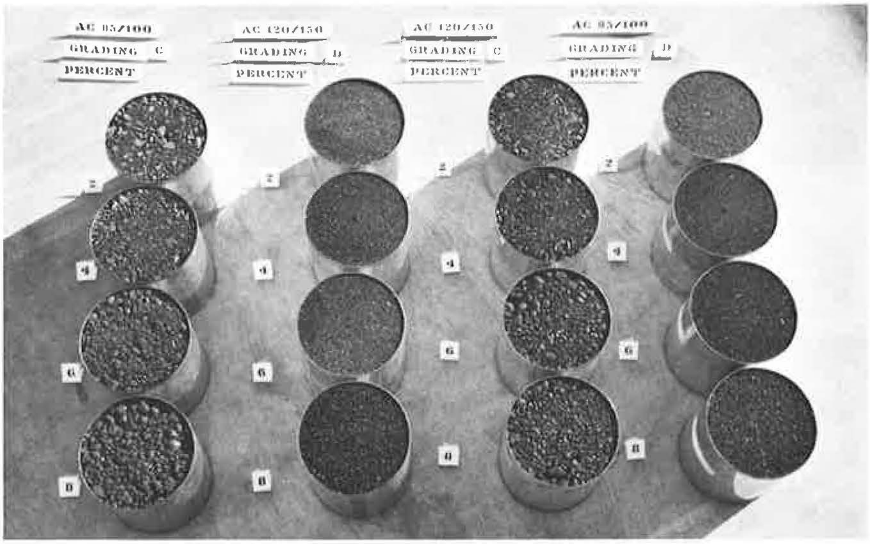

Figure 2. Standards for the four master curves.

then removed. This finishes the leveling of the sample. The container is then loaded into the testing chamber using a special bail. After the container is in place, the transite lid is carefully replaced on the container and the Troxler surface moisture gage positioned on top of the assembly.

A spring-loaded base in the bottom of the test chamber holds the sample container slightly above the surface of the testing chamber. The weight of the moisture gage presses the container flush with the surface of the test chamber. This arrangement insures a good contact between the bottom surface of the moisture gage and the top surface of the container assembly.

Five 1-min readings are taken and averaged; the average count divided by the normal standard count is then used for moisture determinations. This is obtained on the moisture reference standard, which is part of the standard nuclear equipment. The result is expressed as "percent of standard."

The percent of asphalt content is found from a calibrated curve opposite the percent of standard. This completes the nuclear test of asphalt content.

Figure 3. Asphalt sample from the roadway.

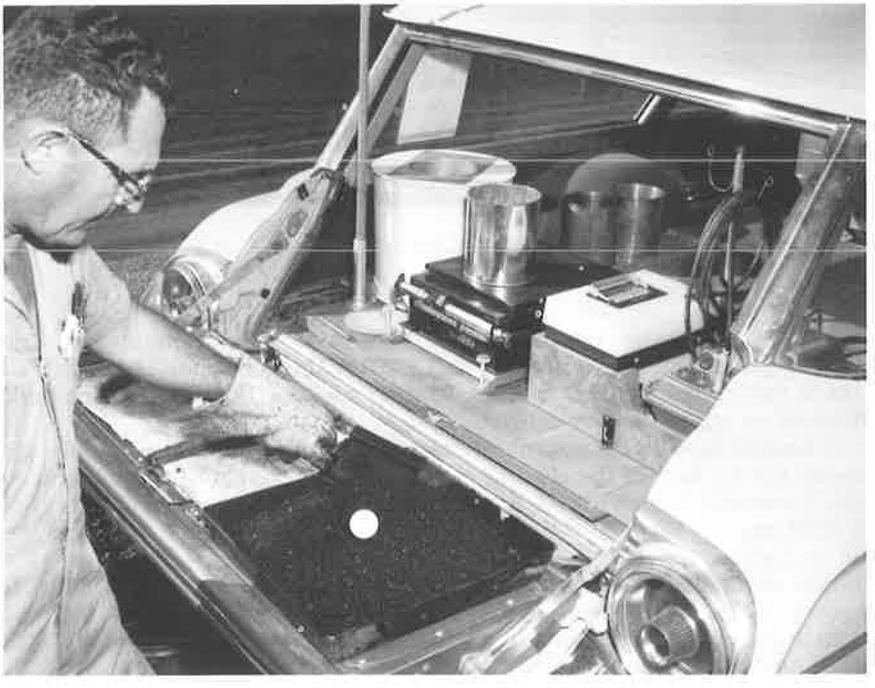

Figure 4. Checking temperature of asphalt in mixing pan.

Figure 5. Putting asphalt sample into gallon container.

