INVESTIGATION OF NUCLEAR ASPHALT CONTENT GAUGE

FINAL REPORT

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ABSTRACT

The introduction of new aggregate sources to Louisiana in the mid 1980s has presented problems in asphalt concrete mix design and construction. Absorptive aggregates such as reclaimed portland cement concrete and some stones now being supplied have made asphalt content determination a critical aspect of mix control. Current test procedures take several hours to determine asphalt content. In addition, the use of chlorinated solvents is being reduced nationally because of their hazardous storage, handling and disposal problems. This study evaluated the operation and performance of the nuclear asphalt content gauge as a replacement for existing methods to reduce test time and eliminate the use of hazardous solvents.

The variation in test results between centrifuge, reflux and the nuclear asphalt content gauge was evaluated for one week's production at six asphalt plants. Three batch plants and three drum plants were examined. Moisture content for the correction of nuclear content results was determined using both a microwave and the ASTM D1461 distillation method. Cold feed gradations were compared to extracted gradations from the samples tested for asphalt content.

The pooled standard deviations for the nuclear asphalt content gauge were similar to the reflux extraction results regardless of plant type with the batch plant deviation slightly lower than the drum plant. Both the nuclear gauge and the reflux had lower standard deviations than the centrifuge extractor. All moisture contents were negligible indicating reduced need for this test. Cold feed gradations were similar to hot mix extracted results with occasional bias because of the type of plant emission control and return system. The cold feed standard deviations for each sieve were comparable to the extracted hot mix samples, historical and Materials Test System (MATT) data bases.

IMPLEMENTATION STATEMENT

A specific plan for the implementation of the nuclear asphalt content gauge and cold feed gradation control has been proposed. This plan provides for a two to fourfold increase in quality control testing frequency. Such a plan should provide a more uniform and higher quality asphalt concrete product.

Recently, an asphalt content incinerator oven has been promoted as providing very accurate asphalt contents while eliminating the need for hazardous solvents. The sampling and test procedure for asphalt content takes approximately one hour. The sample must then be cooled prior to gradation testing such that the overall test time for asphalt content and gradation is approximately two hours similar to current quality control procedures. Although the incinerator asphalt content may improve accuracy, it does not provide increased test frequency. The incinerator would perhaps prove useful in the district laboratories, especially if a decision is made to use the verification sample for gradation acceptance; the nuclear gauge and cold feed gradation could be used to enhance quality control at the plant.

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INTRODUCTION

The introduction of new aggregate sources to Louisiana since the mid 1980s has presented problems in asphaltic concrete mix design and construction. Absorptive aggregates such as reclaimed portland cement concrete and some stones which are now being used in asphaltic concrete have made asphalt content determination a critical aspect of mix control. Current test procedures take several hours to determine asphalt content. It has been established that a nuclear gauge once calibrated, can determine asphalt content within 16 minutes or less. The nuclear asphalt content gauge would provide a faster indication of the need for a correction of asphalt content at the hot mix plant. It would also eliminate the problem of hazardous solvent storage, handling and disposal at the plant site, since the use of solvents for asphalt cement extraction would be terminated.

Currently, hot mix is sampled for asphalt content twice in each lot, normally one day of production. Using the centrifuge extraction method, testing takes approximately two hours, in which time 400-600 tons of mix may be produced. If asphalt content is not within job mix formula tolerances, corrections are made to the plant. However, the mix produced before corrections are made has already been placed on the roadway. Using the nuclear asphalt content gauge, with a testing time of approximately 20 minutes, only 60-80 tons of mix will have been produced before corrections are made.

Use of the nuclear gauge will provide another benefit. It will eliminate the problem of storage, handling and disposal of solvents. 1,1,1 - trichloroethane (ethane) is the solvent most often used in testing for asphalt cement content. The vapors generated by the testing process can produce irritation causing dermatitis, blotches, or blisters. If solvent is splashed in the eye, it will cause irritation and pain. While basic safety precautions can prevent harmful contact, the possibility of accidents cannot be eliminated. With increased restrictions against indiscriminate dumping, disposal of the dirty solvents is becoming more of a problem Contractors could become required to store the waste for disposal by an approved hazardous waste facility. Producers of hazardous waste are classified by the amount of waste produced. If a contractor does not reclaim his solvent, it is possible he would produce as much as 100 kg (about 1/2 drum) per month, which is the criteria for classification as a "small quantity generator, 100 - 1000 kg/mo." When a contractor is so classified, he is required to obtain an EPA identification number and comply with EPA and DOT regulations for storage, shipping and disposal. The waste generated must be offered only to transportation and disposal facilities with an EPA identification number. Further complicating this situation, production of 1,1,1 trichloroethane has been docketed by EPA for termination. Other more potent solvents would have to be substituted which pose additional handling and disposal risks.

Moisture content of the asphalt concrete was another area requiring further investigation before the nuclear asphalt content gauge could be introduced to the contractors. Louisiana's aggregates are normally high in moisture content. The nuclear asphalt content gauge uses a neutron count to determine the amount of hydrogen in the mix such that the total hydrogen content must be corrected for the amount of water to accurately determine asphalt content.

Another area requiring investigation deals with gradation testing. Maintaining aggregate gradation is necessary to insure a mix which can be placed and compacted properly. Currently, the aggregate from which asphalt is extracted is used for acceptance testing for gradation. Use of the nuclear gauge in lieu of the current extraction testing would necessitate a change in the sampling location and method of aggregate gradation testing.

OBJECTIVES AND SCOPE

The major objective of this study was to determine the variation in asphalt cement content found with the nuclear asphalt content gauge during normal plant production. Secondary issues which needed to be resolved for implementation were moisture content determinations for the correction of nuclear readings and the variation associated with changing the sampling location for gradation from extracted mix to cold feed operations.

The scope of the study included asphalt content determination using the nuclear asphalt content gauge and the centrifuge and reflux extraction tests at three drum and three batch plants. One week's production was sampled at each plant. Simultaneously, cold feed samples were taken for gradation analysis. Moisture contents were determined at the plant using the ASTM D1461 and microwave methods.

