FINAL REPORT

EVALUATION OF A NUCLEAR ASPHALT CONTENT GAUGE

by

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Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

December 1970
VHRC 70-R26

SUMMARY

The Troxler Model 2226 asphalt content gauge was evaluated in the laboratory and taken into the field where its results were compared to conventional reflux values. The precision as evaluated in the laboratory was found to be excellent — equivalent to .06% asphalt content with a 45 second count. The gauge does have to be recalibrated each time a different aggregate is used and as a practical matter should be recalibrated for each different mix type. Sample preparation is important and samples should be as uniform as possible. The accuracy appears to be as good as that of the reflux extractor. A recommendation for using the nuclear gauge is appended.

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INTRODUCTION

There have been several reports[1, 2, 3] on the use of nuclear gauges to measure the asphalt content of bituminous mixes. The earliest report[1], presented in 1956 was on research in which experimental equipment was used, and it concluded that although the theoretical principles involved had been experimentally validated, the variability of the results and the cost of the equipment precluded the use of the apparatus at that time. More recent reports have dealt with the use of commercially available nuclear moisture gauges to measure asphalt content, which is possible because of the fact that the measurements of both moisture and asphalt content are based on the detection of thermalized neutrons. However, because equipment adaptation is necessary and the variability of the test results rather large, this equipment has not been widely accepted for measuring asphalt content.

Even more recently gauges designed expressly for the purposes of measuring asphalt content have become commercially available[4]. In 1969 the author[5] reported on the use of such a gauge. It was reported that the precision of the gauge, about .20% asphalt content, was fairly good, but that a relatively long counting time — 18 minutes — was required. Also the accuracy left something to be desired; the correlation between count rate and asphalt content had a standard error of .30% asphalt content. It was suggested that the gauge could be redesigned to improve its accuracy and this conclusion was generally substantiated by a study done at the University of Southwest Louisiana[6]. The manufacturer, Troxler Electronic Laboratories, agreed with this conclusion and made a second generation gauge available in November 1969.

This report is essentially concerned with an evaluation of this gauge, which is the manufacturer's Model 2226 shown in Figure 1. The operation of the gauge is similar to that of the original model in that the sample pan is filled and inserted into a drawer for testing (Figure 2). However, it is different in two important respects. One is that it operates on the basis of direct transmission rather than backscatter. This means that the sample is placed between the source (300 mc. Am Be) and the detector tubes (He_3, which are much more efficient that the BF_3 tubes previously used). This feature

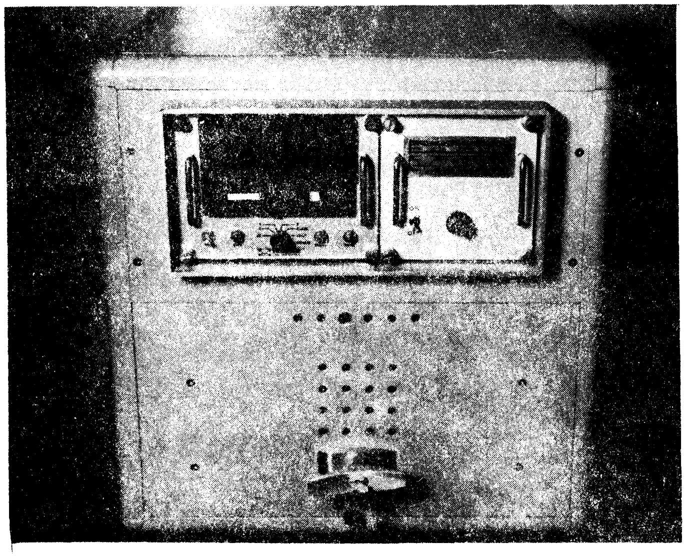

Figure 1. Model 2226 asphalt content gauge.

Figure 2. Asphalt content gauge showing sample pan.

minimizes the influence of the location of the asphalt, a serious drawback in the original gauge. The other difference is the inclusion of a self-standardizing operation (Figure 3) that converts the count obtained from the scaler into a count ratio. This simplifies the gauge operation tremendously by eliminating the requirement for a separate standard count.