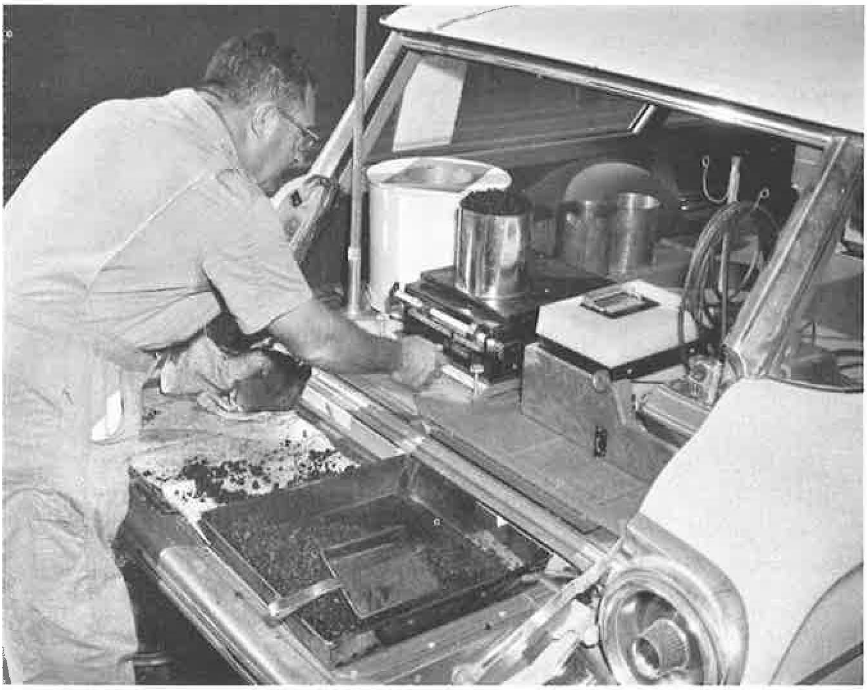

Figure 6. Weighing asphalt sample.

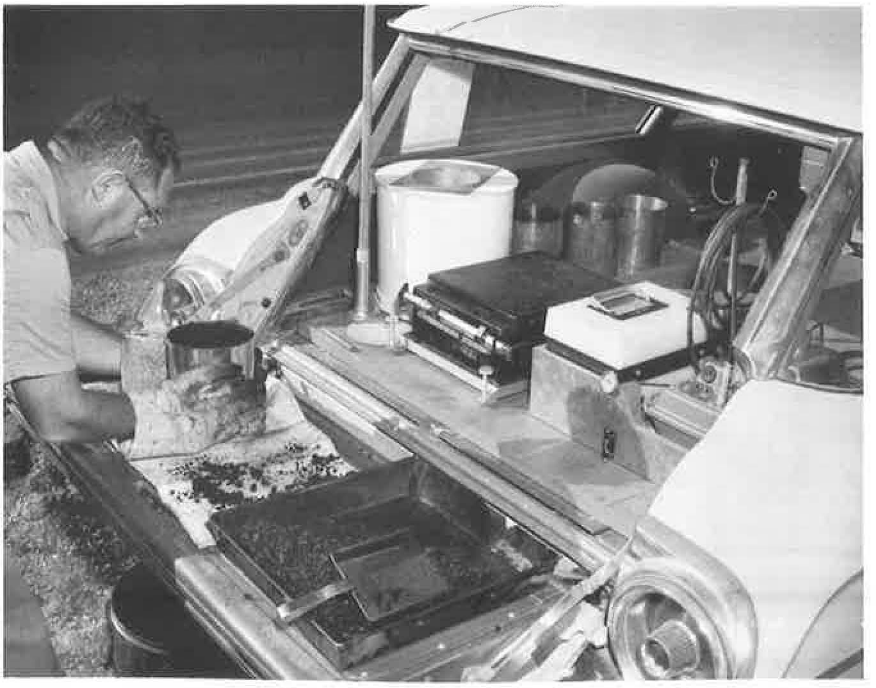

Figure 7. Settling material with rotating motion.

Figure 8. Leveling the material.

Figure 9. Fitting transite lid to container.

Figure 10. Lowering container into chamber.

Figure 11. Replacing transite lid on container.