Accuracy testing was added to the test factorial after widely varying results were found during testing at the first plant. Three asphalt contents for each of two mix types were investigated. Additionally, the effect of mix temperature on the calibration curve and change in sample size versus calibration sample size were evaluated. Also, the loss of an aggregate feed at an asphalt plant was simulated by reducing the fine aggregate feed to determine sensitivity of the nuclear gauge.

METHODOLOGY

INSTRUMENT THEORY

The nuclear gauge used in this investigation was the Troxler 3241B Asphalt Content Gauge. The nuclear gauge operates on the same principal as that of the soil moisture gauge. Percent asphalt cement is based on the thermalization (slowing down) of fast neutron radiation which is predominantly a function of the hydrogen content of the materials and to a lesser degree, by other low atomic number elements such as carbon and oxygen. A key element used in the device is Americium-241. An alpha particle is emitted from the element which reacts with a beryllium nucleus. This reaction prompts the emission of a neutron. The relative size of the hydrogen atom produces a substantial collision with the neutron thus causing a reduction in its energy (i.e. 4.5 Mev to .025 Mev). Among all of the elements in the periodic table, the number of collisions required to produce neutron thermalization is substantially lower for hydrogen atoms. The only other significant elements are oxygen and silicon. For this reason, if neutron thermalization exists, there is a very good chance that it was produced by a hydrogen atom.

Another factor that can affect the performance of the device is the neutron absorption rates of certain elements. In general, the amount of thermalized neutrons produced is proportional to the absorption rate. However, the only elements that are concerned with this phenomenon are elements such as cadmium, boron, chlorine, manganese, iron and potassium. This leads to the detection of thermalized neutrons.

For the nuclear gauge to compute the percent asphalt cement, it must first be able to precisely detect the amount of thermalized neutrons. The detection of the thermal neutrons are afforded by the use of a high pressure Helium-3 isotope which has a very large capture cross section (high absorption rate). The thermal neutrons are counted and registered in the device.

In calibrating the gauge, the operator enters known asphalt contents for two or more samples. The device then performs a least squares calculation to develop a straight line approximation of the form:

$$Y = mX + b$$

where, Y = percent asphalt cement

X = neutron absorption count

m = percent asphalt cement/counts (slope)

b = percent asphalt cement (Y - intercept).

When a sample is actually measured, an asphalt content is automatically calculated and displayed on the screen.

ACCURACY TESTING

This test phase was added to the study after finding widely varying results at a field plant from the first set of test data. After consultation with the equipment manufacturer, modifications were made to the sample preparation and test procedures. These modifications included the sweetening of the mixing spoon, bowl and pans prior to calibration, defining a technique for achieving consistent volume, and using background counts. These procedures were implemented for the accuracy testing. The data from the first field project were discarded and another field project was selected.

Two mix types, a low stability gravel mix and a high stability stone mix, were investigated with the nuclear gauge to determine the accuracy of the device with regard to known samples prepared in the laboratory. For each mix type, samples of 4.6, 5.1 and 5.6 percent asphalt cement were prepared. Each sample was subjected to three tests: nuclear gauge, centrifuge extraction and reflux extraction. The centrifuge samples were corrected for ash content.

One of the mix types was also tested for sample density effects on the nuclear gauge output. After a calibration sample was established, the sample weights were varied 100 and 200 grams on either side of the calibration weight.

An additional mix type was prepared with fine materials completely omitted from the mix composition and with 50 percent of the fine aggregate to simulate either the complete or partial loss of the fine aggregate cold feed. If the nuclear gauge is sensitive to these changes, the gauge could be used for process control at the plant providing enhanced quality control.

Finally, the effect of testing mix at temperatures other than the calibration temperature was studied.

FIELD TESTING

One week's production from each of the three batch plants and three dryer-drum plants was evaluated. Testing included asphalt cement content by the nuclear method, centrifuge extractor and reflux extractor; moisture content by the distillation method and microwave drying; and aggregate gradation based on belt samples and dry hot-bin pull samples for dryer drum and batch plants, respectively.

Eight samples per day for five days were split for use. A comparison of the nuclear asphalt content with the centrifuge and reflux extractions was used to evaluate the variation of the three test methods. Four 4-minute counts were averaged for each nuclear gauge asphalt content determination. All centrifuge tests were corrected for ash content.

The effectiveness of microwave drying versus distillation by ASTM D1461 at the plant site to determine moisture content in the mix, and the variability thereof, was assessed by a comparison of test results on paired samples.

Aggregate samples from the composite cold feed belt at drum plants and from a dry batch at batch plants were collected at the time the hot mix was sampled for asphalt content testing. In this manner the gradation from the extracted hot mix could be compared to the cold feed/dry batch gradations. The number of cold feed/dry batch samples was reduced because of contractor opposition to plant shutdown in order to obtain the samples.

RESULTS

ACCURACY TESTING

Accuracy of Asphalt Content

Both a low stability gravel mix and a high stability stone mix were tested for accuracy of asphalt content at each of three levels, 4.6, 5.1 and 5.6 percent. The typical gravel mix was proportioned at 55 percent crushed gravel, 33 percent coarse sand and 12 percent fine sand. The stone mix consisted of 34.2 percent sandstone, 17 percent silicious limestone, 34.2 percent coarse sand and 9.5 percent fine sand. Calibration was conducted at 135C.

The results of this testing, presented in Table 1, indicate that the nuclear asphalt content gauge was capable of determining a known asphalt content as well or better than existing methods. The centrifuge and reflux were within typical variations for these methods.