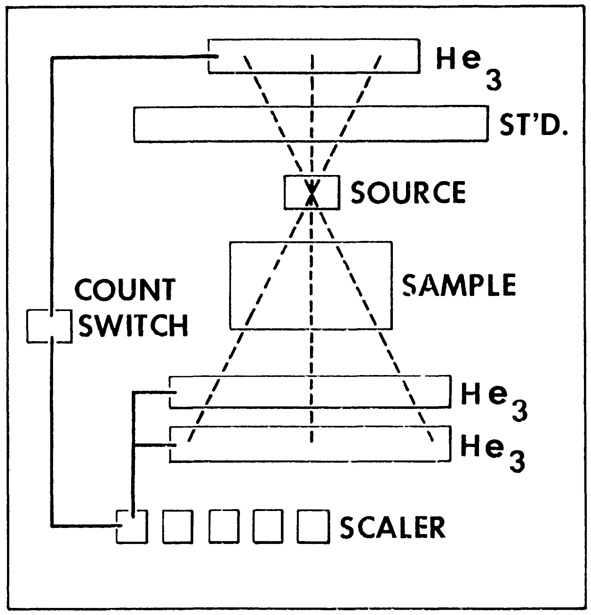

Figure 3. Schematic diagram of Model 2226 operation.

PURPOSE AND SCOPE

The purpose of this evaluation was to determine the precision of the Troxler Model 2226 asphalt content gauge and to evaluate its accuracy under several variables.

A laboratory evaluation of the gauge constituted the initial phase of the project. The precision was determined by performing several repeat tests on the same sample; and the accuracy was evaluated by analyzing the effects of several variables. More specifically, in the latter instance, it was necessary to determine for which variables the gauge must be recalibrated. The variables investigated were aggregate type, gradation, asphalt content and asphalt penetration, and producer. On the basis of the author's previous study it was anticipated that different aggregates would produce different count rates, and to check this expected result four aggregates were chosen:

(1) Granite,
(2) Limestone,
(3) Greenstone, and
(4) Gravel.

Although the previous study had indicated no effect from gradation, it was thought that gradation should be included as a variable. The gradations studied are given in Table I. These variables were included in an experimental design to cover

TABLE I

MIX GRADATIONS

Sieve Size	Percent Passing		
	Coarse	Medium	Fine
1½"	100		
3/4"	75	100	
1/2"			100
3/8"		70	90
4	40	50	60
8	30	35	45
30			
50		10	15
100		6	10
200	3		6
% Asphalt	0 - 5	0 - 6	0-7

an asphalt content range of from 0% to 7% as shown in Table II (all asphalt contents were calculated on a percent by weight basis). Also shown in Table II are the asphalts that were tested based on producer and penetration grade. All mixes were of sufficient weight to allow two samples of 6700 grams each to be tested.

The laboratory phase of the study was followed by a field testing program.

TABLE II

MIXES TESTED

Mix No.	Aggregate	Gradation	Asphalt Content	Asphalt
*1-4	Granite	Coarse	0, 3, 4, 5	#1**(85-100)
5-8	Granite	Medium	0, 4, 5, 6	"
9-12	Granite	Fine	0, 5, 6, 7	"
13-16	Gravel	Coarse	0, 3, 4, 5	"
17-20	Gravel	Medium	0, 4, 5, 6	"
21-24	Gravel	Fine	0, 5, 6, 7	"
25-28	Limestone	Coarse	0, 3, 4, 5	"
29-32	Limestone	Medium	0, 4, 5, 6	"
33-36	Limestone	Fine	0, 5, 6, 7	"
37-40	Greenstone	Coarse	0, 3, 4, 5	"
41-44	Greenstone	Medium	0, 4, 5, 6	"
45-48	Greenstone	Fine	0, 5, 6, 7	"
49	Gravel	Medium	5.0	#1 (85-100)
50	Gravel	Medium	5.0	#2 (85-100)
51	Gravel	Medium	5.0	#1 (60-70)

* Each mix was split and duplicate samples run for each mix.