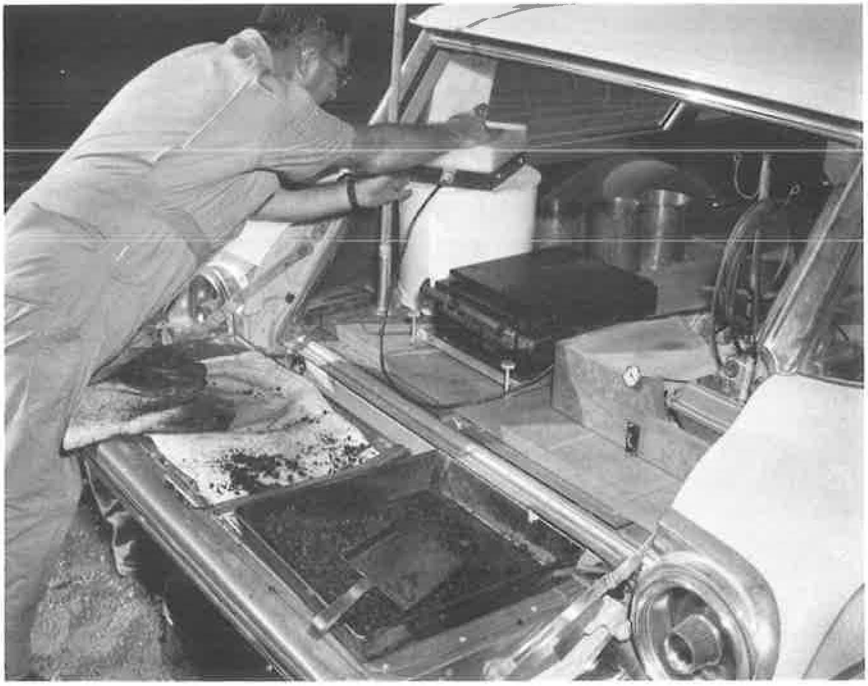

Figure 12. Placing Troxler neutron probe on chamber.

Figure 13. Taking five minute reading.

## CALIBRATION

The curve used to determine the asphalt content is calibrated from standards of 2.0, 4.0, 6.0 and 8.0 percent. These standards are made by weighing the dry aggregate material and the asphalt in calculated proportions to form the percent required, and then mixing thoroughly by hand. The temperature of the aggregate and asphalt is held at approximately 280 F to 300 F during the weighing and mixing.

## FIELD STUDY

The field comparison study consisted of taking nuclear tests of asphalt content and comparing the results with reflux methods and with the plant calculations.

Because of the time involved in the reflux test, it was difficult to obtain many comparisons per day. However, by taking additional nuclear tests throughout the day and averaging these tests, the comparison between the plant calculations for the day and average nuclear values for the day became more realistic. The equipment used for nuclear testing of asphalt is completely portable and the entire test may be performed wherever the sample is obtained. It is not necessary to return to the field test lab.

The first attempt to measure asphalt content began at Breed-Monument project I-25-2(48) 150. There were two pits used on this project, one for Item 32 and the other for Item 34. Examples of the average gradation of each pit are shown.

| Higginson Pit (Granite) | | | | Pioneer Pit (Limestone) | | | |
|---|---|---|---|---|---|---|---|
| Screen | % Passing | Screen | % Passing | Screen | % Passing | Screen | % Passing |
| 3/4 In. | 100 | No. 40 | 15 | 3/4 In. | 100 | No. 30 | 25 |
| No. 4 | 55 | No. 200 | 6.9 | 1/2 In. | 100 | No. 80 | 12 |
| No. 10 | 35 | | | No. 4 | 54 | No. 200 | 7.4 |
| | | | | No. 8 | 40 | | |

Asphalt 85/100 AC Hydrated Lime 0.5% and 1.0%.