TABLE 1. ASPHALT CONTENT ACCURACY (PERCENT)

DESIGN	GRAVEL MIX			STONE MIX		
	NUKE	CENT	REFLUX	NUKE	CENT	REFLUX
4.6	4.64	4.46	4.51	4.59	4.71	4.44
5.1	5.03	5.13	4.98	5.02	5.32	5.27
5.6	5.57	5.63	5.41	5.62	5.61	5.71

Effect of Sample Size

The effect of sample size was evaluated to determine differences in asphalt content because of an error in weighing the sample size. The gravel mix at an asphalt content of 5.1 percent was examined using the calibration weight of 6666 g at a temperature of 135C. The weights were varied 100 and 200 g on either side of the calibration weight. Each sample was compacted to a constant volume. Table 2 demonstrates that a change in mass of plus or minus 100 g would not provide a significant change in asphalt content.

TABLE 2. EFFECT OF SAMPLE SIZE	
SAMPLE WEIGHT, g	ASPHALT CONTENT, %
6466	4.8
6566	5.0
6666	5.0
6766	5.0
6866	5.1

Effect of Gauge Temperature Setting

According to the manufacturer's manual, the nuclear asphalt content gauge automatically compensates for a mix temperature different from the temperature used for calibration. To evaluate this claim, the gravel mix was prepared at both 5.0 and 6.0 percent asphalt using the calibration mass of 6666g at 135C. Asphalt content readings were determined with the gauge set at both the mix temperature and the calibration temperature of 135C. Table 3 indicates that at typical production temperatures, 143-149C, the 6.0 percent asphalt mix demonstrated no difference related to temperature setting while the 135C calibration setting provided a more accurate reading for the 5.0 percent asphalt mix sample. On this basis, the calibration temperature should be used for determining asphalt content. It is suggested, however, that the calibration temperature should probably be the anticipated job mix production temperature.

TABLE 3. EFFECT OF GAUGE TEMPERATURE SETTING (% ASPHALT)				
TEMPERATURE, C	5.0% ASPHALT		6.0% ASPHALT	
	MIX TEMP	135C	MIX TEMP	135C
149	5.25	5.02	6.12	6.07

143	5.29	5.15	6.05	6.09
129	5.23	5.22	6.12	6.15
121	5.27	5.16	6.15	6.03

Effect of Loss of Aggregate Feed

The calibration mix used for this evaluation was composed of 68 percent gravel, 20 percent coarse sand and 12 percent fine sand at 4.5 percent asphalt cement. Mixes were prepared with one half of the fine sand and no fine sand to simulate the loss of this feed during production. The asphalt content was maintained at 4.5 percent in these mixes. Nuclear gauge readings were determined for these samples using the calibration curve along with centrifuge and reflux asphalt contents as presented in Table 4. The nuclear gauge was able to detect both the partial and complete loss of these aggregate feeds. This finding enhances the use of the gauge beyond simply the determination of asphalt content because its usefulness in quality control of the mix from an aggregate feed or change in gradation perspective is increased.

TABLE 4. EFFECT OF LOSS OF AGGREGATE FEED (PERCENT)

DESIGN	1/2 FINE SAND			NO FINE SAND		
	NUKE	CENT	REFLUX	NUKE	CENT	REFLUX
4.5	4.16	4.34	4.51	4.13	None	None

FIELD TESTING

Asphalt Content Measurements

A number of projects were investigated for potential use in this study. The criteria for selection involved the type of plant, batch or dryer drum, and sufficient quantities of mix for a production run of five days using the same mix type. Potential projects were designated "A" through "H." The first project, A, was eliminated when it was found that the nuclear gauge was providing asphalt contents deviating widely from the job mix. At that point the gauge was returned to the laboratory and the accuracy phase of this study was conducted. Afterward, the nuclear gauge asphalt content determinations appeared to be in line with the results of the other test methods. Project D was also eliminated when the contractor ceased operations for an extended period. The remaining projects, B, C, E, F, G and H met the requirements of three batch and three dryer drum plants and were used in the study.

Forty samples were collected and tested from each of the projects according to the research plan with the exception of one project, C, where only 38 samples were obtained. Each project produced only one job mix formula during the sampling period with the exception of project E, where several mix designs were produced. Table 5 presents the mean and standard deviation of the asphalt contents determined by the three methods evaluated. Pooled standard deviations were examined by plant type.

TABLE 5. FIELD ASPHALT CONTENT VARIATION (PERCENT)				
PROJECT JMF %AC	STATISTIC	TEST METHOD		
		NUCLEAR	CENTRIFUGE	REFLUX
B	x	5.22	5.01	4.82
5.1	σ	0.16	0.25	0.18
C	x	4.92	4.65	4.55
4.5	σ	0.24	0.25	0.32
E	x	4.76	4.78	4.49
Varies	σ	0.34	0.29	0.31
F	x	5.23	5.15	5.21
5.2	σ	0.13	0.46	0.18
G	x	4.87	4.80	4.83
4.9	σ	0.22	0.30	0.20
H	x	5.32	5.11	5.13
5.1	σ	0.12	0.38	0.14
POOLED σ				
BATCH		0.17	0.31	0.17
DRYER DRUM		0.25	0.34	0.27

The weighted mean design asphalt content of project E was 4.8. The nuclear gauge provided asphalt contents similar to the job mix formulas, as did the centrifuge and reflux methods. One exception was project C where the nuclear device results were significantly higher. The typical standard deviation for asphalt content for the centrifuge method is 0.25 based on historical and Materials Test System, MATT, data. The pooled standard deviations presented in the table indicate the nuclear gauge results were similar to the reflux method results in both batch and dryer drum plants. Both of these methods produced similar results for the dryer drum plants and lower for batch plants than the MATT standard deviation. The centrifuge results were higher than the typical standard deviation for this method. Better control of asphalt content was indicated for batch plants than dryer drum plants. The implication from this testing is that the nuclear gauge can produce asphalt contents consistent with the job mix while reducing the variation inherent in the test method as long as the calibration sample is consistent with the mix produced at the plant.