** Asphalt No. 1 — Esso
Asphalt No. 2 — Chevron

EVALUATION

Nuclear Tests

Precision

The precision of the gauge was established by performing 30 three-minute (1-position) repeat tests on the same sample. On a 6% fine limestone mix the standard deviation was 130 counts (equivalent asphalt content = .02%), which provided a variation coefficient of .27%. These results are shown in Figure 4, which also shows that count rate is independent of temperature from the normal mixing temperature of 280° F. to 140° F. Based on these data and a 45 second (.25 test position) count rate, it was determined that for a 45 second count the precision, or ability of the gauge to repeat a measurement, would have a 95% confidence limit of .05% asphalt content.

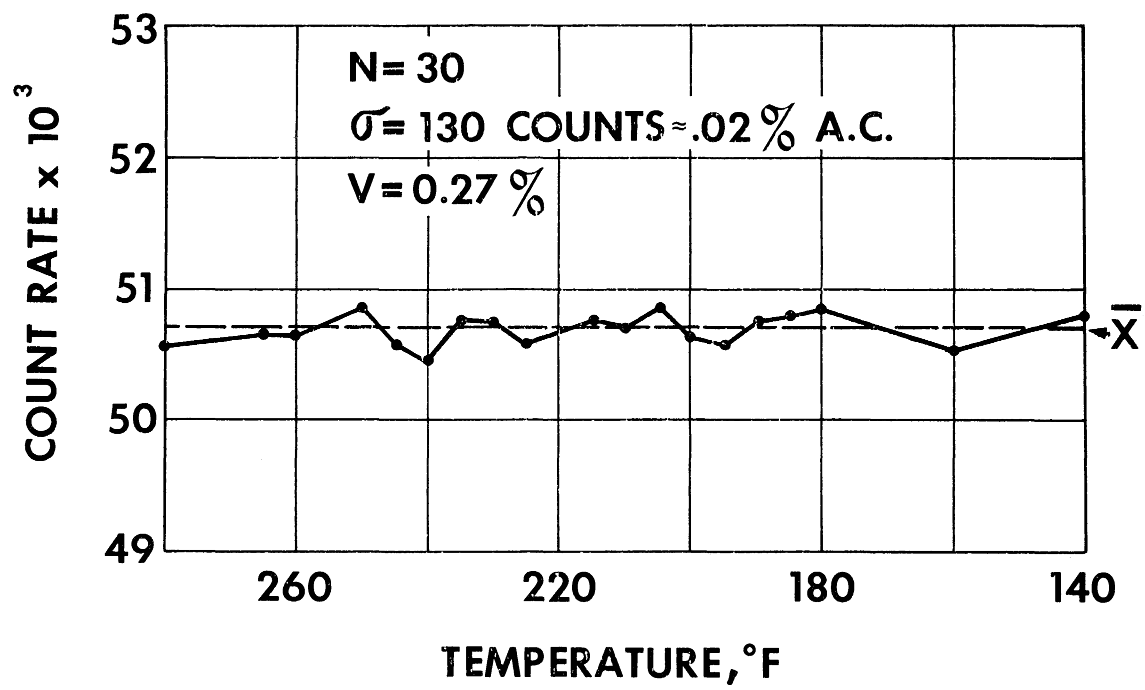

Figure 4. Precision results and lack of temperature influence on count rate.

Accuracy

In order to evaluate the accuracy of the gauge under the previously mentioned variables, two statistical techniques were employed. More specifically, these techniques were used to determine which variables would likely require the establishment of separate calibration curves. The first technique employed was a regression analysis of the first 48 mixes shown in Table II. To gain an indication of the influence of both asphalt penetration and producers, an analysis of variance was performed. These analyses, as well as one between design and extracted asphalt content and one dealing with field calibration and testing, are discussed below.

Sample Preparation

In making all of the mixes sufficient material was used to allow tests on two pans for each mix so that an indication of "between pan" variation could be obtained. The first tests were performed on a fine gradation mix and the difference between the two test pans was much greater than had been found for the "within pan", or precision, data that had been obtained. This led to an investigation of the sample preparation techniques, which revealed much greater reproducibility when a mechanical sample splitter was used than when the sample was split "by hand". This difference is apparent from Table III. The average values for difference between pans was for the type of splitting about .22% for hand and .04% for mechanical. This difference between the two pointed out the necessity for preparing samples with a sample splitter. It also emphasized that differences in asphalt content can be caused by a relatively small amount of segregation, even in a fine graded mix. Thus, as has been recognized in the past, sample preparation is quite important and because it does cause single test values to vary widely, sample averages should be used as extensively as practicable.