## TABLE 1

## COMPARISON OF ASPHALT CONTENT

| Date | Reflux | Nuclear | Diff. | Plant | Nuclear | Diff. |
|---|---|---|---|---|---|---|
| 1963 | | | | | | |
| 5/23 | 6.71 | 6.97 | +.26 | 6.40 | 6.97 | +.57 |
| 5/24 | 6.57 | 6.17 | -.40 | 6.40 | 6.17 | -.23 |
| 5/25 | 6.29 | 6.41 | +.12 | 6.27 | 6.41 | -.14 |
| 5/27 | 6.29 | 6.25 | -.04 | 6.31 | 6.25 | -.06 |
| 5/28 | 5.97 | 5.93 | -.04 | 6.21 | 5.93 | -.28 |
| 5/28 | Note: Sample tested by Nuclear method sent to Denver Materials Laboratory. Their report was 5.89%, Nuclear value, 5.93%, +.04% Difference. | | | | | |
| 6/5 | 6.33 | 6.18 | -.15 | 6.19 | 6.18 | -.01 |
| 6/6 | 6.41 | 6.03 | -.38 | 6.04 | 6.03 | -.01 |
| 6/7 | 6.35 | 6.22 | -.13 | 6.04 | 6.22 | +.18 |
| 6/10 | 5.94 | 6.01 | +.07 | 5.72 | 6.01 | -.29 |
| 6/11 | 6.55 | 6.27 | -.28 | 6.08 | 6.27 | +.19 |
| 6/12 | 6.44 | 6.22 | -.22 | 6.27 | 6.22 | -.05 |
| 6/13 | 6.33 | 6.25 | -.08 | 6.18 | 6.25 | +.07 |
| 6/14 | 6.02 | 5.97 | -.05 | 6.15 | 5.97 | -.18 |
| 6/14 | Note: B.P.R. test sent to Denver Materials Laboratory. Their report was 5.75%, Nuclear value, 5.62%, -.13% Difference. | | | | | |
| 6/15 | 6.62 | 6.25 | -.37 | 6.20 | 6.25 | +.05 |
| 6/17 | 6.67 | 6.22 | -.45 | 6.20 | 6.22 | +.02 |
| 6/18 | 6.15 | 6.16 | +.01 | 6.24 | 6.16 | -.08 |
| 6/20 | 6.55 | 5.97 | -.58 | 6.03 | 5.97 | -.06 |
| 6/21 | 6.52 | 6.14 | -.38 | 6.08 | 6.14 | +.06 |
| 6/22 | 6.34 | 6.17 | -.17 | 6.07 | 6.17 | +.10 |
| 6/24 | 5.99 | 5.87 | -.12 | 5.83 | 5.87 | +.04 |
| 6/25 | 5.96 | 6.05 | +.09 | 5.91 | 6.05 | +.14 |
| 6/26 | 6.11 | 5.89 | -.22 | 5.87 | 5.89 | +.02 |
| 6/27 | 6.07 | 5.86 | -.21 | 5.83 | 5.86 | +.03 |
| 6/28 | 5.92 | 5.87 | -.05 | 5.80 | 5.87 | +.07 |
| 6/29 | 5.87 | 5.80 | -.07 | 5.78 | 5.80 | +.02 |
| 7/1 | 5.83 | 5.83 | .00 | 5.70 | 5.83 | +.13 |
| 7/2 | 5.83 | 5.82 | -.01 | 5.70 | 5.82 | +.12 |
| 7/3 | 5.85 | 5.73 | -.12 | 5.69 | 5.73 | +.04 |
| 7/8 | 5.78 | 5.84 | +.06 | 5.88 | 5.84 | -.04 |
| 7/9 | 5.86 | 5.83 | -.03 | 5.84 | 5.83 | -.01 |
| 7/10 | 5.78 | 5.87 | +.09 | - | 5.87 | - |
| 7/11 | 5.85 | 5.76 | -.09 | 5.70 | 5.76 | +.06 |
| 7/13 | 5.64 | 5.78 | +.14 | 5.66 | 5.78 | +.12 |
| 7/15 | 5.61 | 5.78 | +.17 | 5.67 | 5.78 | +.11 |
| 7/16 | 5.54 | 5.47 | -.07 | 5.60 | 5.47 | -.13 |
| 7/17 | 5.74 | 5.86 | +.12 | 5.65 | 5.86 | +.21 |
| 7/18 | 5.61 | 5.70 | +.09 | 5.65 | 5.70 | +.05 |

Table 1 shows the comparison between the reflux, nuclear and plant averages per day.

Of the 176 tests taken, the average deviation between the reflux and nuclear was -0.19% + 0.11%. The average deviation between the plant and nuclear was +0.11% -0.11%.

Comparisons became more favorable as testing progressed, because of a better understanding of how the sample should be prepared for testing.

The next study consisted of testing on different projects using a curve calibrated on one asphalt material to determine what amount of recalibrating would be necessary for each project.

The following results are on Project F 034-1(5) Harrison Road to U.S. Highway 24. The aggregate gradation is shown.

| Strauss Pit (Granite) | |
|---|---|
| Screen | % Passing |
| ¾ In. | 100 |
| No. 4 | 58 |
| No. 10 | 33 |
| No. 40 | 14 |
| No. 200 | 7.8 |

Asphalt 85/000 AC Grading C Hydrated Lime 1.0%.

Comparison between the reflux and nuclear determinations on Project F 034-1(5) Harrison Road to U. S. Highway 24:

| Date 1963 | Reflux | Nuclear | Diff. |
|---|---|---|---|
| 11/18 | 6.16 | 6.02 | -.14 |
| 11/19 | 6.36 | 6.20 | -.16 |
| 11/20 | 5.98 | 6.20 | +.22 |

Project F 031-1(6) Penrose (Asphalt 120/150 AC Grading C Hydrated Lime 1.0%):

| Date | Reflux | Nuclear | Diff. |
|---|---|---|---|
| 4/2/64 | 5.85 | 5.99 | +.14 |

It was necessary to calibrate a different curve for asphalt 120/150 penetration.

Project S 0002(25) Springfield to Vilas (Asphalt 120/150 Grading D Hydrated Lime 1.0%). In this case a curve was calibrated using Grading "D" material before testing began. Calibration standards were made using aggregate from the Freeman Pit No. 1 near Calhan.