Moisture Content

Moisture content determination using both the distillation procedure of ASTM D1461 and a microwave method developed by the University of Nevada, Reno was evaluated. The distillation procedure was time consuming and the original sampling plan of four samples per day was reduced. Additionally, this procedure posed a safety hazard; fires occurred on several occasions. The microwave oven did not arrive until after projects B, C and H had been completed. Problems were encountered with the explosion of aggregates during the next three projects. Table 6 provides the mean moisture contents determined in percent. These moisture levels are extremely low providing insignificant changes in the asphalt content. Direct comparison of the two procedures provided almost identical results on two projects with the microwave procedure detecting almost twice as much moisture for the third project. It should be noted that the weather was very dry during the conduct of the study. While the department specifies a maximum allowable moisture content of 0.5 percent in the mix, discussions with plant inspectors indicate that moisture contents rarely exceed 0.1 percent. This indicates that nuclear gauge asphalt contents probably should not be routinely corrected for moisture content. A moisture content could be determined if the asphalt content is continually higher than the job mix and the plant totalizing meter.

TABLE 6. MOISTURE CONTENT (PERCENT)

METHOD	PROJECT					
	B	C	E	F	G	H
DISTILL	0.024	0.072	0.058	0.060	0.050	0.044
MICRO	None	None	0.015	0.068	.050	None

Gradation Control

With the elimination of the extraction process for determining asphalt content, gradation control would have to shift to the cold feed. Carey evaluated cold feed control in 1980 to determine the feasibility of screenless batch plant production {1}. In this study, Carey found that cold feed gradations were as accurate as hot mix extractions but that the variation was greater. The cold feed sample results were biased because of the batch plant stack losses. The variation difference was attributed to the cold feed sampling procedure employed.

In the current study the following plant configurations were used: project B and H - screenless batch plant with a baghouse; project C - drum plant with wet scrubber; projects E and F - drum plants with baghouse; and, project G - screenless batch plant with wet scrubber.

Statistical means and standard deviations for extracted hot mix and cold feed gradations are presented in Table 7. Similar to the Carey study, the cold feed gradations were as accurate as the extracted hot mix gradations. Some bias in the mean values is noted depending on plant configuration. For instance, projects B and H, both returning baghouse fines, have cold feeds consistently several percent finer than the extracted gradation. Projects C and G, both using wet scrubbers, compensate for fine aggregate loss as identified in the finer 0.075 screen.

TABLE 7. HOT MIX AND COLD FEED GRADATION CONTROL (% PASSING)

PROJ	STAT	SIEVE SIZE, mm							
		19	12	9.5	4.75	2.00	0.42	0.18	0.075
B	n=40								
HOT	x	100	98.8	88.9	67.7	48.5	24.1	11.4	6.9
	σ	0.00	0.84	2.51	3.72	2.84	1.38	0.76	0.62
	n=3								
COLD	x	100	99.3	89.0	70.0	51.3	26.7	14.0	9.7
	σ	0.00	0.82	2.44	3.74	2.80	1.43	1.13	1.05
C	n=38								
HOT	x	99.4	91.0	78.4	52.5	37.4	26.2	13.9	7.8
	σ	1.18	2.88	4.06	3.98	2.88	2.0	1.00	0.66
	n=4								
COLD	x	97.0	87.8	75.5	51.0	37.8	27.3	14.5	9.3
	σ	2.55	3.30	4.29	3.92	2.81	1.98	1.05	0.90

E	n=40								
HOT	x	99.8	94.9	78.7	56.7	44.6	37.9	12.8	5.7
	σ	0.59	1.89	3.22	3.86	2.32	1.30	0.99	0.81
	n=7								
COLD	x	100	93.4	76.9	55.1	44.3	27.3	11.9	5.6
	σ	0.00	1.93	3.48	4.23	2.95	1.65	1.19	0.92
F	n=40								
HOT	x	100	95.2	84.3	58.3	37.9	22.9	12.5	8.6
	σ	0.00	1.84	3.64	4.25	2.95	1.93	1.45	1.22
	n=8								
COLD	x	100	92.8	80.6	52.8	31.9	17.6	10.5	7.8
	σ	0.00	2.06	3.73	4.76	3.97	3.13	1.98	1.60
G	n=40								
HOT	x	100	97.3	85.9	58.1	43.7	25.6	12.4	7.4
	σ	0.00	1.31	3.03	3.63	2.79	2.82	1.95	1.26
	n=8								
COLD	x	100	97.9	86.8	60.1	45.4	27.1	13.6	8.8
	σ	0.00	1.15	2.33	3.15	2.43	2.86	2.14	1.45
H	n=40								
HOT	x	100	98.6	91.1	71.8	51.4	26.0	12.1	7.8
	σ	0.00	0.86	1.80	2.58	2.12	1.39	0.71	0.46
	n=3								
COLD	x	100	97.7	91.3	73.0	53.0	26.7	13.7	9.3
	σ	0.00	0.47	1.25	2.45	1.63	2.36	1.70	1.25

Unlike the Carey results, the cold feed variation is very similar to the extracted gradation variation indicating that gradations established at the cold feed are just as consistent as extracted gradations. In fact, the variation found in both the extracted hot mix and cold feed gradations are lower or similar to variation determined from historical data and subsequent evaluations of Louisiana's statistically oriented specifications (References 2-4). On this basis, cold feed gradation can be used for quality control testing. Depending on plant configuration, minor adjustments based on typical plant operations may need to be employed.

It should be noted that projects E and G used reclaimed asphalt pavement, RAP, in the mix investigated in this study. These materials were sampled from the RAP feed belt at the same time as the other cold feed materials. The RAP was extracted in the laboratory and the gradations added to the cold feed gradations according to job mix proportions. The use of the RAP affected neither the accuracy nor the variation of the extracted and cold feed gradations.

CONCLUSIONS

The following conclusions are drawn from the data generated in this study and, as such, are constrained by the number of projects examined.

1. The nuclear asphalt content gauge produced results that were as accurate with less variation (more consistent) than the current centrifuge extraction method used for quality control testing. Because of the reduced test time for the nuclear method (20 minutes) versus the centrifuge method (2 hours), additional quality control tests could be required enhancing the process control operation. In addition, the use of the nuclear gauge would eliminate the use of a hazardous solvent at the asphalt plant.