TABLE III

EFFECT OF TYPE OF SPLITTING
(FINE GRADATION)
45 Second Count

Method	Pan No. 1	Pan No. 2	Diff. Count Rate	Diff. % AC
Hand	9658	9574	84	.17
Hand	12840	12974	134	.27
Splitter	9543	9531	12	.02
Splitter	12191	12214	23	.05

Aggregate Effect

In order to determine the influence of aggregate type and gradation, linear regression analyses were performed on each aggregate for each gradation. All gradations were then pooled and a regression analysis made for each aggregate. As was mentioned under Purpose and Scope, the initial study substantiated clearly the theoretical principle that separate calibration curves would be needed for each aggregate. Table IV shows the slopes and intercepts from the linear regression analyses as well as the standard errors and correlation coefficient for each gradation and for each aggregate. Of primary importance initially are the very high correlation coefficients obtained under all gradations and aggregates; all are above .990, which indicates that count rate is definitely related to asphalt content. Also of importance is the standard error, which indicates the level of accuracy that can be expected from the prediction. The standard error values are generally .20% asphalt content or less, except in the case of the gravel mixes.

Table IV also shows that gradations have essentially no effect on calibration or, more precisely, on count rate. The standard errors and correlation coefficients for the individual gradations are not sufficiently improved over the pooled values to warrant the use of the former. This same conclusion is evident in Figures 5, 6, 7 and 8, which are graphical representation of the regression analyses. There is no discernible difference between the gradation points. This does not mean that there is no gradation effect. As stated previously, the effect of gradation or segregation was apparent from tests on supposedly identical samples. Extending the analysis to various gradations in Table V it can be seen that for the limestone gradation, as an example, the average difference between pans increases sevenfold, from .04% in the fine mix to .28% for the coarse gradation. Naturally, this phenomenon is not unique with nuclear testing. However, the ability to retest the same sample and the speed of testing with the nuclear method make the differences much more apparent.

The results from pooled aggregate analysis, reproduced in Table VI, show clearly by the variation in intercepts that separate calibration curves are necessary for each aggregate. And although it does not appear that a change in gradation requires a change in calibration, as a practical matter a change in gradation is normally accompanied by a change in aggregate type. This means that as a practical matter a change in gradation should necessitate at least a recheck on the calibration. This subject will be discussed in more detail under Field Calibration.

Since the slopes between aggregates are reasonably close it was thought it would be possible to use only a 0%, or dry aggregate point, and the average slope of 2013 counts/% asphalt content to establish a reasonably accurate calibration curve. Predictions based on this method did not compare well with the actual asphalt contents and this method was dropped from further consideration.

TABLE IV

GRADATION EFFECT

Aggregate	Gradation	Slope, % A.C./C.R.	Intercept, C.R.	Std. Error % A.C.	Corr. Coef.
Granite	Coarse	1868	38544	.09	.9994
"	Medium	1896	38744	.18	.9985
"	Fine	1883	38907	.13	.9994
"	Pooled	1902	38662	.14	.9985
Limestone	Coarse	2026	38502	.19	.9973
"	Medium	2177	37822	.20	.9981
"	Fine	2209	38213	.15	.9992
"	Pooled	2173	38090	.20	.9972
Greenstone	Coarse	1953	43366	.18	.9976
"	Medium	1873	43850	.07	.9997
"	Fine	1921	44075	.17	.9990
"	Pooled	1940	43665	.19	.9974
Gravel	Coarse	1885	38964	.25	.9955
"	Medium	2091	38919	.39	.9926
"	Fine	1971	39797	.22	.9984
"	Pooled	2038	39040	.33	.9918