The gradations below show the comparison between the Freeman Pit No. 1 and the Rutherford Pit used on the Springfield to Vilas project.

| Curve | | Project | |
|---|---|---|---|
| Freeman Pit No. 1 (Sand & Gravel) | | Rutherford Pit (Sand & Rock) | |
| Screen | % Passing | Screen | % Passing |
| ¾ In. | 100 | ¾ In. | 100 |
| ½ In. | 100 | ½ In. | - |
| No. 4 | 93 | No. 4 | 82 |
| No. 10 | 73 | No. 10 | 64 |
| No. 40 | 21 | No. 40 | 21 |
| No. 200 | 9.4 | No. 200 | 10 |

Comparison between the reflux and nuclear determinations on Project S 0002 (25) Springfield to Vilas:

| Date 1964 | Reflux | Nuclear | Diff. | Plant | Nuclear | Diff. |
|---|---|---|---|---|---|---|
| 4/6 | 7.26 | 7.00 | -.26 | 7.10 | 7.00 | -.10 |
| 4/7 | 7.01 | 7.16 | +.15 | - | 7.16 | - |
| Note: | Changed plant at noon | | | | | |
| 4/7 | 6.79 | 6.60 | -.19 | - | 6.60 | - |
| 4/8 | 6.86 | 6.80 | -.06 | 6.80 | 6.80 | .00 |
| 4/9 | - | 6.80 | - | 6.77 | 6.80 | +.03 |

Project C-22-0059-07 Campo (Asphalt 120/150 AC Grading C Modified no lime):

| Curve | | Project Pit (Limestone) | |
|---|---|---|---|
| Strauss Pit (Granite) | | | |
| Screen | % Passing | Screen | % Passing |
| ¾ In. | 100 | ¾ In. | 100 |
| No. 4 | 58 | No. 4 | 55 |
| No. 10 | 33 | No. 10 | 43 |
| No. 40 | 14 | No. 40 | 20 |
| No. 200 | 7.8 | No. 200 | 6.9 |

Comparisons below are between reflux and nuclear only.

| Date 1964 | Reflux | Nuclear | Diff. |
|---|---|---|---|
| 4/15 | 5.85 | 6.01 | +.16 |
| 4/16 | 5.92 | 5.99 | +.07 |

Project S 0016 (27) Olney Springs to Ordway (Asphalt 85/100 AC Grading C Modified 1.0% Hydrated Lime):

| Curve | | Project Pit (Granite) | | Note Specs |
|---|---|---|---|---|
| Higginson Pit (Granite) | | | | |
| Screen | % Passing | Screen | % Passing | |
| ¾ In. | 100 | ¾ In. | 100 | - |
| ½ In. | - | ½ In. | 100 | 100 |
| No. 4 | 55 | No. 4 | 80 | 65 to 85 |
| No. 10 | 35 | No. 10 | 66 | 60 to 75 |
| No. 40 | 15 | No. 40 | 29 | - |
| No. 200 | 6.9 | No. 200 | 7.4 | 7 to 12 |

The following list includes the average values per day between the reflux and nuclear methods on Project S0016(27) Olney Springs to Ordway.

| Date 1964 | Reflux | Nuclear | Diff. |
|---|---|---|---|
| 5/4 | 6.40 | 6.68 | +.28 |
| 5/5 | 6.59 | 6.59 | .00 |
| 5/6 | 6.94 | 6.94 | .00 |
| 5/11 | 6.66 | 6.72 | +.06 |
| 5/12 | 6.18 | 6.23 | +.05 |

The average deviation of 53 tests using a calibrated curve from one aggregate source to measure an asphalt mix using another aggregate source was +0.14% -0.16%.

The research study to date has revealed that if the penetration range of the asphalt and the type of gradation (Grading C or D) remain the same, there is very little adjusting of the calibrated curve due to different suppliers of the asphalt or type of rock. However, if the penetration or type of grading differs, a new curve must be calibrated.

There are four master curves calibrated:

| Curve No. | Asphalt | Aggregate |
|---|---|---|
| 1 | 120/150 penetration | Grading C |
| 2 | 85/100 penetration | Grading C |
| 3 | 120/150 penetration | Grading D |
| 4 | 85/100 penetration | Grading D |

The slope of the asphalt content curve is less than the moisture curve because only part of the normal volume of the field is used. Research is being conducted at this time to determine a method of improving this.

## SCREEN ANALYSIS

Gradation tests are sampled from the hot bins at the plant. The size of the sample measured in the nuclear test eliminates, to a greater degree, the variation in gradation from sample to sample.

## MOISTURE

The determination of moisture in the bituminous mixture is obtained by AASHO method T 110, which employs a metal still, annealed glass trap and water-cooled reflux glass tube-type condenser. The solvent used is Xylol.