2. Moisture content testing using both the ASTM D1461 distillation method and a microwave method indicated negligible moisture contents in the mix tested for asphalt content. Moisture content determinations would only be necessary when abnormal asphalt contents were found. The distillation procedure was hazardous with several explosions and fires occurring during testing. Its use is not recommended. The microwave test would need further development to eliminate the aggregate explosions experienced during this study.

3. Cold feed gradations were found to be as accurate with similar variation (as consistent) to the extracted hot mix gradations. Minor adjustments may be necessary to remove bias imposed by plant configuration, ie. the loss of fines in a wet scrubber system could be compensated at the cold feed.

4. When compacted to a constant volume, a change in sample weight of up to 100 grams did not provide significant differences in asphalt content determined with the nuclear gauge.

5. The nuclear gauge was able to detect the simulated loss of fine aggregate feed enhancing its use as a quality control tool. If quality control testing is increased because of the quicker test time of the nuclear gauge asphalt content determinations and cold feed gradations, plant malfunctions causing nonspecification mix can be found and corrected much sooner than currently feasible.

6. The calibration temperature should be used during quality control testing. The calibration temperature should be the projected job mix

temperature.

7. The use of RAP in the hot mix did not affect the asphalt contents or cold feed gradations.

RECOMMENDATIONS

The use of the nuclear asphalt content gauge and cold feed gradation for quality control testing is recommended. The results obtained in this study demonstrate these methods to be as accurate and more consistent than the current centrifuge extraction method and can be conducted in much less time. This provides the advantage of conducting more control testing thereby decreasing the opportunity to send nonspecification mix to the roadway. While not tested during this study, the equipment manufacturer now has developed a nuclear gauge capable of testing Marshall specimens in addition to loose mix samples. Additional advantage can, therefore, be made by reducing sample preparation time for the nuclear gauge loose mix samples. Since Marshall testing is currently required four times per lot, such testing would immediately double the quantity of asphalt content control testing while eliminating two hours of sample preparation and test time for extraction and gradation testing. Additional quality control testing for asphalt content or cold feed gradations could be incorporated or the inspector could spend increased time in the plant observing plant operations. With the ability to detect aggregate feed problems and the ability to increase test frequency, a more uniform and higher quality mix should be produced. As an initial program until experience dictates refinement, the following specific recommendations for implementation are offered:

1. Require all Marshall specimens be tested for asphalt content using the nuclear gauge prior to Marshall testing. Four additional asphalt contents should be obtained throughout the lot at random times using the nuclear gauge. This would provide a fourfold increase in quality control testing for asphalt content.

2. Require cold feed gradation testing at least four times at random per lot providing a twofold increase in gradation quality control testing.

3. Require moisture content testing as needed dependent on unexplained high asphalt content determinations that cannot be reconciled through Marshall or gradation results.

4. Either eliminate gradation as an acceptance criteria or use the reflux extracted verification sample for acceptance purposes. This will totally eliminate the need for solvents at the plant, using them only in the more controlled laboratory environment.

REFERENCES

1. Carey, D.E., "Control of Hot Mix Production By Cold Feed Only," Final Report No. 118, Louisiana Department of Transportation and Development, April 1978.

2. Shah, S.C., "Quality Control Analysis, Part I - Asphaltic Concrete," Final Report No. 15, Louisiana Department of Highways, September 1964.

3. Shah, S.C. and Yoches, V., "Quality Control Analysis, Part V - Review of Data Generated by Statistical Specifications on Asphaltic Concrete," Final Report No. 94, Louisiana Department of Transportation and Development, December 1975.

4. Shah, S.C., "Evaluation of Data Generated by Statistically Oriented End-Result Specifications," Final Report No. 125, Louisiana Department of Transportation and Development, January 1979.

APPENDIX A

------------------------------ PLANT=B ------------------------------------

NUKEAC	CENTAC	REFLAC	THRFRTH	ONEHLF	THRETH	NO4	NO10	NO40	NO80	NO200	PLANTAC
5.7	5.2	5.1	100	99	88	67	50	25	11	7	4.9
5.5	5.2	5.0	100	99	91	73	54	27	12	7	4.9
5.2	5.3	4.7	100	97	86	64	46	23	10	6	4.9
5.3	5.0	4.9	100	100	94	72	51	26	11	7	4.9
5.4	5.5	5.1	100	100	90	70	51	26	11	6	4.9
5.3	5.4	4.8	100	99	91	72	53	27	12	7	4.9
5.3	5.1	4.7	100	98	87	67	49	26	11	6	4.9
5.1	5.0	4.8	100	99	91	68	49	23	11	7	4.9
5.1	4.6	4.7	100	99	86	62	45	24	12	7	5.3
5.3	5.1	5.1	100	98	89	70	50	24	11	7	5.3
4.8	4.5	4.3	100	98	84	56	38	20	10	6	5.3
5.3	4.8	4.8	100	99	88	65	47	23	11	7	5.3
5.1	5.0	4.6	100	98	84	61	44	22	10	6	5.2
5.2	4.9	5.0	100	99	90	67	47	23	11	7	5.2
5.3	5.0	4.6	100	97	88	67	49	24	12	7	5.2
5.2	4.9	4.9	100	99	88	66	46	23	12	7	5.2
5.2	5.1	4.9	100	98	91	70	51	25	12	8	4.9
5.2	4.8	4.6	100	97	86	65	47	24	12	7	4.9
5.5	5.1	5.0	100	99	89	69	50	24	11	7	4.9
5.2	5.0	4.9	100	100	92	71	50	25	12	7	4.9
5.3	4.8	4.9	100	100	85	62	46	24	12	8	5.3
5.3	5.0	5.0	100	98	90	70	52	26	12	8	5.3
5.3	5.8	5.0	100	99	90	71	50	24	11	7	5.3
5.2	4.9	5.1	100	98	87	66	48	24	11	7	5.3
5.2	5.2	4.8	100	98	87	66	47	23	10	6	5.1
5.2	5.1	4.8	100	99	87	65	46	22	10	6	5.1
5.3	5.1	4.9	100	100	93	72	50	25	12	7	4.9
5.2	5.0	4.7	100	99	91	69	49	25	11	7	4.9
5.4	5.2	4.8	100	99	92	75	52	24	11	7	4.9
5.2	5.0	4.8	100	99	91	71	49	24	11	6	4.9
5.2	4.8	4.9	100	100	91	70	50	25	11	6	4.9
5.2	4.9	4.7	100	99	91	67	47	23	11	6	4.9
5.1	4.7	4.6	100	100	86	68	48	24	12	7	5.1
5.1	5.2	4.9	100	99	91	69	48	24	12	7	5.1
5.2	4.9	4.8	100	99	89	70	50	24	12	8	5.1
5.1	4.7	4.8	100	99	89	67	48	24	12	8	4.7
4.9	4.6	4.4	100	98	84	61	44	22	11	7	4.7
5.1	5.1	4.7	100	100	90	70	51	25	13	8	5.1
5.0	4.8	4.6	100	98	87	67	49	25	13	7	5.1
5.1	5.0	4.9	100	99	90	69	50	24	12	7	5.1