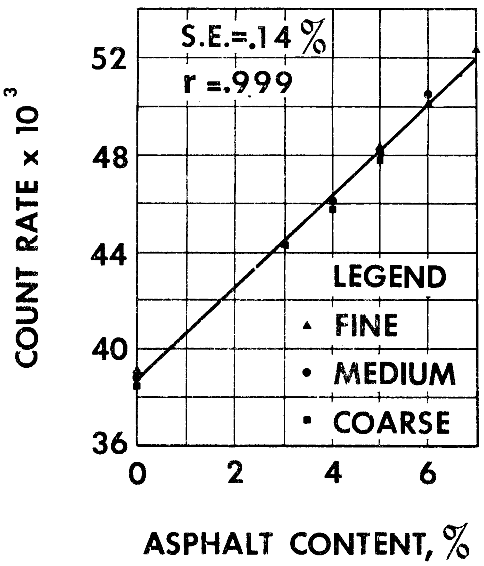

Figure 5. Regression analysis for granite aggregate.

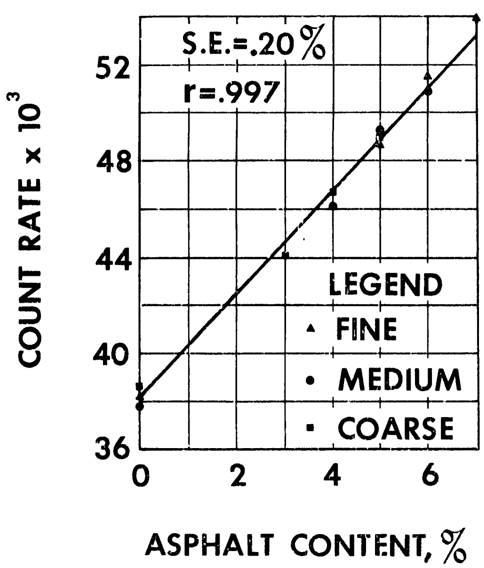

Figure 6. Regression analysis for limestone aggregate.

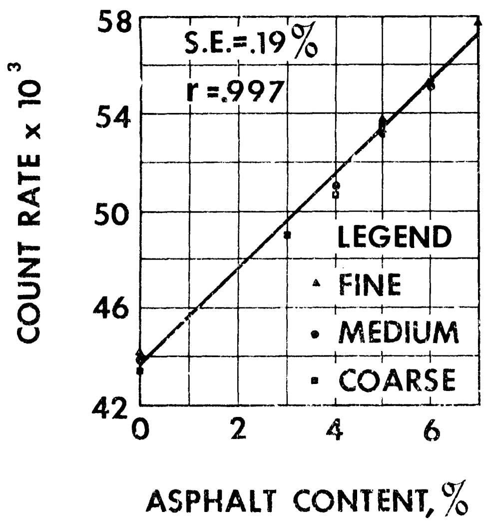

Figure 7. Regression analysis for greenstone aggregate.

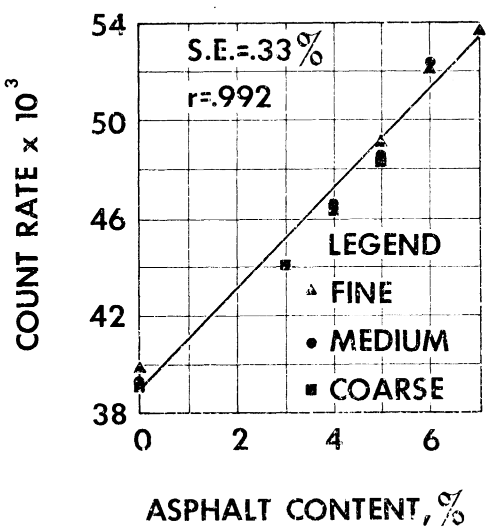

Figure 8. Regression analysis for gravel aggregate.