A moisture test was made twice a day, provided weather conditions remained constant.

## CONCLUSIONS

The nuclear method of measuring asphalt content requires approximately twenty minutes for the complete test. This includes taking the sample from the roadway, handling of the material in preparation for nuclear measurement, the nuclear measurement, and the calculations.

Of the 229 nuclear tests represented in this report, 229 comparisons have been between the reflux method and the nuclear method, and 41 comparisons have been between the plant calculated values and the nuclear method, making a total of 270 comparison tests. Of these, 15 tests have exceeded 0.3 percent difference and the cause is believed to have been determined.

While the values of asphalt percents in a mix are small as compared to moisture tests in soil materials, attention should be directed to the fact that with soils, the material being measured may vary in composition from test to test on a single project. In the measurement of asphalt content, the material being measured is select processed material and if the nuclear method is to be used on the project, it may be easily calibrated for this material.

The sample to be measured is 13 to 15 lb in weight, depending on the gradation of the material. This volume may be handled with reasonable accuracy when preparing a sample for testing.

ACKNOWLEDGMENT

Appreciation is expressed to the field personnel of District II and to the reproduction staff for their assistance in preparing this paper.

# *Discussion*

TAJAMAL HUSSAIN QURESHI, Superintending Engineer, Government of West Pakistan, C & W Department (47-F, Modeltown, Lahore)—Mr. Walters is to be thanked for presenting his paper. The rapidity and reasonable degree of accuracy with which the asphalt content measurements can be taken by this technique deserve serious consideration of its adoption as a standard method. In support of this technique, extracts from recent research at North Carolina State College at Raleigh are presented.

Hydrogen is present in the hydrocarbons which constitute asphalt. The aggregate in the asphaltic concrete can have hydrogen either in the moisture accompanying the aggregate or in the adsorbed layers of the mineral fraction. The aggregate used for asphalt concrete is generally free from such fine fractions which may have adsorbed water to a considerable extent. If some such fraction is present, however, the adsorbed water along with free moisture is almost entirely lost when the aggregate is heated in the dryer. Therefore, the presence of hydrogen in asphaltic concrete is almost entirely due to the hydrocarbons.

The fact that the hydrogen content of the asphalt concrete is found in the hydrocarbons of the asphalt and that hydrogen is the most effective neutron moderator serves as the basis for asphalt content determination by the neutron moderation technique.

## Experimental Procedure

The neutron moderation technique is based on the hydrogen content of the asphalt portion of the asphaltic concrete. As such, the count rate depends on the quantity of asphalt present in a sample. It was concluded, therefore, that keeping the percentage of asphalt the same in a sample and varying its dimensions or density would affect the count rate. Accordingly, the initial studies were directed to the determination of the smallest practicable size of the sample beyond which the count rate would not be affected.

In the experiments the following apparatus was used:

1. Source: 3 millicurie $R_a$ - $B_e$.
2. Reflector: Polyethylene reflector (originally developed for the soil moisture meter).
3. Detector: Neutron Moisture Probe Model 104 Serial 016629 (Troxler).
4. Scaler: Model 200B Serial 203 (Troxler).

Effect of Lateral Dimensions.—To study the effect of lateral dimensions, an asphalt-concrete sample was prepared by mixing 7 percent asphalt with well-graded aggregate in the laboratory and rolling it to 10- by 2- by 2-in. size. Count rate was taken by placing it on the polyethlene reflector. The size of this same sample was then reduced to 8 by 8 by 2 in. and then to 5½ by 5½ by 2 in. For each of these sizes the count rate

TABLE 2

EFFECT OF LATERAL DIMENSIONS ON COUNT RATE
(Asphalt percentage by weight, 7%)

| Test No.[a] | Dimensions of Specimen (in.) | Counts | Count Rate per Min | Avg. Count Rate |
|---|---|---|---|---|
| 1 | 10 × 10 × 2 | 41813 | 10453 | |
| | overturned | 41243 | 10310 | 10,381 |
| 2 | 8 × 8 × 2 | 40034 | 10008 | |
| | overturned | 40388 | 10097 | 10,052 |
| 3 | $5\frac{1}{2} \times 5\frac{1}{2} \times 2$ | 32573 | 8143 | |
| | overturned | 31240 | 7810 | 7,976 |

[a]Time = 4 min.

TABLE 3

EFFECT OF THICKNESS ON COUNT RATE

| Test No.[a] | Specimen Thickness (in.) | Counts | Count Rate per Min |
|---|---|---|---|
| 1 | 2.90 | 42452 | 10,613 |
| 2 | 5.90 | 44673 | 11,168 |
| 3 | 8.15 | 45168 | 11,292 |
| 4 | 10.40 | 45713 | 11,428 |
| 5 | 11.80 | 46232 | 11,558 |

[a]Time = 4 min.

was taken by first placing it on one face and then on the other to guard against any variation due to nonuniformity within the sample. The results are given in Table 2. A $9\frac{3}{4}$- by $7\frac{3}{4}$- by 3-in. size was adopted since a mold was available for further experiments.