------------------------------ PLANT=C ---------------------------------

NUKEAC	CENTAC	REFLAC	THRFRTH	ONEHLF	THRETH	NO4	NO10	NO40	NO80	NO200	PLANTAC
5.2	5.1	4.6	99	92	85	61	44	30	16	9	4.5
4.9	4.5	4.1	100	93	77	50	35	24	14	8	4.5
5.2	4.6	4.4	100	91	79	53	37	26	14	8	4.5
5.2	4.9	4.4	99	93	83	56	40	28	15	9	4.5
5.1	4.5	4.4	98	90	79	52	37	26	14	8	4.5
4.9	4.3	4.1	99	90	78	50	35	25	14	8	4.5
5.4	4.7	4.7	98	92	81	57	41	29	16	8	4.4
5.1	5.0	4.4	100	94	84	58	41	29	15	9	4.4
5.3	4.6	4.6	100	94	80	54	38	26	14	8	4.4
5.2	4.6	4.8	100	93	78	54	38	26	14	8	4.4
4.7	4.5	3.9	100	88	72	47	34	24	12	7	4.6
4.9	4.6	4.3	100	89	76	48	34	24	13	7	4.6
5.4	5.0	4.7	98	95	85	58	41	28	15	8	4.6
5.0	4.8	4.2	100	94	84	53	36	25	13	7	4.6
4.8	4.8	4.3	99	91	78	54	38	26	14	8	4.8
4.5	4.5	3.8	100	89	76	46	33	24	13	7	4.8
5.0	5.1	4.6	100	89	75	52	39	27	14	8	4.4
4.7	4.5	4.4	100	91	76	50	35	24	13	7	4.4
4.6	4.7	4.8	100	90	77	52	37	26	14	8	4.4
4.6	4.2	4.0	100	85	71	46	32	22	12	7	4.4
4.8	4.7	4.6	100	88	76	52	37	25	13	8	4.4
4.8	4.4	4.6	100	86	72	49	35	24	12	7	4.4
4.7	4.3	4.8	97	90	77	51	35	24	13	8	4.4
5.1	4.4	4.7	100	91	77	50	36	25	13	7	4.8
5.0	5.0	4.7	100	95	81	57	42	30	15	8	4.8
5.1	5.0	5.0	100	90	81	57	41	28	15	8	4.8
4.6	4.4	4.6	100	90	76	48	35	25	13	7	4.3
5.2	5.2	5.2	100	94	82	58	43	30	15	8	4.3
4.9	4.5	5.3	99	87	72	45	34	24	13	7	4.3
4.9	4.5	4.6	94	86	70	48	35	25	13	7	4.3
4.8	4.8	4.9	100	91	77	50	37	26	14	7	4.3
4.5	4.3	4.4	100	89	76	50	36	25	13	7	4.6
4.8	4.5	4.5	98	87	78	54	39	27	14	8	4.6
4.9	4.5	4.8	100	90	76	50	37	27	14	8	4.6
4.9	4.8	4.7	100	94	85	58	41	29	15	8	4.6
4.9	4.6	4.8	100	97	84	57	39	28	15	9	4.6
4.5	4.5	4.5	100	96	82	54	36	26	14	9	4.6
4.9	4.8	4.6	100	93	83	56	40	28	14	8	4.6