TABLE V

SAMPLE GRADATION EFFECT, LIMESTONE

Gradation	Average Diff., C.R. Between Pan#1 & Pan #2	Diff., % A.C.
C	140	.28
M	50	.10
F	20	.04

TABLE VI

MATERIAL EFFECT

Material	Slope, C.R./A.C.	Intercept, C.R.	St'd Error, % A.C.
Granite	1902	38662	.14
Limestone	2173	38090	.20
Greenstone	1940	43665	.19
Gravel	2038	39040	.33
Average	2013		

Asphalt Effect

In order to determine whether either asphalt producer or asphalt penetration affect the count rate, three mixes (49, 50, and 51 in Table II) were tested. These used a single gradation, aggregate type and asphalt content and varied only in penetration or producer. An analysis of variance indicated that statistically there was a significant difference between asphalts and in this case the difference appeared due to penetrations. Table VII shows the average count rate and the equivalent asphalt contents measured. Although there may have been some difference attributable to penetration it appeared to be reasonably small and it is believed that it can be accommodated in the field calibration.

TABLE VII

EFFECT OF ASPHALT

	Esso 85/100	Esso 60/70	Chevron 85/100
Average Count Rate	49268	49024	49280
Asphalt Content, %	5.00	4.88	5.01

Conventional Tests

In order to establish a basis for comparison between nuclear asphalt content values and conventional reflux values, thirty-six of the first forty-eight mixes (12 were dry or 0% asphalt mixes) were extracted by the reflux method and the values correlated with the design asphalt content. Figure 9 shows the regression line and the pertinent statistical information. As would be expected, the correlation coefficient was high (.994) and the slope was almost unity (1.02). But the average extracted asphalt content was .10% lower than the design average, which indicated a bias in the method. This bias in extracted asphalt content was not unexpected, since it is quite often found that the amount extracted is not as high as that put into the mix. This bias should be considered whenever it is desired to correlate nuclear values and extracted values, since the plant input asphalt content cannot be controlled as well as that in a laboratory.

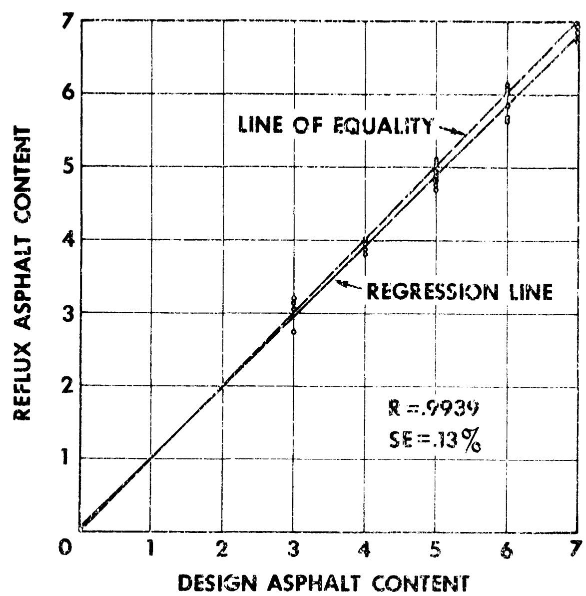

Figure 9. Regression analysis — design versus extracted asphalt content.

The standard error of the conventional values versus design values was 0.13% as compared to generally less than .20% for the nuclear correlations in Table IV. Because of the great speed advantage in the nuclear method the slight loss in accuracy should be more than compensated for by making more tests.

Field Calibration

The primary criteria for establishing a field calibration procedure were that it must be technically sound and also practical. From the first viewpoint the following guidelines were established.

(1) Each aggregate must be calibrated separately.
(2) At least two points are necessary to establish a calibration curve.
(3) Each mix type must be checked for calibration, and
(4) Asphalt type should be checked for calibration periodically.

From the practical viewpoint the procedure must be one that plant personnel can master and the calibration procedure must not be lengthy or be required too often.

With these guidelines it was decided to calibrate as soon as possible after starting up a plant. Because moisture variations affect the count rate of the gauge, the ideal sampling point appeared to be the hot bin, where the moisture content should be reasonably stable. This was also advantageous because the aggregate, after blending in the proper proportions, could be tested dry to establish the 0% point on the calibration curve, and then, since it was still hot, could be mixed with an asphalt sample from the storage tanks to produce a second point on the calibration curve near the optimum asphalt content for that mix. With this procedure about one hour is required for establishing a calibration curve; afterwards, testing can commence. The main parameter established by this process is the slope of the curve, because the intercept will change from time to time depending on the moisture in the aggregate. Therefore the 0% point only should be checked at least once a day and more often if weather creates variable moisture conditions in the aggregate stockpiles.