Effect of Thickness.—Similarly, count rates were taken by successively increasing the thickness of the samples on the reflector. It was found that the count rate increased for every added thickness (Table 3). A 3-in. thickness of the samples was adopted for further experiments.

## Relationship Between Asphalt Content and Count Rate

Varying densities also affect the count rate. Accordingly, it was considered necessary to use samples of the same dimensions throughout the studies and, to obtain uniform density for every sample, the same quantity of asphalt concrete was compacted to the same size in every case.

A mold to give a size of $9\frac{3}{4}$ by $7\frac{3}{4}$ by 3 in. was used throughout, and the weight of asphaltic concrete contained in the sample was 7.7 kg in every case. Due to the difficulty of obtaining exact measurements and weights, a tolerance of ± 1 percent was accepted as a maximum. All samples used in the experiments were within this variation.

Having determined a procedure for preparation of samples of uniform dimensions and uniform densities, samples of asphaltic concrete were prepared containing 2 to 7 percent asphalt. The count rates are given in Table 4. Count rate vs asphalt percent-

TABLE 4

RELATIONSHIP OF ASPHALT PERCENTAGE TO COUNT RATE

| Test No.[a] | Asphalt (%) | Counts | Count Rate |
|---|---|---|---|
| 1[b] | - | 120,133 | 30,033 |
| 2 | 2 | 51,547 | 12,887 |
| 3 | 3 | 53,359 | 13,339 |
| 4 | 4 | 55,897 | 13,974 |
| 5 | 5 | 58,166 | 14,541 |
| 6 | 6 | 60,040 | 15,010 |
| 7 | 7 | 61,753 | 15,438 |
| 8 | 7 | 62,114 | 15,528 |
| 9 | 6 | 60,605 | 15,151 |
| 10 | 5 | 58,860 | 14,715 |
| 11 | 4 | 56,231 | 14,058 |
| 12 | 3 | 53,716 | 13,429 |
| 13 | 2 | 51,666 | 12,916 |
| 14[b] | - | 120,633 | 30,158 |

[a]Time = 4 min.
[b]Polyethylene standard block.

Note: Tests Nos. 8 through 14 are repetitions of 1 through 7 in reverse order.

age was plotted in Figure 14, and a linear relationship was established. It was, however, noticed that the count rate drifted considerably during the experiments, as seen from the count rates recorded at different instants for the polyethylene block, as well as those recorded for the samples by repeating the counting. To eliminate errors due to this drifting, the next set of readings was obtained for each sample alternately with the standard polyethylene block, so that a count rate was available for the standard block before and after the count rate for each sample, and a count rate ratio could be obtained. To minimize errors due to any nonuniformity within the sample the count rate was taken by placing each sample first on one face and then reversing it. The record of count rates and count rate ratios is given in Table 5.

Figure 15 was plotted between count rate ratio and asphalt percentage and

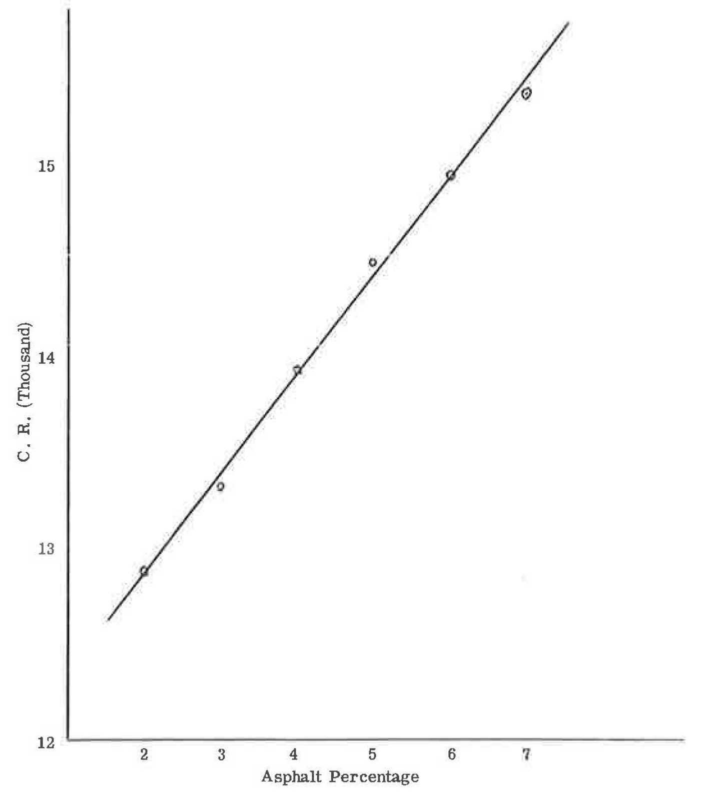


Figure 14. Relationship of asphalt percentage to count rate.