------------------------------ PLANT=E ----------------------------------

NUKEAC	CENTAC	REFLAC	THRFRTH	ONEHLF	THRETH	NO4	NO10	NO40	NO80	NO200	PLANTAC
5.5	5.2	5.0	100	92	81	62	45	27	12	6	4.9
4.9	5.1	4.8	100	95	81	60	46	28	12	5	4.9
5.2	5.1	4.9	99	93	80	59	44	28	13	6	4.9
5.3	4.9	4.9	100	97	82	59	44	28	14	6	4.9
5.1	5.1	5.0	98	93	77	54	44	28	13	5	5.1
5.2	4.9	4.9	100	93	75	54	43	28	13	6	.
5.2	5.0	4.8	100	94	79	58	46	29	13	5	.
4.8	5.0	4.3	100	95	79	54	44	28	12	6	4.4
3.9	4.1	3.9	100	93	75	52	42	26	12	5	4.4
5.0	4.8	4.0	100	98	80	54	43	27	12	5	4.4
4.6	4.9	4.4	100	94	77	55	44	28	12	5	4.6
4.8	5.0	4.6	100	93	75	52	43	28	12	5	4.6
4.4	5.0	4.4	100	92	70	49	40	25	11	4	4.6
4.4	4.5	4.4	100	96	77	52	42	27	12	5	4.6
4.7	4.5	4.5	100	96	76	55	44	28	13	6	4.6
4.5	5.0	4.6	100	98	81	58	45	27	12	5	4.6
4.4	4.5	4.3	100	97	79	57	45	28	13	6	4.6
4.0	4.5	3.9	100	96	75	54	43	26	11	5	4.5
4.4	4.7	4.3	100	92	78	57	45	29	13	5	4.5
4.4	4.4	4.1	100	96	77	55	44	28	13	6	4.5
4.6	4.4	4.4	100	93	73	54	43	27	13	5	4.5
4.5	4.3	4.2	100	95	75	50	39	25	11	5	4.5
4.6	4.4	4.5	100	95	81	57	43	28	12	6	4.6
4.6	4.3	4.2	100	95	78	56	44	27	12	5	4.6
4.5	4.5	4.2	100	96	80	59	46	29	13	6	4.6
4.5	4.6	4.2	100	96	82	61	49	32	16	9	4.6
4.6	5.1	4.2	100	98	81	57	46	29	13	6	4.6
4.6	4.8	4.3	100	92	78	56	44	29	14	7	4.6
4.6	4.7	4.2	99	95	86	55	44	28	14	6	4.6
5.0	5.3	4.4	97	90	75	51	41	26	12	6	4.6
4.8	5.0	4.2	100	97	84	64	49	30	14	6	4.8
4.9	4.6	4.5	100	95	82	62	48	29	14	6	4.8
5.1	4.9	4.7	100	96	81	63	49	30	14	6	4.8
5.1	4.9	4.9	100	94	80	61	47	28	13	6	4.8
5.1	4.9	4.9	100	95	80	59	45	27	12	6	4.8
5.0	5.0	4.8	100	97	83	62	47	28	13	6	4.8
4.9	4.8	4.6	100	96	82	64	49	29	13	6	4.8
4.8	5.1	4.6	100	95	81	60	47	28	13	7	4.8
5.0	4.7	4.8	100	94	79	58	47	28	12	5	.
4.9	4.8	4.6	100	91	69	45	36	23	10	5	.

------------------------------- PLANT=F -----------------------------------

NUKEAC	CENTAC	REFLAC	THRFRTH	ONEHLF	THRETH	NO4	NO10	NO40	NO80	NO200	PLANTAC
5.3	4.8	5.2	100	93	83	58	37	22	12	8	5.2
5.2	4.9	5.1	100	94	85	58	37	23	13	9	5.2
5.4	5.1	5.2	100	93	83	56	36	22	12	8	5.2
5.3	4.9	5.3	100	97	84	54	34	21	11	8	5.2
5.3	5.2	5.1	100	95	85	56	36	23	13	9	5.2
5.4	5.6	5.3	100	95	82	55	35	22	12	8	5.2
5.4	5.0	5.4	100	95	80	53	34	20	10	7	5.2
5.1	4.9	4.9	100	89	74	50	32	19	9	6	.
5.2	5.6	5.3	100	96	84	58	37	23	12	8	.
5.3	5.2	5.4	100	93	79	56	37	23	13	9	.
5.3	5.4	5.4	100	97	89	65	43	26	15	11	.
5.3	5.1	5.4	100	94	79	51	36	25	14	9	.
5.3	4.8	5.4	100	98	88	66	44	26	14	10	.
5.2	5.0	5.2	100	94	82	59	38	23	12	8	.
5.3	4.9	5.4	100	95	86	56	36	22	11	8	.
5.0	4.6	4.9	100	97	88	60	39	25	15	11	.
5.4	5.7	5.4	100	98	92	65	40	24	13	9	.
5.2	5.4	5.2	100	95	85	58	39	24	14	10	.
5.3	5.5	5.3	100	97	89	65	41	23	13	9	.
5.3	6.1	5.1	100	95	83	55	36	21	12	8	.
4.8	4.9	4.9	100	93	83	59	39	24	13	9	.
5.4	5.3	5.4	100	97	87	62	40	22	11	7	.
5.1	4.8	4.9	100	93	85	60	41	25	13	9	.
5.2	5.8	5.6	100	93	85	60	41	25	13	9	.
5.3	5.2	5.3	100	93	85	60	41	25	13	9	.
5.2	5.3	5.0	100	93	85	60	41	25	13	9	.
5.2	4.9	5.1	100	93	85	60	41	25	13	9	.
5.2	4.8	5.1	100	93	85	60	41	25	13	9	.
5.3	5.2	5.3	100	93	85	60	41	25	13	9	.
5.0	4.6	4.8	100	93	85	60	41	25	13	9	.
5.2	5.1	5.2	100	93	85	60	41	25	13	9	.
5.2	4.6	5.3	100	93	85	60	41	25	13	9	.
5.2	5.7	5.2	100	93	85	60	41	25	13	9	.
5.1	4.7	5.3	100	93	85	60	41	25	13	9	.
5.3	4.6	5.3	100	93	85	60	41	25	13	9	.
5.1	4.6	4.9	100	93	85	60	41	25	13	9	.
5.2	6.8	5.1	100	93	85	60	41	25	13	9	.
5.2	5.2	5.2	100	93	85	60	41	25	13	9	.
5.3	5.1	5.3	100	93	85	60	41	25	13	9	.
5.0	4.9	5.1	100	93	85	60	41	25	13	9	.