Field Testing

Using the above procedure five plants were checked during the fall of 1970. Table VIII shows the results of the nuclear tests using both 1 and .25 position counts, as well as the corrected reflux results. The correction values are the differences between the design asphalt content used in making up the calibration sample and the amount extracted by the reflux test. This procedure is in agreement with results of the correlation under Conventional Tests.

The comparison between nuclear and corrected reflux averages is very good with the average difference for all results being only .13% asphalt content for the 1 position and .09% asphalt content for the .25 position.

It is felt from these limited data that the potential of the nuclear asphalt content is very great; it will provide very accurate results in a very short period of time.

TABLE VIII

RESULTS OF FIELD TESTING

Plant #	Calibration No.	Mix Type	No. of Tests	Nuclear Ave.		Corrected Reflux Ave. %	Correction % A.C.
				1 Position	.25 Position		
1	1	Base	10	4.82	4.87	4.85	.50
1	2	Base	8	5.31	5.32	5.19	.84
2	1	Surface	10	5.70	5.69	5.74	.28
2	2	Surface	10	5.86	5.78	5.78	.16
3	1	Inter-mediate	10	4.60	4.57	4.57	.19
3	2	Inter-mediate	6	4.29	4.21	4.88	.05
3	3	Surface	6	4.53	—	4.74	.17
4	1	Surface	10	5.51	5.61	5.72	.11
5	1	Base	8	3.96	—	4.16	.22
5	2	Inter-mediate	7	5.12	—	4.96	.14

The adoption of a rapid asphalt content test method for acceptance of asphalt content does require a reevaluation of the method of acceptance for asphaltic concrete gradation. Having to wait for a gradation obtained from a washing process would appear to negate some of the advantage of the speed of the nuclear asphalt content test. It appears that the best way of similarly speeding up gradation results would be through the use of hot bin samples for gradation acceptance. Such samples are being used in conjunction with the nuclear asphalt content gauge on a field project in order to evaluate the entire acceptance procedure.

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APPENDIX

RECOMMENDED PROCEDURES FOR OPERATING NUCLEAR ASPHALT CONTENT GAUGE

Calibration

A. Calibrate for each mix type.

B. Recalibrate for each job mix change.

C. Check calibration periodically for asphalt source.

D. Procedure.

1. Take sufficient hot bin samples to obtain two combined samples of 7,000 gr. each.
2. Split hot bin samples.
3. Combine hot bin samples proportionately to obtain an aggregate sample of 7,000 gr.
4. Place 6,700 gr. in pan and compact with steel plates.
5. Test pan in calibrate position.
6. Plot count rate vs. 0% asphalt content.
7. Mix sufficient aggregate and known amount of asphalt to produce 6,700 gr. of mix at desired (design) asphalt content.
8. Place 6,700 gr. of mix in pan and compact with steel plate.
9. Test pan in calibrate position.
10. Plot count rate vs. design asphalt content.
11. Draw calibration line between two points.
12. Reestablish 0% asphalt content at least once a day from hot bin sample.
13. Use slope of curve in step 11 to draw new calibration line.

Testing

A. Take sample for nuclear test at least at same time as reflux sample is taken.

B. Samples for nuclear test may be taken more often.

C. Procedure.

1. Split sample to obtain at least 7,000 gr. for nuclear test.
2. Place 6,700 gr. of mix in pan and compact with steel plate.
3. Test pan in 1-position count.
4. Read count rate on calibration line to obtain asphalt content.

Nuclear vs. Reflux Comparison

A. Nuclear and reflux will often differ.

1. Due to sampling differences.
2. Due to testing differences.

B. Procedure.

1. In Calibration step D-8, after nuclear test, run a reflux test on the sample to obtain asphalt content.
2. Obtain difference between reflux asphalt content and design asphalt content.
3. Use this difference to correct future reflux results.
4. List nuclear and corrected reflux asphalt contents for each sample.