TABLE 5

RELATIONSHIP OF ASPHALT PERCENTAGE TO COUNT RATIO OF SPECIMEN AND POLYETHYLENE STANDARD BLOCK

| Test No.[a] | Item | Counts | Count Rate | Count Rate Avg. | Count Rate Avg. of Poly. Std. | Count Rate Ratio |
|---|---|---|---|---|---|---|
| 1 | Poly. std. | 90,017 | 30,006 | | | |
| 2 | 2% Asphalt sample | 37,859 | 12,620 | 12,636 | 30,058 | 0.42038 |
| 3 | Reversed | 37,956 | 12,652 | | | |
| 4 | Poly. std. | 90,331 | 30,110 | | | |
| 5 | 3% Specimen | 39,314 | 13,105 | 13,241 | 30,109 | 0.43976 |
| 6 | Reversed | 40,132 | 13,377 | | | |
| 7 | Poly. std. | 90,323 | 30,108 | | | |
| 8 | 4% Specimen | 40,990 | 13,663 | 13,750 | 30,103 | 0.45676 |
| 9 | Reversed | 41,514 | 13,838 | | | |
| 10 | Poly. std. | 90,293 | 30,098 | | | |
| 11 | 5% Specimen | 42,340 | 14,113 | 14,275 | 30,096 | 0.47431 |
| 12 | Reversed | 43,315 | 14,438 | | | |
| 13 | Poly. std. | 90,285 | 30,095 | | | |
| 14 | 6% Specimen | 44,290 | 14,763 | 14,708 | 30,126 | 0.48821 |
| 15 | Reversed | 43,957 | 14,652 | | | |
| 16 | Poly. std. | 90,473 | 30,157 | | | |
| 17 | 7% Specimen | 44,851 | 14,950 | 15,099 | 30,151 | 0.50077 |
| 18 | Reversed | 45,747 | 15,249 | | | |
| 19 | Poly. std. | 90,435 | 30,145 | | | |

[a]Time = 3 min.

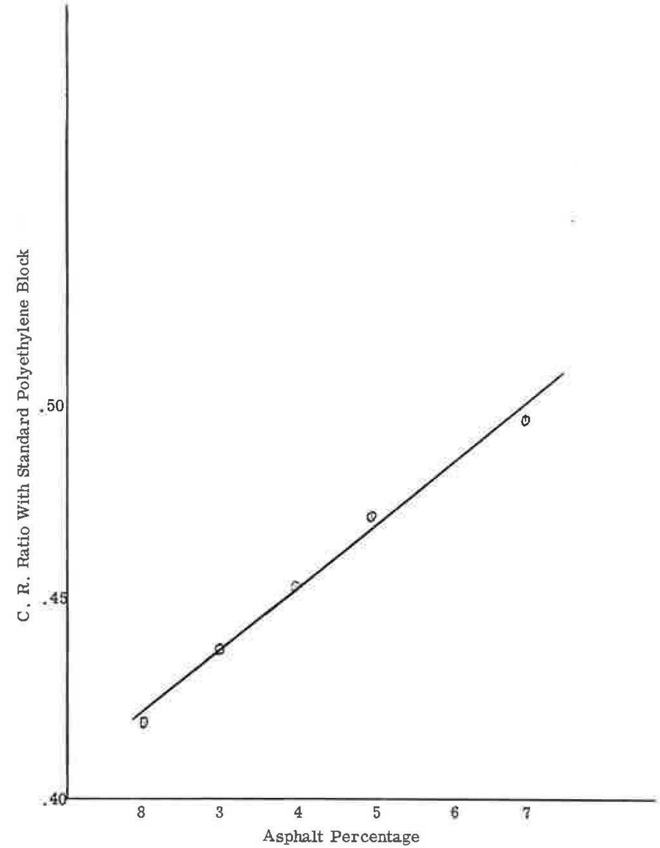


Figure 15. Relationship of asphalt percentage to count rate ratio.

indicates a linear relation with a straight line passing very close to each point given by the observations.

The linear relations established by the experiments indicate that the maximum deviation from the fitted curve is less than ± ¼ percent asphalt.

H. W. WALTERS, Closure—I am very pleased with the discussion by Tajamal Hussain Qureshi on Nuclear Asphalt Content Determination.

Considering the fact that there was no communication between us during the time this research work was being done, I am impressed with the similarity of the results.