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NUKEAC	CENTAC	REFLAC	THRFRTH	ONEHLF	THRETH	NO4	NO10	NO40	NO80	NO200	PLANTAC
5.0	5.0	4.9	100	99	89	63	47	27	12	7	5.1
5.0	4.4	4.9	100	97	82	57	43	25	12	7	5.1
4.8	4.9	5.0	100	98	85	56	43	25	12	7	5.1
4.8	5.1	4.7	100	96	88	61	46	28	14	9	5.1
4.6	4.2	4.8	100	96	80	51	38	23	11	7	5.1
4.5	4.7	4.5	100	95	85	57	43	26	13	8	5.1
4.9	4.3	4.8	100	94	78	50	39	24	12	7	5.1
4.7	4.6	4.7	100	99	87	58	43	25	12	7	5.1
4.0	4.2	4.1	100	96	79	49	38	23	11	6	5.1
5.0	4.8	5.0	100	97	85	59	45	27	13	8	5.1
4.8	4.7	4.6	100	97	84	57	44	27	13	8	5.0
4.9	4.9	5.0	100	98	87	61	47	28	14	8	5.0
4.8	4.4	4.5	100	95	83	56	43	26	13	8	5.0
5.0	5.1	4.8	100	96	85	60	45	27	14	9	5.0
4.9	4.5	4.7	100	99	88	61	46	27	13	8	5.2
5.0	4.9	4.9	100	98	87	61	46	27	13	8	5.2
4.6	4.2	4.5	100	96	79	51	37	12	5	4	5.2
4.7	5.1	4.8	100	98	88	57	42	22	7	4	5.2
4.8	4.9	4.8	100	95	80	52	37	19	7	4	5.3
5.2	4.8	5.1	100	97	87	60	45	27	13	8	5.3
5.1	4.9	4.9	100	98	86	61	46	28	15	9	5.3
5.1	5.5	4.9	100	97	88	59	44	26	12	7	5.3
5.0	4.7	5.0	100	96	87	61	47	28	14	9	5.3
5.0	4.9	4.8	100	98	88	60	45	26	13	7	5.2
4.7	5.1	4.8	100	99	90	64	48	28	14	8	5.2
5.1	4.8	5.1	100	98	89	63	47	27	13	8	5.2
5.0	4.9	5.1	100	98	89	61	45	26	14	9	5.2
5.1	5.1	5.0	100	99	89	63	47	28	14	9	5.3
4.9	4.7	4.9	100	98	85	57	43	26	13	8	5.3
4.7	5.0	4.8	100	99	89	60	44	26	13	7	5.3
4.7	4.4	4.7	100	96	85	56	44	27	14	8	5.3
5.0	5.1	5.0	100	99	88	58	44	26	13	7	5.3
4.8	5.1	4.8	100	97	86	54	41	25	12	6	5.3
5.0	4.8	5.1	100	99	87	59	44	26	12	6	5.2
4.8	4.9	4.8	100	98	88	61	45	26	13	8	5.2
4.7	4.7	4.8	100	98	87	57	43	26	13	8	5.2
5.0	5.0	5.0	100	98	87	55	40	24	12	7	5.2
5.0	5.1	4.8	100	97	86	59	44	26	13	8	5.2
5.2	4.8	5.0	100	98	87	58	43	26	12	7	5.2
4.8	4.6	4.9	100	97	87	59	45	27	13	8	5.2

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NUKEAC	CENTAC	REFLAC	THRFRTH	ONEHLF	THRETH	NO4	NO10	NO40	NO80	NO200	PLANTAC
5.4	4.5	5.2	100	98	92	72	50	25	11	7	5.2
5.4	5.1	5.3	100	100	95	75	52	25	11	7	5.2
5.4	4.6	5.3	100	99	89	67	49	25	12	8	5.2
5.5	5.7	5.3	100	99	94	76	55	28	13	8	5.2
5.4	5.4	5.2	100	98	87	71	57	26	12	8	5.4
5.3	5.0	5.1	100	100	92	73	52	27	13	8	5.4
5.4	5.2	5.2	100	99	92	72	51	26	12	8	5.4
5.4	4.1	5.1	100	99	93	74	53	27	13	8	5.4
5.4	5.7	5.0	100	98	91	72	52	26	12	8	5.4
5.4	5.3	5.2	100	98	92	72	52	26	12	8	5.4
5.5	4.5	5.1	100	98	92	71	50	24	11	7	5.4
5.4	5.4	5.2	100	100	91	70	50	26	12	8	5.4
5.4	5.1	5.0	100	97	90	70	50	24	11	7	5.3
5.4	5.3	5.1	100	99	93	75	54	27	13	8	5.3
5.4	5.1	5.1	100	99	94	75	53	25	13	8	5.3
5.4	5.3	4.9	100	100	92	71	50	24	12	8	5.3
5.4	5.4	5.1	100	100	93	73	50	24	12	8	5.3
5.4	5.3	5.1	100	99	89	73	51	24	12	8	5.3
5.3	5.3	5.1	100	99	91	71	51	27	12	8	5.0
5.2	5.2	5.1	100	98	92	75	54	29	14	9	5.0
5.3	5.3	5.3	100	97	91	70	50	26	12	8	5.0
5.2	5.0	5.2	100	98	89	70	50	26	12	8	5.0
5.3	5.0	5.1	100	99	90	71	51	27	12	8	5.0
5.2	5.0	5.0	100	98	88	68	49	26	11	7	5.9
5.5	5.6	5.2	100	98	89	70	51	22	11	7	5.9
5.4	4.9	5.1	100	99	89	68	50	26	12	8	5.9
5.1	4.9	4.9	100	97	89	67	48	26	13	8	5.9
5.2	5.1	5.1	100	97	90	68	49	26	12	8	5.9
5.3	4.8	5.1	100	99	92	74	53	27	13	8	5.2
5.3	5.5	5.2	100	98	91	74	53	26	12	8	5.2
5.2	5.1	5.1	100	98	91	72	50	26	12	8	5.2
5.0	5.3	5.0	100	98	90	71	50	26	11	7	5.2
5.3	5.6	5.1	100	99	92	76	56	29	13	8	5.2
5.3	4.4	5.1	100	99	91	71	50	25	11	7	5.2
5.2	4.7	5.0	100	98	91	70	50	26	12	8	5.2
5.3	5.4	5.1	100	100	93	75	54	28	12	8	5.2
5.3	5.1	5.2	100	98	91	74	53	27	12	8	5.2
5.3	5.1	5.2	100	99	92	74	53	27	12	8	5.2
5.3	5.6	5.6	100	99	92	74	53	27	12	8	5.2
5.0	4.4	4.7	100	98	87	66	47	25	12	7	5.2